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PHASE I: THE PIPELINE GAS DEMONSTRATION PLANT

TECHNICAL SUPPORT PROGRAM REPORT

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ABSTRACT

Contract No. EF-77-C-01-2542 between Continental Oil Company and the United States Department of Energy requires Continental Oil to design, construct, and operate a Demonstration Plant capable of converting bituminous caking coals into pipeline quality gas. One of the assignments under the contract is to obtain the requisite data base for the process and engineering design of the Demonstration Plant.

The British Gas/Lurgi slagging gasifier was the process selected by the Contractor to convert the coal to a crude synthesis gas which can be processed to yield pipeline quality gas. This gasifier had been primarily developed, prior to the contract execution date, for processing non-caking bituminous and sub-bituminous coals, but the data base was insufficient for designing the gasifier and associated upstream and downstream processing units for processing the coals selected for the Demonstration Plant.

A technical support program to provide the requisite data base was implemented at the Westfield Development Centre of British Gas Corporation. This facility was selected because a large slagging gasifier pilot plant is located there. The technical support program has been completed, and the data and information required by British Gas Corporation and Lurgi Kohle und Mineraloeltechnik to design the gasifier and the Gasification Section of the Demonstration Plant were obtained. The program also provided the data and other information needed to design the associated upstream and downstream processing units.

The technical support program verified that the British Gas/Lurgi slagging gasifier can satisfactorily process bituminous caking coals, and considerable start-up and operating experience on such coals was obtained in carrying out the program.

1.0 INTRODUCTION

Continental Oil Company and the U.S. Department of Energy (DOE), executed Contract No. EF-77-C-01-2542 on May 27, 1977. This contract requires Continental Oil Company, as Contractor, to analyze, design, construct, test, evaluate, and operate a Demonstration Plant capable of converting high-sulfur bituminous caking coal to a pipeline quality gas.

The contract specifies that the work shall proceed in three phases:

Phase I - Development and Engineering
Phase II - Demonstration Plant Construction
Phase III - Demonstration Plant Operation

The contractual stated cost of Phase I is 25.15 million dollars. The estimated budgetary costs for Phases II and III in 1975 dollars are 170 and 176 million dollars, respectively. More accurate cost estimates for these two phases will be established during Phase I.

Phase I costs are financed entirely by the United States Government. Phase II and III costs will be shared equally by the United States Government and private industry.

Prior to executing the contract, Continental Oil Company informed DOE that the existing data base was insufficient for designing the Gasification Section, particularly the gasifier, and associated upstream and downstream processing units for the coals selected for the Demonstration Plant. The contract provides for the requisite work effort to obtain the needed data base and to fill data gaps and resolve technological problems that may be identified in implementing the Phase I work assignments. This contractual provision is Task IX-Technical Support of the Appendix A Statement of Work. Sub-task IX-A explicitly provides for the acquisition of design data for the Demonstration Plant coals. These coals are Ohio No. 9 and Pittsburgh No. 8.

The major work effort to satisfy the requirements of Sub-task IX-A was subcontracted to British Gas Corporation. British Gas has a pilot plant slagging gasifier located at its Westfield Development Centre near Cardenden, Scotland. A subcontract with Lurgi Kohle und Mineraloeltechnik GmbH of Frankfurt (Main), Federal Republic of Germany, was also executed to obtain Lurgi's advice and assistance in implementing the Sub-task IX-A technical support program.

The original subcontract with British Gas provided for eight months of pilot plant operations at Westfield Development Centre. A second subcontract was executed to provide an additional two and one-half months of pilot plant work in order to fulfill all of the Task IX work requirements.

The pilot plant work has been completed, and the requisite data base for designing the Demonstration Plant is now available.

The balance of this report gives the details of the technical support activities under Contract No. EF-77-C-01-2542.

2.0 SUMMARY AND CONCLUSIONS

Fifteen pilot plant runs were completed at Westfield Development Centre - 11 under the original subcontract and four under the second subcontract. Ohio No. 9 coal, Pittsburgh No. 8 coal, Scottish Frances coal, and metallurgical coke were gasified during the program.

The first seven runs disclosed that the pilot plant gasifier, as constructed, had difficulty processing bituminous caking coals for sustained periods although it could gasify weakly-caking Frances coal and metallurgical coke with ease. Information, data, and observations obtained during these runs led to changes in the gasifier configuration and internal components which ultimately permitted operating the pilot plant successfully over sustained periods on both Ohio No. 9 and Pittsburgh No. 8 coals.

The pilot plant program fully accomplished the work requirements for Sub-task IX-A of the Statement of Work in the prime contract. In addition critical design and technological problems which surfaced during the initial pilot plant runs on Ohio No. 9 coal were resolved satisfactorily. Continental Oil Company, British Gas Corporation, and Lurgi Kohle und Mineraloeltechnik are collectively confident that the British Gas/Lurgi slagging gasifier can process most, if not all, bituminous caking coals and yield a crude synthesis gas which can be converted to high-Btu pipeline quality gas using proven downstream processes.

2.1 Major Conclusions And Achievements

- Data and information required for the design and construction of an operable and environmentally acceptable Demonstration Plant have been obtained.
- Operability of the British Gas/Lurgi slagging gasifier has been demonstrated with Pittsburgh No. 8 coal and to a somewhat lesser extent with Ohio No. 9 coal.
- Operability of the slagging gasifier with other eastern bituminous coals can be predicted with confidence.
- Operability of the slagging gasifier with bituminous caking coals containing 23 percent fines (¼" x 0) has been demonstrated. The absolute limit of fines tolerance was not determined.
- The inherent advantages of the slagging gasification process have been confirmed, and considerable start-up and operating experience was obtained in implementing the technical support program.

Design Data And Information

The Westfield Technical Support Program (TSP) provided the data and information required by British Gas and Lurgi to complete the process, engineering, and mechanical design of the Demonstration Plant gasifier. The TSP confirmed that compared with the original Westfield pilot plant the Demonstration Plant gasifier should be designed to provide a longer upper shaft and a different shaft and hearth configuration, a modified coal distributor/stirrer and distributor/stirrer drive mechanism, and a modified internals configuration for the slag quench vessel. These changes, except shaft length, were in part evaluated during the TSP.

The Westfield TSP also provided the operating data, product yields, and product compositions required by Lurgi to design the downstream gas processing units for the Demonstration Plant. Adequate heat and material balances could and were prepared from the test data for most pilot plant runs (see Appendix A).

The Westfield TSP provided the data and information required for the design of the coal and flux preparation facilities, the air separation unit (oxygen plant) and the steam generation facilities for the Demonstration Plant. The TSP suggests that a washed coal feed to the gasifier is preferable and advantageous. A washed coal feed significantly reduces the amount of extraneous inorganic matter (soil, slate, rocks, etc.) entering the gasifier. This is particularly advantageous for surface-mined coal feedstocks.

Data and samples relating to the environmental effects of the Demonstration Plant effluents were obtained in implementing the TSP. These data will enhance the ability to design an environmentally acceptable process and plant.

Demonstration of Operability

Sustained trouble-free operation was demonstrated for Pittsburgh No. 8 coal, Scottish Frances coal, and metallurgical coke. Short periods of trouble-free operation on Ohio No. 9 coal were also demonstrated. The properties of these feedstocks span the range of properties of Eastern U.S. coals. Some of the important coal parameters and the ranges investigated are shown below:

Property	Range
Ash Content, Weight Percent	6 to 30
Moisture Content, Weigh Percent	4 to 8
Free Swelling Index	0 to 8
Fines (¼" x 0) Content, Weight Percent	4 to 23

Although the pilot plant gasifier operated satisfactorily with both Pittsburgh No. 8 and Ohio No. 9 coals, the performance with Pittsburgh No. 8 coal was superior. This may have been due to its lower ash level and the fact that it had been washed prior to being fed to the gasifier. Metallurgical coke, which is a logical start-up feedstock, also ran smoothly.

The slagging gasifier ran successfully on a 1 1/2" x 0 Pittsburgh No. 8 coal feed. This feed contained 23 percent of 1/4" x 0 coal fines. The important process impact of this achievement is that most, if not all, of the fines in run-of-mine bituminous caking coals can be fed directly to the gasifier. Excess fines, if any, can be consumed in an on-site steam power unit to provide the steam and power requirements for a commercial gasification plant.

Removal of coal ash as slag from the bottom of the gasifier was automatically controlled in every run, and information relative to the required level of flux as a function of coal ash level and composition was obtained.

Problems caused by the caking properties of bituminous coal feedstock were encountered and solved.

The materials of construction and equipment life were satisfactory with only one component failure occurring in the program. The failure was the result of prolonged operation with abnormal bed behavior, and recurrence is preventable.

Demonstration of the Inherent Advantages of the Slagging Gasifier

The inherent advantages of the British Gas/Lurgi slagging gasifier have been confirmed during the program. Some of these advantages are listed below for Pittsburgh No. 8 coal as feedstock.

High Coal Throughput	- 870 pounds of MAF coal per hour per square foot of gasifier cross-sectional area.
Low Steam Requirement	- 0.39 pound of steam per pound of MAF coal.
Modest Oxygen Consumption	- 0.56 pound of oxygen per pound of MAF coal.

The pilot plant coal throughput exceeds the original design throughput for the Demonstration Plant gasifier even though the operating pressure for the pilot plant gasifier was 85 psi lower than the design pressure for the Demonstration Plant gasifier. Higher operating pressures will allow even greater throughputs while maintaining stable bed conditions (i.e., constant gas-side pressure drop across the bed). Gasifier throughput may be increased very nearly in proportion with the square root of an operating pressure increase without upsetting bed conditions. Thus, a pressure increase from 365 psia (Westfield) to 450 psia (Demonstration Plant) corresponds to an 11 percent increase in throughput.

A series of improvements were made during the Westfield TSP. These set the stage for a series of runs leading to the achievements list above. The most important of these improvements are:

- The use of a layering procedure to prolong operations which led to a better understanding of the gasifier.

- Modification of the coal bunker to allow use of dual feedstocks.

- Modification of British Gas proprietary equipment to eliminate fouling of the slag quench chamber.

- Installation of an improved stirrer and stirrer/distributor drive to correct problems with massive caking of the coal feed below the stirrer.

- The temporary feeding of metallurgical coke to correct gasifier bed behavior problems due to caking of the coal feed below the stirrer in the event that such a malfunction occurs.

- The development of a procedure of controlled load reduction for coping with a hang/slip phenomenon in the gasifier shaft in the event such a malfunction occurs.

2.2 Continental Oil's Assessment of the Technology

Continental Oil Company's approach to the Demonstration Plant program is one of minimizing risks, i.e., each of the process steps except gasification and possibly methanation rely on commercially-proven technology. Methanation had previously been demonstrated on a large scale by Continental Oil; so the major uncertainty was gasification.

Selecting a gasifier for the Appalachian coals presented a problem because of the caking problems and because of the low melting point of the ash. However, the latter problem was turned into an advantage by modifying a conventional Lurgi dry-bottom gasifier into one that would handle a liquid ash, or slag. The advantage is magnified because much less steam is required. This not only lowers operating costs but also greatly increases capacity and reduces investment costs.

As this report concludes, the British Gas/Lurgi slagging gasifier pilot plant successfully gasified two Appalachian coals, and one can extrapolate with considerable confidence that any eastern U.S. coal can be gasified in this fashion. In addition it is clear that the gasifier is quite tolerant of fines; so that a potential problem of fines disposal is quite probably eliminated. It is expected that the gasifier can gasify all of the liquid hydrocarbons which are produced, if desired.

Since the slagging gasifier is exposed to much higher temperatures, and hot liquid slag must be contained in the gasifier, considerable attention was paid to materials of construction. Although no single pilot plant run lasted longer than 5 days, virtually all of the equipment was used repeatedly. This start and stop operation is a more severe test than sustained operation; so a reasonable degree of confidence was developed for the durability of the gasifier components.

As with any developing technology there are some risks and uncertainties, which is a reason for constructing and operating a demonstration plant prior to a commercial plant. One risk is scale-up. This risk should be nominal because the diameter of the Demonstration Plant gasifier is only 1.67 times that of the pilot plant gasifier. Another risk is the materials of construction - particularly in the very hot hearth. As described in the previous paragraph, the pilot plant observations support the belief that this risk is small. And finally there is the risk that for some reason the individual commercially-proven process units will not integrate. This risk should also be quite small, not only because these units have been used in similar situations, but also Continental Oil Company has operated an integrated semi-commercial plant with each of the main process units, except the gasifier, to manufacture SNG. This manufactured SNG was distributed to consumers for a period of about two months, and the consumers detected no difference compared with natural gas.

Thus, the experimental program conducted at Westfield, Scotland has removed most of the uncertainty of gasifying Appalachian coals in the system Continental Oil has proposed. Continental Oil's assessment is that the technology developed in the pilot plant is now ready to be evaluated on a demonstration plant scale and that on this scale the data support the expectation that it will be successful technically.

2.3 British Gas Corporation's Assessment of the Gasifier Technology

Quoted below is British Gas Corporation's assessment of the gasifier technology. This assessment was provided by Mr. R. B. Sharman, Director of International Consultancy Service, by telex dated September 26, 1978.

> "The British Gas Corporation has successfully completed the Technical Support Programme to the extent permitted by time and financial restraints.
>
> Prior to the Technical Support Programme, operation of the gasifier had largely been confined to weakly caking coals, with only limited running on moderately caking coal (Illinois No. 5). Whilst experience on the latter coal indicated that gasification of caking coals was likely to be successful, data was limited. However it was recognised that, for coals with higher caking and swelling properties, such as Ohio No. 9 and Pittsburgh No. 8, particularly with high ash contents, modifications to the reactor configuration were desirable to ensure long trouble free operations. Some of these anticipated changes were carried out prior to the Technical Support Programme. There was also a need to obtain data for the design of a purpose built plant, only obtainable by operations with selected coals.

Early experience during the Technical Support Programme did indeed confirm that changes in configuration were necessary and, where possible, such changes were carried out during the course of the programme, culminating in the later runs with essentially satisfactory performance. Experience also suggested that even better running could be obtained from a purpose designed and built gasifier which would give attention in particular to shape and length of the gasifier shaft. These changes, including the above mentioned longer gasifier, can be incorporated in the Demonstration Plant design which British Gas is confident will successfully handle the highly caking and swelling coals.

The Technical Support Programme also demonstrated that the gasifier can handle highly caking coals containing a considerable amount of fines and hence a wide size range of feedstock. There was no indication that a limit had been reached in this respect. During the course of the programme the data acquired was sufficient to enable the overall gasification scheme to produce SNG to be designed with confidence but time did not permit optimisation of the performance of the gasifier to be pursued, particularly with respect to process parameters and further work is desirable in this respect.

The close agreement with predicted operating performance strengthened the claim for the British Gas/Lurgi slagging gasifier in comparision with other gasification systems. Proprietary equipment and systems designed to inject steam/oxygen into the gasifier and to handle and remove molten slags worked very well during the programme, despite occasional severe conditions, and these can be considered to have performance and lifetimes compatible with commercial running of the gasifier. Of the two caking coals which were gasified during the Technical Support Programme the performance on Pittsburgh No. 8 coal was the better although it remains uncertain as to whether or not the Ohio No. 9 would operate equally well if washed. Operation on the weakly caking Frances coal was good. The use of bituminous coals of widely differing caking properties has been demonstrated successfully and we are confident that a Demonstration Plant as has been proposed would handle a wide range of bituminous coals. The scale-up from the pilot plant is modest as is the increase in operating pressure thus enabling the above prediction to be made with confidence."

2.4 Lurgi's Assessment of the Gasifier Technology

Quoted below is Lurgi Kohle und Mineraloeltechnik's assessment of the gasifier technology. This assessment was provided by Mr. Paul Rudolph, Director of Coal Technology Division, by letter dated September 13, 1978.

"After the TSP has come to an end, it is now appropriate for each party concerned to draw conclusions from the results obtained.

Lurgi as being responsible for the top part of the British Gas/Lurgi slagger and as being the engineering company in charge of the basic engineering received in cooperation with British Gas those results which are necessary to design the reactor and the process plant.

As far as material balance is concerned the tests have yielded sufficient information on Ohio No. 9 and on Pittsburgh No. 8 coals. We are in a position to predict the product distribution within a range of 10 percent for the design of the gasifier as well as for the downstream units.

For the reactor design we have learned that we need a longer reactor system to handle eastern U.S. coals. We are quite confident that we can prepare a design which would facilitate the processing of Pittsburgh No. 8 coal. We also feel the gasifier has the potential to handle Ohio No. 9 coal.

Considering the favorable results with Pittsburgh No. 8 coal, especially with the wide size range feed, we hope that the work will go on."

3.0 TECHNICAL SUPPORT BACKGROUND

This section of the report provides background information on the slagging gasifier technology, the contractual technical support work requirements, the technical support program carried out at Westfield Development Centre, and the facilities available at Westfield. This background information provides a basis for understanding the pilot plant runs reported in Section 4.0 and the data reported in Appendix A.

3.1 British Gas/Lurgi Slagging Gasification Technology

Coal was first gasified on a commercial scale to supply gaseous fuels in the mid-1800's and continued to be a major source of gaseous fuels in the United States and many other countries until shortly after World War II. At that time the United States began to exploit its huge natural gas resources, and coal gasification rapidly declined in importance as a domestic source of gaseous fuels. Other countries turned to petroleum as their major fuel source so that today commercial use of coal gasification for manufacturing fuels is very limited.

This situation is changing, particularly in the United States, and coal is expected to become again a major source of gaseous fuels. The United States Department of Energy and its predecessors, the Energy Research and Development Administration and the Office of Coal Research, recognized that coal gasification would again become an important fuel source for the United States and for some 20 years has taken a leading role in developing new and improved coal gasification technology.

Lurgi Kohle und Mineraloeltechnik has been and is a leader in the development and commercialization of coal gasification technology throughout the world. Lurgi developed and markets a pressurized, oxygen-blown (or air-blown) fixed-bed, non-slagging gasifier which is commonly known as the "Lurgi gasifier" or the "Lurgi dry-bottom gasifier." This gasifier operates at a bottom temperature which is below the melting point of the coal ash so that the ash is produced as a particulate solid which resembles very coarse sand.

Nearly 70 Lurgi gasifiers have been built and operated successfully throughout the world. An additional 34 gasifiers have been ordered for a coal conversion plant in South Africa. The Lurgi gasifier is particularly suitable for processing high reactivity, high ash-fusion point coals of the types found in the western United States. Trial runs sponsored by the American Gas Association and the Office of Coal Research at Westfield Development Centre verified that the Lurgi gasifier can also gasify eastern bituminous coals.[1] The steam and oxygen requirements for processing such coals, however, are relatively high.

Care must be taken to keep combustion temperature in the bottom of the Lurgi gasifier below the fusion temperature of the ash.

Large excesses of steam are used in the steam-oxygen mixture to reduce combustion temperatures. The steam cools the combustion zone by endothermic reactions with carbon and acts as a heat sink.

The maximum thermodynamic efficiency at equilibrium conditions for fixed-bed coal gasification, such as the Lurgi gasifier, occurs at a steam to oxygen volumetric ratio of 1.1 to 1.5.[9] This low ratio would result in a bottom gasifier temperature of over 2,700°F which is well above the melting point of most coal ashes. Consequently, the Lurgi dry-bottom gasifier requires a substantially higher steam to oxygen ratio than desired for maximum thermal efficiency in order to keep the ash in a free-flowing solid form so that it can be removed from the gasification reactor via a movable grate.

Lurgi began the development of a pressurized slagging gasifier shortly after World War II. A small pilot plant, in reality a process development unit, was constructed and operated at the Holten Works of Ruhrchemie AG. Lurgi later sold the pilot plant to the Gas Council, now British Gas Corporation. British Gas continued the development of the fixed-bed slagging gasifier technology at its Midlands Research Station in Solihull, England, during the period 1955-1965.[2,3,4]

In 1974, British Gas restarted the development of the slagging gasifier technology in a large pilot plant constructed at its Westfield Development Centre which is located near Cardenden, Scotland. This program was sponsored by a group of United States companies (coordinated by Continental Oil Company), and it continued for a period of three years ending in March, 1977.

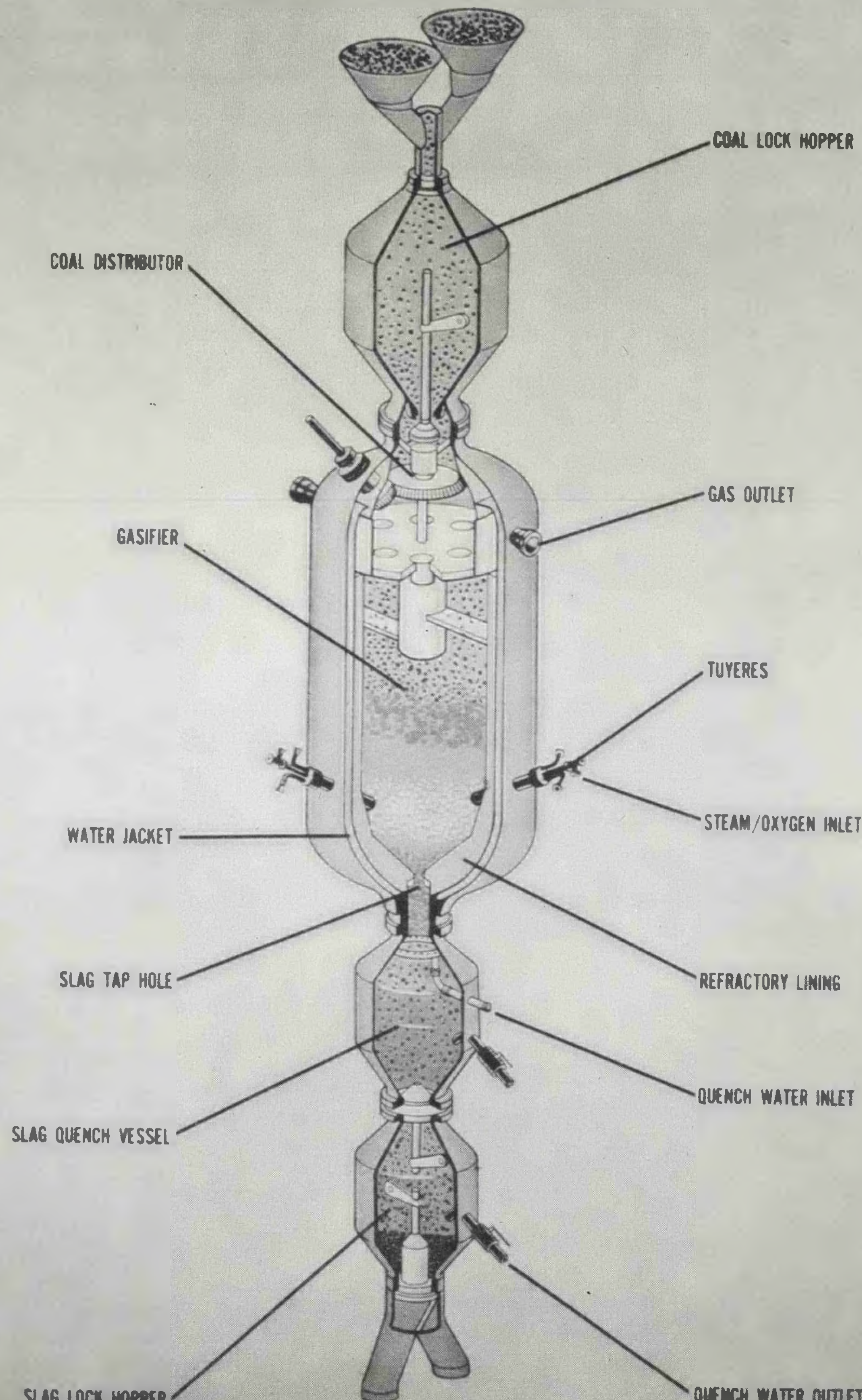
By operating the gasifier in the slagging mode, it becomes possible to operate within the range of highest theoretical efficiency (1.1 to 1.5 steam to oxygen ratio) as noted above.

The British Gas/Lurgi slagging gasifier is a pressurized, oxygen-blown, fixed-bed, slagging gasifier. It is operated at a bottom temperature which is above the melting point of the coal ash so that the ash is removed from the gasification reactor as a liquid slag. An artist's conception of the gasifier is shown on the next page.[5] While it is not accurate in detail, it shows the salient features of the gasifier.

The slagging gasifier operates at an elevated pressure. The Westfield pilot plant is normally operated at 350 psig, and the Demonstration Plant gasifier will be designed to operate at 450 psia. The gasifier is water jacketed and refractory lined. The gasifier is in essence a Lurgi dry-bottom gasifier which has been modified for slagging operations.

The British Gas/Lurgi slagging gasifier is particularly suitable for gasifying eastern bituminous caking coals which are

FIXED BED SLAGGING GASIFIER



characterized by low reactivity and low ash-fusion points. It can be used, however, to process western subbituminous coals and eastern anthracites.

Run-of-mine coal must be crushed and screened prior to being fed to the gasifier. Non-caking coals must be sized by screening to produce a nominal 2" x ¼" fraction for gasifier feed. Bituminous caking coal feeds can contain a large quantity of the ¼" x 0 coal fines fraction - at least 25 percent and probably more.

A fluxing agent must be added to some coals, including most eastern bituminous coals. This fluxing agent blends with the molten coal ash in the bottom of the gasifier to control its viscosity and enhance the slag tapping operation. The fluxing agent, if required, is fed to the gasifier in admixture with the coal feed.

The sized coal feed with fluxing agent, if required, is transferred by belt conveyor to an elevated coal storage bunker which is situated above the gasifier. Since the gasification reactor operates at an elevated pressure, the coal/flux feed is introduced into the reactor via a lock hopper system similar to that used with the Lurgi dry-bottom gasifier.

The coal/flux feed flows by gravity from the pressurized lock into the top of the gasification reactor. It is mechanically distributed uniformly across the reactor by a rotating distributor system. Hot rising synthesis gases rapidly heat the coal to effect devolatilization and coking or charring. A stirrer is provided to fracture the coke as it is formed. The stirrer may not be needed for some coals.

The devolatilized coal gradually moves downward through the reactor as it is gasified. Steam and oxygen are introduced at the bottom of the gasifier through tuyeres to effect the gasification reactions and to produce the hot synthesis gas which flows upward counter-current to the downward flowing fuel bed.

The gasification reactor is in reality a moving bed reactor. Counter-current flow of fuel and gases provides excellent heat exchange which increases gasification efficiency. Heat is provided for the gasification reactions by combustion of the devolatilized fuel in a raceway zone in front of the tuyeres. This raceway is related to that found in blast furnaces used by the steel and iron industry.

Temperatures in the raceway are above the melting point of the ash. The molten ash falls to the bottom of the gasifier on to the hearth. It combines with the fluxing agent, if required, and is removed from the gasifification reactor via a proprietary slag tapping system and procedure.

The molten slag falls into a water quench vessel where it is rapidly solidified to form a particulate frit. The solidified slag drops into a lock hopper from which it is periodically discharged from the system.

Crude synthesis gas leaves from the top of the gasification reactor and passes through a quench scrubber and waste heat boiler in much the same manner as gas from a Lurgi dry-bottom gasifier.

Auxiliary fuels such as coal fines, tars, oils, etc. may be introduced into the gasification reactor through the tuyeres, if desired.

3.2 Pre-Contract Status of Development

Prior to the start of the Westfield Technical Support Program, the technical feasibility of the British Gas/Lurgi slagging gasifier had been demonstrated using various coals in two programs. A smaller scale reactor (3-foot diameter) was operated by British Gas Corporation at their Midlands Research Station at Solihull, England. The results of this program, which ended in 1964, led to a larger scale pilot plant development program which was sponsored by a group of U.S. companies and carried out between 1975 and 1977 at the Westfield Development Centre.

These development programs demonstrated the salient features of the slagging gasifier which are listed below:

- High coal throughput
- Low steam consumption
- High thermal efficiency

In addition, experience was obtained during these programs which established the technical feasibility of the process using weakly caking feedstocks. The ability to tap slag was shown, and an automatic control system was developed. Equipment of proprietary design was installed to meet the special requirements of the slagging gasifier. These developments culminated in the achievement of an extended run of over three weeks duration.

Very little information was obtained during these programs on the performance of the gasifier while feeding high sulfur caking coals, such as those proposed for the demonstration project. A single short duration run was made using Illinois No. 5 coal as feedstock. The results of this run were encouraging in that no major operating problems were encountered and that there was no significant penalty in the process performance. Although the results of this run were encouraging, further experimental work was required to establish the design basis for the Demonstration Plant and to establish the technical feasibility of the slagging gasifier for high sulfur eastern bituminous caking coals.

3.3 Contractual Statement of Work

The Statement of Work for Task IX in Appendix A of the prime contract (No. EF-77-C-01-2542) is given below:

Task IX - TECHNICAL SUPPORT

The purposes of Task IX will be:

a. To identify data gaps, technological problems, high risk areas, and other short-comings critical to the success of the Demonstration Plant;

b. To propose solutions to the problems, high-risk areas, and short-comings;

c. To prepare plans and to estimate costs for proving the solutions or filling data gaps; and

d. To implement the plans after receiving DOE approval.

Some data gaps are described in Sub-task IX-A. Procedures for supplying the needed data are also proposed in Sub-task IX-A. Other problems, data gaps, high risk areas, and short-comings will be handled at the time that they occur or are identified.

Work under this task will be a combined effort by the Contractor and all major subcontractors.

Sub Task IX-A: Design Data for Demonstration Plant Coals

The fixed-bed, slagging gasifier is expected to be fully developed and ready for commercial demonstration by the Contract starting date. However, process design data for the coal feeds to the Demonstration Plant will not have been obtained. Specifically, design data for processing Ohio No. 9 coal and Pittsburgh No. 8 coal are needed to complete the design of the Demonstration Plant.

Other data gaps and unresolved technical problems which will exist at the start of Phase I are: The composition of the gas liquor from the processing of American coals.

Early in the Phase I program, a plan will be submitted for DOE approval to obtain the needed process design and other data and to resolve the remaining problems. The plan will be implemented upon receiving approval. The Sub-task IX-A plan will be carried out at British Gas' Westfield Development Centre, Cardenden, Scotland.

The Sub-task IX-A program will be under the direction and guidance of the project's Research Manager. Major assistance will be provided by engineers and scientists from British Gas and Lurgi Kohle und Mineraloeltechnik.

Sub-Task IX-B: Identify Critical Problem Areas

Key personnel on the Contractor's Project Management Team, in the Foster Wheeler Energy Corporation, Lurgi and British Gas organizations, and in the Engineering Center of Continental Oil Company will continuously and purposefully evaluate the Demonstration Plant process, its design, and its engineering to uncover potential problem areas that could prove detrimental to the success of the Demonstration Plant. The problem areas will be reviewed in depth. Those which need to be resolved will be reported immediately to DOE. Plans for resolving the critical problems will be developed, and costs for implementing the plans will be estimated. The plans and costs will be submitted to DOE for approval. The plans will be implemented after approval is received. Implementation of these plans will represent new cost items. They will be undertaken as new Sub-Task Assignments requiring approval by the DOE Contracting Officer.

In order to satisfy the Task IX work requirements, subcontracts with British Gas Corporation and Lurgi Khole und Mineraloeltechnik GmbH were executed on June 2, 1977, and June 1, 1977, respectively. These subcontracts, identified as the Westfield Agreement with British Gas and the Engineering Agreement Gasification Plant with Lurgi, were implemented shortly after work on the project started in July, 1977. A second subcontractor, identified as the Westfield II Agreement, was executed with British Gas on May 19, 1978. Work under the two Westfield agreements was completed on August 15, 1978.

The subcontracts with British Gas and Lurgi specify that the design, engineering, specifications, hardware, etc., of certain components of the British Gas/Lurgi slagging gasifier are based on proprietary know-how. These components, termed collectively "proprietary equipment," are listed below:

a. Gasification reactor including all internals;
b. Coal distributor drive mechanisms;
c. Coal lock chamber and associated valving and internals and coal feeding chutes;
d. The tuyeres for the injection of steam, oxygen, coal fines, and tar;
e. The slag tap and any associated extension;
f. The ring and lance burner units;
g. The hearth with respect to materials of construction, cooling equipment and their arrangement within the gasifier;
h. The quench spray ring;
i. The slag quench vessel;
k. Control system for operation of the coal lock chamber and slag lock chamber;

l. Jacket steam system;
m. Control system for gasification agents; and
n. Control system for operation of the slag tap.

Information on the proprietary equipment can be obtained only from the following:

a. Director of International Consultancy Service,
British Gas Corporation,
326 High Holborn,
London WC1V 7PT, United Kingdom; or

b. Director of Coal Technology Division,
Lurgi Kohle und Mineraloeltechnik GmbH,
6000 Frankfurt (Main),
Postfach 119181,
Federal Republic of Germany.

3.4 Technical Support Program

The Technical Support Program was established to carry out the contractual Statement of Work. The broad goals of the program were:

a. To establish technical feasibility of gasifying moderately caking, high ash, high sulfur Ohio No. 9 coal.

b. To establish technical feasibility of gasifying at least one other highly caking eastern coal (Pittsburgh No. 8).

c. To develop design data needed by British Gas Corporation and Lurgi Kohle und Mineroloeltechnik for design of the Demonstration Plant.

d. To obtain samples necessary for a proper environmental assessment of the process.

e. To pinpoint critical or potential problem areas for the Demonstration Plant.

The prerequisite for accomplishing these goals was to reconfirm the operability of the gasifier with a weakly caking Scottish coal (Frances). This was to verify the integrity of the Westfield slagging gasifier which had been refurbished for the Technical Support Program.

In addition to demonstrating technical feasibility, it was planned to study the effects of several key process variables. These variables included:

a. Coal throughput rate as determined by the level of oxygen input feed rate to the qasifier. This is often termed "oxygen loading" or just "loading." Coal throughput rate is proportional to oxygen loading.

b. The level of steam input relative to the oxygen input (steam/oxygen ratio, expressed volumetrically).

c. The choice of flux as to type and the addition rate required.

d. Feed of recycle solids-laden tar to the top of the gasifier.

e. The size consist of the feed coal, especially with respect to the content of material less than 1/4-inch.

f. Rotational speed of coal distributor and stirrer.

The operating life of each of the critical gasifier components was to be evaluated.

On a lower priority, alternate means of minimizing potentially undesirable by-products, such as coal fines and tar, were to be studied. Items (d) and (e) listed under process variables were to contribute to this goal.

Heat and material balance data and analytical data relating to environmental impact were required from every run of reasonable duration and stability. An analytical program was established to allow for prompt reporting of key analytical data. Each run was also to produce data to allow characterization of bed behavior and slag tapping performance.

Thus, the goals of the program were set to provide the data necessary to design and construct a demonstration plant based on the British Gas/Lurgi slagging gasifier technology.

In accord with the Westfield Agreement, a Technical Support Program (TSP) Committee was formed to act periodically on technical matters related to the program. This committee was assigned the responsibility and authority to examine pilot plant results and plan or modify the Technical Support Program as it was being implemented. The first meeting of the committee was held in London on June 13, 1977, and each month thereafter until completion of the pilot plant program at Westfield. Most of the meetings were held at Westfield Development Centre.

Membership of the committee was designated at the first meeting, and no changes were made in the course of the program.

Membership was as follows:

	Members	Designates
Continental Oil	J. D. Sudbury W. B. Watson	G. P. Curran C. E. Fink
British Gas	J. McHugh D. Hebden	P. Faulkner J. A. Gray
Lurgi	P. F. Rudolph H. Vierrath	U. D. Marwig M. Bierbach
Dept. of Energy	C. L. Miller	R. A. Verner

Dr. J. D. Sudbury was appointed permanent Chairman, and Mr. M. R. Tooley of British Gas was designated permanent Secretary. Minutes of each meeting were promptly submitted to all attendees and are included in Appendix D of this report.

It was agreed that Mr. James Scott, General Manager, Westfield Development Centre, and Mr. Carl Fink, On-Site Representative for Continental Oil Company, should also attend each meeting. It is the Chairman's view that this TSP Committee functioned well and willing cooperation was extended by all members.

Continental Oil was responsible for establishing the schedule of runs to be made and for preparing a detailed program for each run. British Gas was responsible for carrying out each run and for issuing appropriate run reports.

Appendix A.1 of the Westfield Agreement between Continental Oil Company and British Gas Corporation lists 11 pilot plant runs to be carried out under the agreement. This run program was prepared in January, 1977, during contractual negotiation. Continental Oil decided during the six-month interval between contractual negotiations and the implementation of the Westfield Agreement that the Appendix A.1 program should be modified and revised.

Subsequently, with the advice of the Program Committee and the consent of British Gas, a revised 11 run pilot plant program was submitted to DOE on August 24, 1977. This program is attached to the minutes of TSP Committee meeting No. 3 in Appendix D. DOE approved this program by letter dated September 13, 1977.

As the Technical Support Program proceeded, the TSP Committee from time to time modified the program to permit the resolution of new technical problems as they arose. These modifications, the technical problems to be resolved, and the committee deliberations are summarized in the Appendix D minutes.

It developed that the 11-run program covered by the original Westfield Agreement, which terminated on March 31, 1978, did not provide the technical data base desired by DOE and Continental Oil Company. A second agreement, the Westfield II Agreement, was negotiated with British Gas to permit four additional pilot plant runs. These additional runs were completed on August 15, 1978.

The requisite technical data base for designing and constructing the Demonstration Plant is now in hand.

3.5 Westfield Development Centre

The Westfield Development Centre was originally an operating town gas works designed and constructed for the Scottish Gas Board, now the Scottish Gas Region of British Gas Corporation. Scottish Gas operated the facility as a commercial plant from December, 1960, through June, 1974. The plant was shut down at that time because of the availability of natural gas for the consumers in the plant's gas distribution area.

The Westfield gas works has been described in detail.[6, 7, 8] The plant manufactured up to 40 million standard cubic feet per day of town gas (ca 450 Btu/SCF). The works consisted of four Lurgi dry-bottom gasifiers, three coal-fired steam boilers, oxygen plant, CO shift conversion unit, Benfield plant, Bischoff plant, gas drying plant, sulfur recovery plant, gas liquor separation unit, benzole absorber, and ancillary facilities.

Conoco Methanation Company negotiated a contract with British Gas Corporation in 1972 for the construction and operation of a semi-commercial Rectisol/Methanation facility. This facility was designed to convert 10.2 million SCFD of synthesis gas from the Lurgi gasifiers into 2.6 million SCFD of pipeline quality gas (SNG). This facility was successfully operated over a period of 14 months ending in September, 1974. The technology for converting coal-derived synthesis gas into saleable SNG was convincingly demonstrated in this program. The Rectisol/Methanation facility is now part of Westfield Development Centre.

British Gas Corporation converted the Westfield Works into a research and development facility in July, 1974, and re-named it the Westfield Development Centre. One of the existing Lurgi gasifiers was extensively modified into a large British Gas/Lurgi slagging gasifier pilot plant. This pilot plant and supporting facilities were used to carry out the Technical Support Program under Contract No. EF-77-C-01-2542.

The simplified flow diagram on pages 25 - 26 of this section shows the pilot plant. As illustrated, coal and flux are elevated to the overhead storage bunker via belt conveyors. During the Technical Support Program, the overhead bunker was modified to accommodate two coal feedstocks and two types of fluxes so that either coal or flux could be alternately fed to the gasifier, if desired.

Coal is fed batchwise into the depressurized coal lock via gravity flow. Flux is simultaneously metered into the coal lock via vibrating feeders. The coal lock is then raised to gasifier pressure with either nitrogen or recirculated lock gas before the coal is dropped into the distributor section of the gasifier. The distributor is continuously rotated to effect even distribution of coal and flux over the cross-sectional area of the gasifier. After the coal lock has emptied, it is depressurized by venting the gas to the Lock Gas Holder.

Recycle tar from the bottom of the Tar Separator can be fed to the top of the gasifier by the Recycle Tar Pump. Tar is recycled in order to control coal and char dust carryover with the crude synthesis gas and to dispose of solids which accumulate in the tar.

Crude synthesis gas rising countercurrent to the downward flow of coal and flux leaves the top of the gasifier through two offtake lines. Agglomerates of coal which may form in the top of the gasifier bed are fractured by a stirrer mechanism. The stirrer is integrally linked to the distributor, and both are rotated with the same drive mechanism. The stirrer is designed to maintain a downward flow of bed solids and to minimize the formation of large voids.

Steam and oxygen are injected as one stream into the fuel bed near the bottom of the gasifier. High-pressure, superheated steam for gasification is supplied by the Westfield boilers. Oxygen (about 95 volume percent purity) for gasification is supplied by the Westfield oxygen plant. An oxygen preheater was installed following TSP Run 7 to raise the temperature of the steam/oxygen stream entering the gasifier. Oxygen and steam are mixed at controlled rates external of the gasifier and are distributed to the tuyeres by a bustle manifold.

The gasifier is water-jacketed to reduce the inner shell surface temperature. Steam is produced in this jacket, and it is injected into the crude synthesis gas downstream of the gasifier. Water is circulated through the jacket and the stirrer/distributor assembly by the Jacket Water Recirculation Pump.

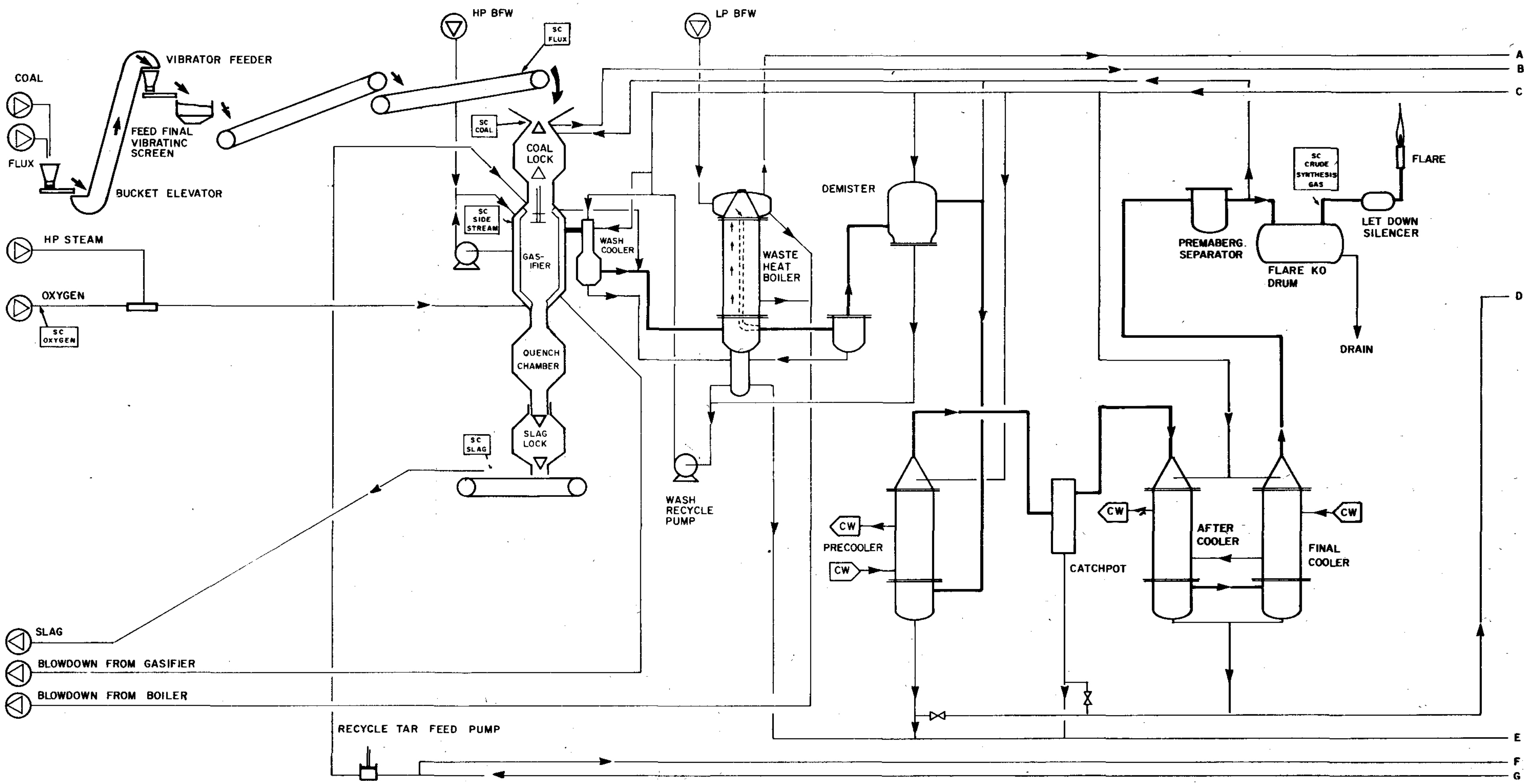
Molten ash and flux collect as slag on the hearth at the bottom of the gasifier. The slag is discharged into the pressurized Quench Chamber through a tap hole. Slag tapping is controlled by a proprietary system. The slag is almost immediately solidified in the Quench Chamber and falls as a dense, small-grained frit into the Slag Lock Hopper. Slag is periodically removed from this lock hopper on a depressurizing-pressurizing cycle, and it falls onto a belt conveyor which transfers the slag to storage.

Two separate and similar gas cooling trains are used to cool the hot curde synthesis gas which leaves the gasifier. The gas is first quenched with a circulating gas liquor stream in the Wash Cooler. It is further cooled in the Waste Heat Boiler. The gas liquor for quenching is recirculated from the sump of the Waste Heat Boiler by the Was Recycle Pump. Part of the gas liquor stream which consists of tar, oil, dust, and phenolic water is pumped to the Tar/Liquor Separation Plant.

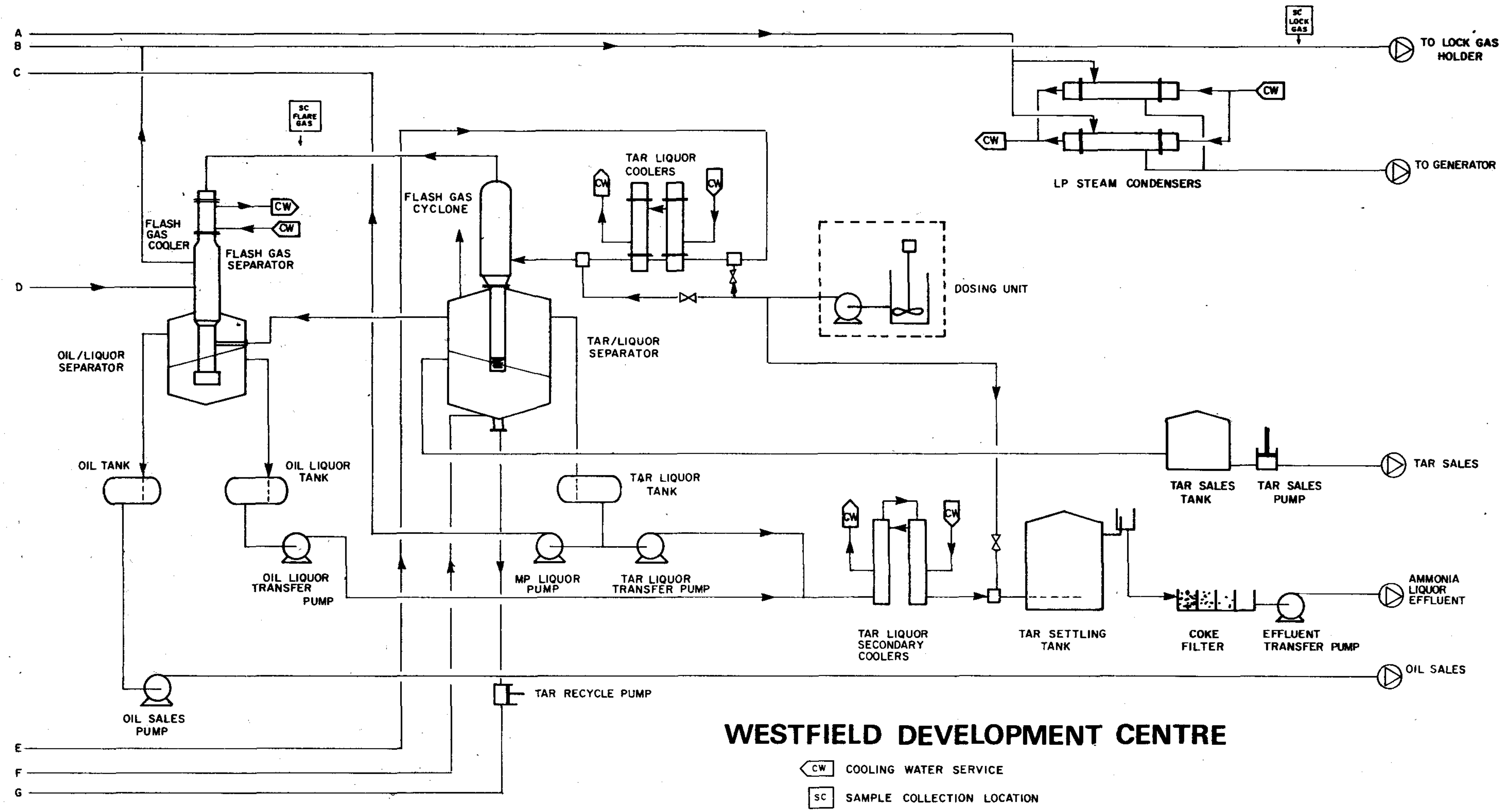
The crude synthesis gas leaves the Waste Heat Boiler and is further cooled by a series of water-cooled heat exchangers--the Pre-cooler, After-cooler, and Final Cooler. Condensate from these coolers is transferred to the Oil/Liquor Separation plant.

The cooled synthesis gas is metered, and its pressure is reduced. It is then burned in an elevated flare.

Various gas liquor, oil, and tar condensates are separated into tar, oil, and gas liquor in the gas liquor separation unit which consists of the Tar/Liquor Separation Plant and the Oil/Liquor Separation Plant. The solids (dust) in the tar settle toward the bottom of the tar in the Tar Separator. This solids-laden tar fraction is usually recycled to the top of the gasifier as discussed previously. Clear tar and oil are disposed of locally.



HP BFW
LP BFW
SC FLUX
VIBRATOR FEEDER
COAL
FEED FINAL VIBRATINC SCREEN
FLUX
BUCKET ELEVATOR
SC COAL
COAL LOCK
SC SIDE STREAM
GAS-IFIER
WASH COOLER
WASTE HEAT BOILER
DEMISTER
PREMABERG. SEPARATOR
SC CRUDE SYNTHESIS GAS
FLARE
LET DOWN SILENCER
FLARE KO DRUM
DRAIN
HP STEAM
OXYGEN
SC OXYGEN
QUENCH CHAMBER
SLAG LOCK
SC SLAG
WASH RECYCLE PUMP
CW
PRECOOLER
CW
CATCHPOT
CW
AFTER COOLER
CW
FINAL COOLER
SLAG
BLOWDOWN FROM GASIFIER
BLOWDOWN FROM BOILER
RECYCLE TAR FEED PUMP
A
B
C
D
E
F
G


A
B
C
D
E
F
G
SC LOCK GAS
TO LOCK GAS HOLDER
CW
LP STEAM CONDENSERS
TO GENERATOR
SC FLARE GAS
FLASH GAS COOLER
FLASH GAS SEPARATOR
FLASH GAS CYCLONE
TAR LIQUOR COOLERS
DOSING UNIT
OIL/LIQUOR SEPARATOR
TAR/LIQUOR SEPARATOR
OIL TANK
OIL LIQUOR TANK
TAR LIQUOR TANK
TAR SALES TANK
TAR SALES PUMP
TAR SALES
OIL LIQUOR TRANSFER PUMP
MP LIQUOR PUMP
TAR LIQUOR TRANSFER PUMP
TAR LIQUOR SECONDARY COOLERS
TAR SETTLING TANK
COKE FILTER
EFFLUENT TRANSFER PUMP
AMMONIA LIQUOR EFFLUENT
OIL SALES
OIL SALES PUMP
TAR RECYCLE PUMP
WESTFIELD DEVELOPMENT CENTRE
CW COOLING WATER SERVICE
SC SAMPLE COLLECTION LOCATION

Flash gases from depressurizing the gas liquor, tar, and oil in the gas liquor separation unit are cooled and transferred to the Lock Gas Holder. Gas from the Lock Gas Holder is either burned in the boiler house or used to repressurize the coal lock.

4.0 SUMMARY OF PILOT PLANT RUNS

A total of 15 pilot plant runs was completed at Westfield Development Centre under the two Westfield Agreements between Continental Oil Company and British Gas Corporation. These runs are identified in this report in a numerical sequence beginning with TSP Run 1 and ending with TSP Run 15. In previous technical progress reports, interim run reports, Program Committee minutes, and the Westfield II Agreement some runs were given a different designation. The previous run designations compared with the designations used in this report are given below:

Task IX Report, Run Identity	Previous Run Designation
TSP Run 1	Run 1
TSP Run 2	Run 2
TSP Run 3	Run 3
TSP Run 4	Run 4
TSP Run 5	Run 5
TSP Run 6	Run 6
TSP Run 7	Run 7
TSP Run 8	Run 8
TSP Run 9	Run 9-A
TSP Run 10	Run 9-B
TSP Run 11	Run 9-C
TSP Run 12	Run A
TSP Run 13	Run B-1
TSP Run 14	Run B-2
TSP Run 15	Run C

This section of the report gives summaries of the 15 pilot plant runs including operations and post-run inspection of the gasifier. The data collected during each run are given in Appendix A.

A standard start-up procedure for the pilot plant gasifier was used for each run. The gasifier is first pressure tested at 350 psig, and all supporting systems are checked. The gasifier is then filled without heating and at atmospheric pressure with lumps of petroleum coke. The gasifier is then pressurized to about 100 psig with nitrogen. Next air is introduced through the tuyeres, and the coke is ignited.

As soon as coke combustion has stabilized on air, steam and oxygen are admitted to the gasifier through the tuyeres. Concurrently, the start-up fuel for the run is fed into the top of the gasifier through the coal lock hopper. The start-up fuel for all pilot plant runs was either Scottish Frances coal or blast furnace metallurgical coke. Operating conditions are adjusted to those specified for the pilot plant run.

The start-up procedure is relatively simple, and it was used throughout the technical support program without encountering any difficulties. Start-up is usually completed within two or three hours.

4.1 TSP Run 1 Summary

TSP Run 1 was the first run of the Westfield Technical Support program. The main objective of the run was to commission the gasifier and its systems, both of which had undergone considerable overhaul and modifications since the last test series under a privately-funded program. The major changes to the plant prior to TSP Run 1 included: (1) a new stirrer/distributor system; (2) instrumentation modifications to allow automatic control of slag tapping from the main panel board; and (3) a new system to feed flux into the coal lock. Secondary objectives of this run were to confirm the operability of the gasifier on Frances coal (as previously demonstrated during the privately-funded program), to investigate gasifier behavior at lower than normal load (oxygen supply rate) and at higher hearth temperatures in anticipation of Ohio No. 9 coal feed, to investigate gasifier performance while fluxing Frances coal with blast furnace slag, and to collect heat and material balance data.

Operations commenced at 1107 on August 17, 1977. After standard start-up procedures, gasification of Frances coal was established at 160,000 SCFH oxygen (95% purity), 1.35 volumetric steam/oxygen ratio, and 350 psig system pressure. The gasifier ran for two days at these conditions to establish the integrity of the refurbished reactor and its systems. There were two brief standby periods during this time due to slight problems with coal locking, but recovery from these was rapid and complete.

The fluxing system was commissioned on blast furnace slag at these conditions. The system worked well, providing a reproducible flow of flux and fuel into the coal lock as evidenced by slag analyses. Good slag tapping was maintained. After 8.5 hours, the flux trials were terminated. Gasifier operation was slightly smoother during the fluxing period than during the previous unfluxed period.

After the fluxing period, the low load trials were commenced. The gasifier load was reduced in stepwise fashion from 160,000 to 122,000 SCFH oxygen rate over a 16-hour period. Operation was stable at all load levels, but it was decided to reconfirm gasifier performance at 130,000 SCFH oxygen.

This load was established and maintained for a period of nearly nine hours, with 6.5 hours unfluxed and 2.5 hours fluxed operation. As with the previous flux trials, gasifier operation was slightly smoother while adding blast furance slag.

Flux addition was maintained at the same rate, but the steam/oxygen ratio was next trimmed from 1.35 to 1.15. After a brief period at 140,000 SCFH oxygen, the load was cut to 130,000 oxygen. These conditions were maintained for the last 3.5 hours of the run. Then the gasifier was subjected to a controlled shutdown, all objectives having been achieved.

The post-run inspection revealed that the top of the gasifier shaft was in excellent condition, and the new stirrer/distributor system had come through its first test well. At the bottom, the hearth showed slight, expected wear. The slag tap and quench chamber systems were in good condition.

During TSP Run 1, the gasifier and its systems were successfully commissioned and their mechanical integrity demonstrated during 97 hours of operation feeding Frances coal. This long-term operation confirmed the reliability of the system while gasifying Frances coal, as demonstrated previously during the privately-funded program. During the run, the oxygen loading was ranged from 160,000 to 122,000 SCFH and the steam/oxygen ratio ranged from 1.35 to 1.15. After observing gasifier operation at these conditions, it was decided that 130,000 SCFH and 1.15 steam/oxygen would be the most desirable conditions at which to make the transition from Frances coal to Ohio No. 9 coal in TSP Run 2. The new flux feed system was also demonstrated to be a reliable method of adding flux to the coal lock. Gasifier operation was found to be slightly smoother when fluxing than when not. Heat and material balance data were collected during both the fluxed and the unfluxed periods of operation. On two occasions, the ability of the system to recover from standby conditions was demonstrated. After all run objectives had been achieved, the gasifier was subjected to a scheduled, voluntary shutdown. Inspection showed that the gasifier had operated for approximately 97 hours without significant damage to internals.

4.2 TSP Run 2 Summary

After establishing the integrity of the refurbished Westfield slagging gasifier and identifying satisfactory operating conditions for processing Ohio No. 9 coal during TSP Run 1, TSP Run 2 was planned to introduce Ohio No. 9 coal to the gasifier. Prolonged operation would be required so that key parameters (including tar recycle rate to the top of the gasifier, stirrer speed, and flux/ash ratio) could be tuned to provide reliable operation. Steady operation of 12 to 24 hours was planned in order to collect detailed heat and material balance data. A further objective was to compare operation while gasifying both narrow-range (1" x 5/8") and wide-range (2" x 1/4") Ohio No. 9 coal feedstock.

Prior to TSP Run 2, the tuyere nozzles were changed for nozzles of a different diameter to give the desired blast velocity. The slag removal system was modified to improve reliability. The flux feeder was also modified slightly to provide more consistent feed rates.

After a standard start-up on petroleum coke, slagging gasification on Frances coal began at 1115 on September 7, 1977. After a four hour settling down period, the rates were established at 130,000 SCFH oxygen rate, 1.15 steam/oxygen ratio, and 350 psig system pressure. Operation at this steam/oxygen ratio was initially unsteady. The ratio was increased to 1.35 before fluxing operations commenced. While fluxing with blast furnace slag, the ratio was again trimmed to 1.15. This time steady operation was achieved.

Before preparations to accept Ohio No. 9 coal were completed, a loss of oxygen led to a 3.5 hour stand-by period. Although the switch to stand-by conditions was executed promptly, the sudden loss of oxygen may have resulted in steam alone going into the gasifier for a brief period. Recovery from stand-by was not completely successful. One tuyere remained black, but it was decided to continue running on the remaining tuyeres.

Conditions were re-established to those in effect just before the stand-by period. Narrow-sized Ohio No. 9 coal was charged to the near empty bunkers at 1148 on September 9, 1977. The transition to Ohio No. 9 coal was relatively smooth with steady offtake temperatures and good slag tapping. Gasification continued smoothly for the next 15 hours, although it was noticed that slag was dribbling (falling intermittently) from the tap. This caused some slag to build up on the bottom of the burner.

A second tuyere went black after 15 hours on Ohio No. 9 coal and was switched off even though full gas flow continued down the tuyere.

Gasification on the remaining tuyeres continued satisfactorily, except for steadily increasing fouling in the quench chamber. Growths in the quench chamber finally restricted visibility to the point that slag taps could no longer be observed. The plant was shut down at 1029 on September 9, 1977.

Post-run bed inspection revealed massive caking of coal below the stirrer and numerous 6 to 12 inch lumps of caked coal/char agglomerates. The nozzle of one tuyere was plugged with frozen slag. This may have accounted for the low flow down the tuyere after stand-by. The refractory walls of the shaft and hearth were in good condition.

Satisfactory operation on narrow-sized Ohio No. 9 coal was demonstrated for 23 hours during TSP Run 2. During this period, the gasifier was tuned to provide steady operation and heat and material balance data were collected. The run terminated before wide-range coal could be fed to the gasifier.

During the final period of Ohio No. 9 coal gasification, conditions were identified which resulted in slag growths in the quench chamber. The system again demonstrated its ability to recover from standby. Inspection showed that operation on Ohio No. 9 coal had not caused significant damage to gasifier internals, after 46 hours of operation during TSP Run 2.

4.3 TSP Run 3 Summary

Termination of TSP Run 2 was forced by quench chamber fouling, preventing controlled slag tapping. The primary objectives of TSP Run 3 were to eliminate slag buildup in the quench system and demonstrate gasifier operation while feeding 1-3/4" x 1/4" Ohio No. 9 coal. It was also planned to use limestone as the fluxing agent and study the effect of flux/ash ratio on gasifier performance. A final objective for TSP Run 3 was to range the steam/oxygen ratio and observe gasifier performance.

Slagging gasification on Frances coal, via a standard start-up on petroleum coke, began at 1507 on September 28, 1977. After five hours of operation, rates were established at 130,000 SCFH oxygen, 1.35 steam/oxygen ratio, 350 psig gasifier pressure, and flux addition in the form of blast furance slag.

There was a one-hour stand-by period at this stage due to a faulty level control valve on one of the Waste Heat Boiler Sumps. Rates were quickly established after standby and the first lock of Ohio No. 9 coal was charged to the gasifier at 0117 on September 29. The transition to Ohio No. 9 coal was smooth, and the initial period of gasification was steady. At 0320 there was a high offtake temperature spike accompanied by a rise in the pressure drop (DP) in the gasifier bed. This was followed ten minutes later by a similar but more severe incident, with sharp rises of the offtake temperature, bed DP, carbon dioxide content of the offgas, and stirrer torque. The stirrer tripped out and stopped at this point, and the gasifier was placed on stand-by. The distributor was restarted briefly, but bed conditions remained poor. This led to a decision to terminate the run.

Post-run inspection showed several large agglomerates of caked coal in the distributor. This may have restricted free flow of coal to the top of the gasifier. Fine coal and lumps of blast furance slag were found lodged in the distributor gear drive. This could have been at least partly responsible for the stirrer/distributor trip at the end of the run.

Below the stirrer, extending roughly three feet down the bed, was a plug of strongly caked coal. Underneath this zone was a bed of char which contained a few football-size agglomerates of char/caked coal. This char zone was four to five feet deep and was supported by another large plug of caked coal extending down to the tuyeres.

The hearth, slag tap, and quench chamber systems were in good condition.

Gasifier operation on 1-3/4" x 1/4" Ohio No. 9 coal was limited to just over 2-1/2 hours during TSP Run 3. This was not sufficient time to allow evaluation of efforts to limit quench chamber fouling. Early termination also forestalled demonstration of limestone fluxing and ranging of the steam/oxygen ratio. An evaluation of bed conditions during TSP Run 3 led to the conclusion that coal flow had been interrupted due to "hanging" of the fuel bed. Following the hang, the bed had "slipped", allowing fresh coal to fall below the influence of the stirrer before caking was completed. These events demonstrated the need to control "hang/slip" behavior in the bed, as evidenced by offtake temperature excursions. They also demonstrated the need for a more rugged stirrer system. Following this run, planning commenced for a new drive mechanism and an extension to the stirrer shaft.

During the Frances coal gasification period, the system again demonstrated its ability to recover from standby conditions. The duration of operation during TSP Run 3 was 11 hours. The bed conditions leading to high offtake temperatures and the distributor stoppage during the run did not result in significant damage to gasifier internals.

4.4 TSP Run 4 Summary

Operation during TSP Run 3 demonstrated the conditions which led to "hang/slip" behavior in the fuel bed. Experience with Frances coal gasification during TSP Run 1 suggested that operation at a higher steam/oxygen ratio reduced the tendency for hang/slip conditions in the bed. Therefore, it was planned to make the transition from Frances coal to Ohio No. 9 coal during TSP Run 4 at a higher steam/oxygen ratio. It was also planned to demonstrate the effect of temporary load reductions in overcoming hang/slip conditions and other major bed instabilities. Three additional objectives from TSP Run 3 were carried over to TSP Run 4: (1) gasify Ohio No. 9 coal fluxed with limestone and range flux addition rate; (2) range steam/oxygen ratio; and (3) eliminate slag buildup in quench chamber. Finally, heat and material data were to be collected for Ohio No. 9 coal gasification using limestone as flux.

Standard start-up procedures began early on October 19, 1977, and by 1156 the desired rates were established while gasifying Frances coal fluxed with blast furnace slag. There was an immediate problem with the burner which could best be interpreted as some form of blockage at the burner itself. This gave rise to poor flame characteristics and could not be remedied. The slag tap pattern was poor, and it was not clear whether this was being caused by the burner or some other unkown effect.

Despite these non-ideal conditions, it was decided to press on with the run and by the end of the day, the gasifier had been brought to (130,000 SCFH oxygen and 1.35 steam/oxygen ratio) conditions ready to accept Ohio No. 9 coal. Ohio No. 9 coal was charged to the gasifier at 2247 on October 19. The transition was smooth, and gasification continued steadily for four hours. At 2304 on October 19, the gasifier offtake temperature rose sharply and the bed DP increased, indicating hang/slip conditions in the bed. The oxygen loading was reduced momentarily, resulting in decreases in both the offtake temperature and bed DP.

At 0300 on October 20, fluxing was changed from blast furnace slag to limestone. There was a rapid deterioration in slag tapping performance but little effect elsewhere in the bed. The steam/oxygen ratio was trimmed to 1.25 to improve the situation, but this had little effect, and slag tapping continued to be poor. Slag growths in the quench chamber were also beginning to interfere with slag tapping.

Two tuyeres had become black by 0945, and attempts to improve the situation by lowering the steam/oxygen ratio further proved unsuccessful. One of these tuyeres was turned off at 1130, and 15 minutes later another tuyere became black. Although slag tapping had improved over the last two hours, quench chamber fouling had increased, limiting visibility and diverting slag flow. With obvious bottom-of-the-gasifier problems, the run was terminated at 1226 on October 20.

Post-run inspection revealed a pillar of caked coal extending down to the tuyere level. This pillar of caked coal was surrounded by a 6-inch annulus of loose char. The hearth and tuyeres were in reasonable condition, but the quench chamber was heavily fouled with slag. Burner systems were examined, but no conclusive evidence could be found as to what caused the poor conditions in the hearth and slag tapping, which were apparent from the start of the run.

The transition from Frances coal to Ohio No. 9 coal during TSP Run 4 was made at 1.35 steam/oxygen. This transition was smoother than those observed during TSP Runs 2 and 3 at a lower steam/oxygen ratio. The use of temporary load reductions was shown to be effective in correcting hang/slip bed conditions and minimizing temperature excursions. Operation of the stirrer at higher speeds also contributed to the elimination of serious bed problems during TSP Run 4. The use of limestone as flux while gasifying Ohio No. 9 coal was demonstrated. The results indicated that slag tapping was quite sensitive to the flux/ash ratio when fluxing with limestone. The run terminated before the flux/ash ratio could be ranged. The steam/oxygen ratio was ranged to some extent, but little information on the effect of this variable was obtained due to the existing poor hearth conditions. Slag buildup in the quench chamber was not eliminated during the run. Post-run inspection confirmed that bed problems were caused by the presence of uncaked coal below the stirrer region. Heat and material balance data were collected during the period of Ohio No. 9 coal gasification with limestone fluxing. TSP Run 4 lasted 23 hours. Some wear occurred on the slag tap due to non-ideal conditions in this run. No other significant damage was sustained by gasifier internals.

4.5 TSP Run 5 Summary

The experience from TSP Run 4 led to the decision to defer introduction of limestone as flux until the effects of the major variables, oxygen loading and steam/oxygen ratio, could be assessed. The primary objectives of TSP Run 5 were to determine the effects of oxygen loading and steam/oxygen ratio on gasifier performance and to eliminate the conditions leading to slag quench system deposits and black tuyeres. If these objectives were accomplished, further objectives were to introduce limestone to the gasifier at the optimum conditions as specified above and to range the limestone addition rate so that slag tapping could be optimized. Heat and material balance data were to be collected during steady periods of operation.

The overhead bunker was split into two sections prior to TSP Run 5. This would permit a changeover in fuels to be made quickly at any time. An additional flux bunker and flux feeding system were also installed so that either limestone or blast furnace slag could be charged to the gasifier. A newly designed burner was fitted, and quench chamber internals were modified to minimize slag growths.

Steam/oxygen gasification of Frances coal fluxed with blast furnace slag started at 0316 on November 11, 1977 after a standard start-up. Gasifier operation was initially unsteady but settled down once fluxing commenced. Ohio No. 9 coal was charged to the gasifier at 1509, and the changeover was accomplished with no problems. Slag tapping was good, but the tuyeres were dim and by 1754 two tuyeres had gone black. Since the tuyeres remained black, it was decided to revert to Frances coal for a short period.

Fluxed Frances coal was charged for 2.5 hours and had the desired effect of restoring the tuyeres to full brightness. Ohio No. 9 coal was recharged to the gasifier at 0020 on November 12 at 130,000 SCFH oxygen and 1.25 steam/oxygen ratio. This second period on Ohio No. 9 coal was satisfactory, with good slag tapping snd reasonably bright tuyeres. Gasification continued for 12 hours with no problems except that tuyeres were dimmer than normal and flashing bright and dark occasionally. Conditions in the quench chamber were good with no evidence of deposits interfering with slag runs.

At this point, the load was increased to 140,000 SCFH oxygen over an hour while maintaining a constant steam/oxygen ratio. This action produced a marked change in gasifier performance. Offtake temperatures and carbon dioxide content of the synthesis gas rose but became very steady. Bed DP's were also steady. Tuyeres continued to flash, however, and the heat load on all tuyere tips became high and erratic. The whole hearth area appeared to have become much hotter as evidenced by high heat losses.

Gasification under these conditions continued unchanged for six hours, but by 1815 growths of slag in the quench chamber were interfering with slag tapping. About this time, all the tuyeres went black for some time, and the slag tap DP spiked high for a few minutes.

Ohio No. 9 coal feed was halted, and Frances coal was charged to the gasifier. This action produced some improvement in gasifier performance, and by 1923 all tuyeres were bright again. After only half an hour on Frances coal, however, the slag tap failed. This forced termination of the run at 1925 on November 12.

Post-run inspection revealed a large pillar of caked coal extending to tuyere level. This pillar was surrounded by an annulus of loose char up to a foot wide in parts. Significant fouling was evident in the quench chamber.

During TSP Run 5, the oxygen loading was varied slightly from 130,000 to 140,000 SCFH. Even this variation produced a marked change in gasifier performance, however, with the hearth area becoming hotter as evidenced by high heat losses. The run terminated before the steam/oxygen ratio could be ranged or optimum conditions identified for limestone fluxing. Efforts during the run to eliminate both quench chamber fouling and black tuyeres proved unsuccessful. The switch from Ohio No. 9 coal to Frances coal and back again demonstrated the gasifier purge with non-caking fuel technique made possible by the modified coal bunker. TSP Run 5 was the only run in the Westfield program in which internal hearth equipment failed. This failure was thought to be due to prolonged operation of the gasifier with large masses of caked coal in the hearth region. Heat and material balance data were collected during the Ohio No. 9 coal gasification period at both 130,000 and 140,000 SCFH oxygen. Total operation during TSP Run 5 was 40 hours.

4.6 TSP Run 6 Summary

The results of the Ohio No. 9 coal gasification periods during TSP Runs 2, 3, 4, and 5 indicated that a longer stirrer would be required as a long-term solution to the problems caused by caking coals. Until the stirrer modifications could be made, however, it would be worthwhile to pursue other temporary solutions to the problem. One such solution investigated during TSP Run 6 was the reduction of the oxygen loading (and hence, coal throughput rate) so as to increase the residence time of the coal in the region affected by the stirrer blades. A further objective during TSP Run 6 was to reconfirm the system's ability to gasify Frances coal for an extended period at reduced rates. Secondary objectives were to control buildup of slag deposits in the slag quench chamber and to obtain heat and material balance data during periods of steady operation.

Prior to TSP Run 6, the hearth and slag tap were replaced as a result of damage sustained during TSP Run 5. In order to maintain communication between the raceway and the slag pool at reduced loads, the number of tuyeres was reduced from previous runs.

Standard start-up procedures were employed, and slagging gasification on unfluxed Frances coal commenced at 2052 on December 4, 1977. Gasification at 100,000 SCFH oxygen, 1.35 steam/oxygen ratio, and 350 psig pressure was achieved within an hour. After five hours of running under these conditions, hearth conditions were still unsettled. Addition of blast furnace slag at 0147 on December 5 produced a rapid improvement in hearth conditions.

Operation on Frances coal continued to be steady for the next two days. With other conditions unchanged, Ohio No. 9 coal was charged to the gasifier at 2100 on December 6, and a satisfactory transition was made to the new feedstock. Slag tapping was satisfactory during the first few hours of Ohio No. 9 operation, but then conditions began to deteriorate. Poor hearth conditions led to a decision to revert to Frances coal at 0310 on December 7.

Satisfactory conditions were re-established after eight hours, and Ohio No. 9 coal was again charged to the gasifier at 100,000 SCFH oxygen. This second attempt on Ohio No. 9 coal was more successful than the first. By 1900 high heat loads on the slag tap prompted a further load reduction to 80,000 SCFH oxygen and 1.30 steam/oxygen ratio. The load reduction immediately relieved the hot hearth conditions.

Gasification continued satisfactorily for the next 9.5 hours, although there was evidence of slight irregularities in hearth conditions. The slag tap blocked unexpectedly at 0441 on December 8. This forced the termination of the run.

The condition of the bed following TSP Run 6 was similar to that following TSP Runs 4 and 5--a fused pillar of caked coal extending down to tuyere level. The pillar was surrounded by a one-foot annulus of loose char. Hearth materials and quench chamber systems were in good condition.

The results of TSP Run 6 showed that Ohio No. 9 coal gasification at low load did not eliminate the formation of large masses of caked coal below the stirrer. The presence of this fused pillar of caked coal in the lower bed was evidenced by black and flashing tuyeres, hearth irregularities, and poor slag tapping. These results reconfirmed the need for a redesigned stirrer/ distributor system. Operation with Frances coal feed was steady and uneventful. This period reconfirmed the ability of the system to gasify Frances coal, as previously demonstrated during TSP Run 1.

Operation during TSP Run 6 demonstrated the use of a reduced number of tuyeres when operating at low load on both Frances coal and Ohio No. 9 coal feedstocks. This run also proved that re-introduction of non-caking coal to the gasifier could eliminate the symptoms of the caked pillar. Slag deposits were present in the quench chamber and restricted visibility near the end of the run, but were not directly responsible for run termination. Heat and material balance data were collected during the Frances coal period at 100,000 SCFH oxygen load and during the Ohio No. 9 coal period at both 100,000 and 80,000 SCFH oxygen loadings. The gasifier operated for 75 hours during TSP Run 6 without significant damage to gasifier internals.

4.7 TSP Run 7 Summary

TSP Run 6 demonstrated that operation at low load did not eliminate the formation of large masses of caked coal below the stirrer when gasifying Ohio No. 9 coal. While awaiting design changes planned for the stirrer/distributor system, a second proposed solution to the problem of caking coals was tested during TSP Run 7--charging of alternating locks of Ohio No. 9 coal and blast furnace coke, or "layering." It was hoped that the use of periodic blast furnace coke purges would effectively break up any large masses of caked Ohio No. 9 coal below the stirrer before serious bed and hearth instabilities developed. The initial objective of TSP Run 7, then, was to demonstrate the suitability of blast furance metallurgical coke as a feedstock for the slagging gasifier. This feed also represented a practical start-up material for the Demonstration Plant. If blast furnace coke proved a feasible feedstock, the next objective was to investigate the effect of feeding layered Ohio No. 9 coal and blast furnace coke in increasing ratios of coal to coke. Operation at ratios ranging from 1:2 (v/v) coal to coke to 4:1 coal to coke were planned. Heat and material balance data would be collected during periods of steady operation.

Prior to TSP Run 7, a new, sophisticated drive was installed on the stirrer/distributor system. It was decided to revert to the standard loading and standard number of tuyeres for this run, since the low load trials during TSP Run 6 had proved unsuccessful.

Standard start-up procedures were used, and by 1118 on December 18, 1977, steam/oxygen gasification of Randolph Colliery coke at 350 psig system pressure was established. The rates were ranged from 130,000 to 160,000 SCFH oxygen and from 1.15 to 1.45 steam/oxygen ratio over the next 42 hours. Gasification was satisfactory throughout this period.

Just before 0718 on December 20, the first mixed-fuel period began with two locks of coke charged for every lock of Ohio No. 9 coal. Rates were maintained at 130,000 SCFH oxygen and 1.30 steam/oxygen ratio. Gasifier operation was satisfactory, although not as smooth as the 100 percent coke period. The progression to a 3:1 ratio of coal to coke was achieved on schedule, but operation on all these feedstock mixes (particularly at the 2:1 and 3:1 levels) displayed characteristics of undiluted Ohio No. 9 coal feed--erratic bed DP's and offtake temperatures, flashing tuyeres, high heat load excursions in the hearth, and slag dribbling.

It was decided not to proceed to the 4:1 level because of the erratic behavior of the tuyeres and hearth, but to revert back to the 2:1 layering mix. Even at this lower coal to coke ratio gasifier performance continued to be erratic, and slag growths in the quench chamber began to divert the slag runs and restrict visibility.

Ohio No. 9 coal feed to the gasifier was halted after an additional 1.5 hours, and operation continued on 100 percent blast furnace coke. After a further hour of operation, visibility in the quench chamber was reduced to near zero. This forced a termination of the run at 2025 on December 21.

After the run, the gasifier bed was found to consist of loose coke alone. There was no evidence of caked Ohio No. 9 coal. It appeared from this evidence that five successive locks of coke just prior to shutdown were sufficient to purge the bed completely. Deposits of slag in the quench chamber were extensive, but the hearth, shaft, and stirrer systems were in good condition.

Gasification of blast furnace metallurgical coke was successfully demonstrated for 46 hours during TSP Run 7, including the final period on undiluted blast furnace coke. During this time, the oxygen loading and steam/oxygen ratio were ranged widely. Gasification of layered coal and coke at the 1:1 level resulted in cyclic, but steady, operation with no symptoms of massive caking below the stirrer. At the 2:1 and 3:1 levels, operation became unsteady with apparent hearth and slag tapping irregularities. Heat and material balance data were collected during the initial blast furnace coke period. The new drive system on the stirrer/distributor system performed as expected. The brief coke period at the end of the run demonstrated the fact that five successive locks of non-caking material were sufficient to purge the gasifier and remove any evidence of caked masses. Programmed run duration of 79 hours was achieved, including 33 hours on layered feedstock, without significant damage to gasifier internals.

4.8 TSP Run 8 Summary

Some modifications were made to the system between TSP Runs 7 and 8 to alleviate problems with poor bed behavior caused by the presence of caking coal below the stirrer. These included: (1) extension of the stirrer system; (2) lowering of the hearth; (3) equipment modifications and streamlining in the quench chamber to combat fouling; (4) addition of thermocouple branches at the top of the gasifier; and (5) installation of an oxygen preheater capable of increasing the steam/oxygen mix temperature by 50°F.

In view of these modifications, the initial objective of TSP Run 8 was to demonstrate the integrity of the new systems. The second objective was to evaluate their effect on gasifier performance while feeding layered and blended mixtures of Ohio No. 9 coal and blast furnace metallurgical coke. If increasing concentrations of layered and blended feedstocks could be gasified, it was ultimately planned to gasify undiluted Ohio No. 9 coal. Heat and material balance data would be collected during periods of steady operation.

There was an aborted attempt at TSP Run 8 on February 20, 1978. This attempt was terminated just after start-up due to failure of the bottom cone of the coal lock to seat properly. This problem was corrected, and standard start-up procedures for the second attempt were initiated on February 26. A good start was achieved and full operating conditions of 160,000 SCFH oxygen, and 1.15 steam/oxygen ratio at 350 psig pressure were reached while gasifying blast furnace metallurgical coke. Two hours after start-up, problems with steam and oxygen supplies resulted in a brief stand-by period. Services were quickly restored, and the gasifier was brought back on line at 1547.

Gasification of coke fluxed with blast furnace slag continued for the next nine hours before the load was reduced stepwise to 130,000 SCFH oxygen in anticipation of Ohio No. 9 coal feed. A 12-hour period of gasification on layered 1:1 feedstock (coal to coke) followed and proved to be satisfactory.
The gasifier was purged for two hours on 100 percent coke and then was fed a 1:1 (v/v) blend of Ohio No. 9 coal and coke. This period lasted almost 24 hours, but was interrupted by a brief standby due to failure of coal lock hydraulics. Gasifier performance during this period was satisfactory, but toward the end of the period fouling in the quench chamber had become a problem.

Layering of 2:1 coal:coke was introduced to the gasifier briefly at 2243 on February 28, but fouling had reached the point where it diverted the slag stream and restricted visibility into the quench chamber. Ohio No. 9 feed was discontinued, and the last 8 hours of the run were carried out on 100 percent coke.

A decision was made to terminate the run because of critical slag fouling in the quench chamber. Just prior to shutdown at 0908 on March 1, two successive locks of undiluted Ohio No. 9 coal were charged to the gasifier to determine how this fuel moved in the bed.

Post-run inspection showed modest, but critical, slag fouling in the quench chamber. The two locks of Ohio No. 9 coal fed at the end of the run had progressed below the stirrer in the bed, apparently having overtaken some of the coke fed earlier. Caking of the coal was still taking place in the region below the stirrer. The slag tap was in good condition, but the tuyere tips and hearth did show some wear.

TSP Run 8 demonstrated the mechanical integrity of the extended stirrer, new hearth, quench chamber modifications, thermocouple branches, and oxygen preheater. Both the layered and blended 1:1 feedstocks produced satisfactory gasification with very little difference in smoothness of operations between the two periods. The first significant observation of slag fouling was made while gasifying blended feedstock, but this was probably due to the cumulative effect of extended operation rather than a consequence of the feedstock itself. Gasification of layered 2:1 feedstock was abandoned when slag deposits in the quench chamber became severe. The results of this run confirmed the need for further quench chamber modifications to enable long-term operation with Ohio No. 9 feedstock. During the initial blast furnace coke gasification period, the system again demonstrated its ability to recover from standby conditions. Heat and material balance data were collected during the 1:1 layered period of operation. TSP Run 8 achieved program duration of 62 hours without significant damage to gasifier internals.

4.9 TSP Run 9 Summary

TSP Run 8 further highlighted the problem of slag fouling in the quench chamber. Based on the results from this and previous runs further modifications were made to proprietary equipment in the quench chamber to eliminate slag growths.

At this time, it was thought that the existing stirrer in the gasifier could not produce a narrow-sized char feed to the tuyeres when operating with caking coal. Therefore, it was planned to feed wide-sized (2" x 0") blast furnace metallurgical coke to the gasifier to highlight problems occuring in the tuyere region.

A further objective of TSP Run 9 was to gasify Pittsburgh No. 8 coal layered with blast furnace coke. Although Pittsburgh No. 8 coal was characterized by a higher free swelling index than Ohio No. 9 coal, it was hoped Pittsburgh No. 8 would form coke that could be readily broken up by the stirrer. Additionally, the ash content of Pittsburgh No. 8 coal was less than that of Ohio No. 9 coal (8.5% versus 22%, respectively). It was thought this lower ash content offered the advantages of (1) reduced fouling in the quench chamber; (2) more rapid heating of coal at the top of the bed due to reduced heat sink; and (3) lower flux requirements. It was hoped these factors, along with the additional modifications to the quench chamber, would increase the chances for a successful run and provide useful information that would help to solve the problems encountered with Ohio No. 9 coal.

TSP Run 9 began on March 15, 1978, at 0345. Standard start-up procedures were used and full rates of 160,000 SCFH oxygen, 1.35 steam/oxygen ratio, and 350 psig pressure were established while gasifying 20 x 10 mm blast furnace coke fluxed with blast furnace slag. By 0940, the load was reduced to 130,000 SCFH and at 1105 the fluxing rate was reduced. Post-run assessment indicated that the actual fluxing rate was lower than intended.

Operations continued to be satisfactory for the next 12 hours, although the slag appeared to be rather viscous and slag tap control was relatively poor. The hearth conditions deteriorated sharply after 1800. Despite remedial action, which included cutting the steam/oxygen ratio to 1.15 and increasing the fluxing rate to its previous level, the deterioration proved to be irreversible and a blocked tap forced shutdown at 1920. When the gasifier was cooled down and unloaded of fuel and slag, all systems were found to be in good condition.

None of the original objectives of TSP Run 9 were achieved owing to the short duration (14 hours) of the run. Reduction of the flux/ash ratio to a level lower than intended did identify the lower limit for flux addition. During the brief period of operation, no significant slag fouling was observed. Although a blocked tap forced a shutdown, no significant damage was sustained by gasifier internal equipment.

4.10 TSP Run 10 Summary

After the forced shutdown of TSP Run 9 due to a blocked tap hole, a quick turnaround was made with no alterations to gasifier systems. The objectives of TSP Run 10 were the same as those for TSP Run 9: (1) eliminate slag fouling in the quench chamber; (2) investigate effects of wide-sized blast furnace metallurgical coke on gasifier and its systems; and (3) investigate gasifier performance while feeding Pittsburgh No. 8 coal layered with blast furnace metallurgical coke.

Gasifier operation was recommenced for TSP Run 10 on March 20. A standard start-up was again used, but fluxing was maintained at a higher rate than that used in TSP Run 9. Stable conditions were maintained for 13 hours while gasifying 20 x 10 mm coke at 130,000 SCFH oxygen and 1.25 steam/oxygen ratio. Wide-range coke (2" x 0) was charged to the gasifier at 0745 on March 21. This fuel produced erratic behavior in the gasifier bed with respect to offtake temperature, bed DP's and carbon dioxide level in the synthesis gas. The tuyeres were also dim and flashing, but slag removal was satisfactory. More seriously, the large amount of fines and subsequent dust carryover resulted in problems with the Wash Cooler Recirculation Pumps and with the Waste Heat Boiler sump level control system. The situation rapidly became intolerable and charging of the sized (20 x 10 mm) coke was recommenced at 1207. Downstream equipment problems were eased somewhat, but it was apparent that further operation on wide-size range coke was not possible.

A large amount of wide-size range coke remained in the overhead bunker, however, and had to be consumed before Pittsburgh No. 8 coal could be charged. While running out the wide-size range coke, air flow to the main burner was lost at 0945 on March 22 due to a compressor failure. The gasifier was placed on standby, but not before a 20-minute period has passed when slag tapping was not possible.

Air service was restored, and the burner was relit. Satisfactory slag tapping was obtained. As the gasifier was prepared for restart, however, it became apparent that the tuyeres were blocked, and the run had to be terminated at 1120 on March 22.

The gasifier was again cooled down and unloaded of fuel and slag. Inspection showed that the gasifier and its systems were in good condition except the tuyeres were blocked with frozen slag. A pillar of coke dust was found in the center of the bed extending from the bottom of the stirrer to the hearth. The rest of the bed was filled with mostly normal-sized coke.

After 50 hours of operation on blast furnace metallurgical coke, the quench chamber showed only minimal fouling and no damage to gasifier systems was observed. The run identified the sensitivity of the system to fines while gasifying blast furnace metallurgical coke. Run termination was due to failure of the system to recover from standby conditions, the only such incident in the Westfield program.

4.11 TSP Run 11 Summary

TSP Run 10 achieved two of the three major objectives originally planned for TSP Run 9. Thus, the remaining objective, gasification of layered Pittsburgh No. 8 coal and blast furnace metallurgical coke became the major objective of TSP Run 11. Secondary objectives were to obtain heat and material balance data during periods of steady operation and to collect drum samples of effluent materials for environmental analysis purposes.

The gasifier was again turned around quickly after TSP Run 10 to commence operations on March 25, 1978. After a standard start-up and six hours of operation on sized blast furnace metallurgical coke, the stirrer rotation rate was increased and feed of Pittsburgh No. 8 coal layered 1:1 (v/v) with blast furnace metallurgical coke was commenced at 0340 on March 26. Use of blast furnace slag as the fluxing agent was maintained.

The initial transition to Pittsburgh No. 8 coal was marked by sharply spiking bed DP's and distributor torque, dimming tuyeres, and poor slag tapping. Within an hour, however, the gasifier had settled to stable operation. The gasifier exhibited cyclic behavior in many areas, including offtake temperature, bed DP's, stirrer torque, offgas composition, and slag tapping, but there was no significant deterioration in overall performance. Running continued for over five days at constant conditions and 1:1 layering until 0924 on March 31 when, with blast furnace coke stocks almost exhausted, the gasifier was subjected to a controlled shutdown.

The bed following TSP Run 11 showed alternating layers of blast furnace coke and Pittsburgh No. 8 coal. There was no evidence of caked agglomerates below the stirrer. No significant slag fouling was observed in the quench chamber. There was some sign of wear on the hearth refractory.

TSP Run 11 demonstrated long-term (121 hours) operation on layered Pittsburgh No. 8 coal and blast furnace metallurgical coke. Slag fouling of the quench chamber was minimal, reflecting the effectiveness of the modifications made prior to TSP Run 9. Heat and material balance data were collected during the periods of layered operation, and effluent samples were collected. Post-run examination of the bed revealed no massive caking below the stirrer and confirmed plug flow conditions in the gasifier. The run exceeded programmed duration without significant damage to gasifier internals.

4.12 TSP Run 12 Summary

TSP Run 12 followed the successful 5-day run on Pittsburgh No. 8 coal layered (1:1) with blast furnace metallurgical coke. Information gained during TSP Run 11 supported the belief that Ohio No. 9 coal could be gasified successfully under similar conditions. The primary objectives of TSP Run 12 were to demonstrate gasification of Ohio No. 9 coal layered (1:1) with blast furnace coke and to obtain the necessary data to allow comparison of the results of TSP Run 12 with those of TSP Run 11.

Gasifier systems were the same for TSP Run 12 as for the previous run.

Start-up began on petroleum coke on May 29, 1978. After four hours of steady operation on blast furnace coke fluxed with blast furnace slag, the gasification rates were adjusted to 130,000 SCFH oxygen and 1.25 steam/oxygen ratio. Gasifier pressure was 350 psig. The first lock of Ohio No. 9 coal was charged to the gasifier at 2006. Alternate locks of Ohio No. 9 coal and metallurgical coke were fed to the gasifier. The transition from coke to layered operation was somewhat unsettled with erratic bed behavior. The gasifier settled to more stable operation within two hours, but cyclic behavior was still evident with respect to offtake temperature, bed DP's, offgas composition, and slag tapping. Cyclic behavior resulted from the alternate feedstocks. Running continued steadily for the next 24 hours with only a minor incident on May 30 when the bottom cone of the coal lock did not seat properly during depressurization.

Early on May 31 there was concern that the cyclic hearth conditions may have created some wear at the hearth bottom. The situation continued to deteriorate and posed the risk of damage to hearth internals. In order to preserve the bed for post-run inspection and provide a direct comparison with the post-Run 11 bed, the gasifier was shut down in controlled fashion at 0150 on June 1.

Inspection of the bed following shutdown revealed alternating layers of coke and Ohio No. 9 coal. The Ohio No. 9 coal layer consisted of a caked mass of coal in the center surrounded by an 18-inch annulus of loose char.

Slight damage to the hearth bottom was sustained and several of the tuyeres had worn slightly, but there was still considerable tolerance for further wear. The quench chamber was in good condition with no significant amount of slag fouling.

TSP Run 12 confirmed the long-term operability of the gasifier while processing layered Ohio No. 9 coal and blast furnace coke. The results indicated that hearth conditions were more irregular for layered Ohio No. 9 operation during this run than for layered Pittsburgh No. 8 operation during the previous run. Heat and material balance data and effluent samples were collected during the layered Ohio No. 9 coal gasification period. TSP Run 12 was concluded with a planned, orderly shutdown. Post-run bed inspection reconfirmed plug flow conditions in the gasifier and revealed that no significant damage to internal equipment had occurred during the 65 hours of gasifier operation.

4.13 TSP Run 13 Summary

After the reliable operation achieved on layered Pittsburgh No. 8 coal and blast furnace metallurgical coke during TSP Run 11, TSP Run 13 was planned to gasify undiluted (100 percent) Pittsburgh No. 8 coal fluxed with blast furnace slag. If operation proved satisfactory, the next objective would be to range the oxygen loading and identify maximum throughput capability. A complete set of heat and material balance data and effluent samples would be collected.

Gasifier systems were the same as those for TSP Run 12 except that the hearth was relined.

Standard start-up procedures commenced on June 19, 1978 and satisfactory gasification was established on blast furnace metallurgical coke at 350 psig system pressure with rates adjusted to 130,000 SCFH oxygen and 1.30 steam/oxygen ratio. Pittsburgh No. 8 coal was charged to the gasifier at 2002. Bed conditions were initially unsteady, characterized by erratic bed DP's offtake temperature, and distributor torque. After this transition period, which lasted about one hour, the gasifier settled down to steady operation.

Gasification continued in reliable fashion for 48 hours. During this time recycle tar feed to the distributor was systematically turned on and off to assess its effect on gasifier performance. The results of these trials are discussed in Section 5.7.

The oxygen feed rate was increased to 135,000 SCFH at 2000 on June 21. Oxygen feed rate increases continued in stepwise fashion to 170,000 SCFH. Gasification at the higher loading was slightly less steady than at lower loadings, but satisfactory. At the highest loading, the stirrer/distributor system tripped out briefly after a high torque incident, and the load was reduced as a precautionary measure. Gasification at 160,000 SCFH oxygen continued satisfactorily for a further 12 hours. The gasifier was shut down in controlled fashion at 1135 on June 23. All objectives of the run had been achieved.

Following the run, the bed was found to contain primarily loose Pittsburgh No. 8 char below the stirrer. A few 6-inch lumps of char/lightly caked coal were present. The hearth bricks had suffered minor wear, with the slag tap and tuyeres in good condition. The quench chamber was in good condition with no significant slag fouling.

As a result of 88 hours of steady gasification, TSP Run 13 demonstrated the long-term operability of the system while feeding 100 percent Pittsburgh No. 8 coal. Operation was satisfactory at all levels of oxygen loading, although less steady at the highest loading (170,000 SCFH) than at lower loadings. The highest demonstrated loading corresponded to 870 lb (maf)/hr-ft^2 coal throughput, which exceeded the proposed Demonstration Plant design basis. Heat and material balance data and drum samples of effluent materials were collected. Results of the tar recycle trials indicated that bed behavior was smoother without tar recycle to the top of the gasifier than with tar recycle. TSP Run 13 concluded with a scheduled voluntary shutdown after programmed run duration had been achieved. Post-run inspection confirmed the absence of massive caking below the stirrer and revealed that no significant damage was sustained by gasifier internals during 96 hours of operation.

4.14 TSP Run 14 Summary

After successfully demonstrating long-term operability while gasifying layered Ohio No. 9 coal in TSP Run 12 and undiluted Pittsburgh No. 8 coal in TSP Run 13, a short run was planned to demonstrate gasification of 100 percent Ohio No. 9 coal. TSP Run 14 also called for the use of Frances coal instead of blast furnace metallurgical coke as the start-up and purge feedstock. This change was made in an effort to provide smoother transition to Ohio No. 9 coal. A full set of heat and material balance data would be collected for periods of steady operation.

Standard start-up procedures began on June 27, 1978, and steady gasification was quickly established on Frances coal fluxed with blast furnace slag at 350 psig system pressure. After adjusting the rates to 130,000 SCFH oxygen and 1.30 steam/oxygen ratio, Ohio No. 9 coal was charged to the gasifier at 2252.

The transition from Frances coal to Ohio No. 9 coal was quite smooth. After less than two hours, however, problems developed with the feeding of Ohio No. 9 coal from the overhead bunker into the coal lock. There appeared to be a large amount of wet, clay-like material in the coal which caused coal particles to lump together and stick to the walls of the bunker. As a result of the feed flow problems with Ohio No. 9, it was necessary to revert to Frances coal feed to the gasifier.

Ohio No. 9 coal charging recommenced at 0330 on June 28, but flow restrictions from the bunker reappeared after four hours of satisfactory gasification. A further 7-hour period of Frances coal gasification was required before Ohio No. 9 coal feed could be resumed at 1522.

At 1710, the fluxing rate was reduced slightly to conserve blast furnace slag stocks. After three hours, slag tapping deteriorated and tuyeres began to flash and go black. This deterioration was arrested when the flux rate was returned to its former level, and the steam/oxygen ratio was reduced to 1.25.

Gasification continued in satisfactory fashion for the remainder of the run, although tuyeres continued to flash and turn black. Slag tapping was satisfactory during the last 25 hours of continuous running, except for a second period of poor tapping due to under-fluxing. The run was terminated with a controlled shut-down at 1632 on June 29.

Post-run inspection revealed a bed of mostly loose char below the stirrer with a few larger lumps of lightly fused char/coal. There was one large lump of caked coal, approximately four feet square, attached to the wall about half-way down the shaft of the gasifier. There was also a region of dust and a pocket of flux just above the tuyere level. Gasifier internals had suffered no damage during the run, and quench chamber fouling was minimal.

Long-term operability on 100 percent Ohio No. 9 coal was successfully demonstrated during the final 25 hours of TSP Run 14. A smooth transition from Frances to Ohio No. 9 coal was accomplished on three occasions--after initial start-up and following two standby periods. Variations of the flux/ash and steam/oxygen ratios confirmed the effects of these parameters on slag tapping performance. Heat and material balance data were collected during the final extended period of operation. TSP Run 14 concluded with a scheduled, voluntary shutdown after achieving programmed duration. Post-run inspection confirmed the absence of massive caking below the stirrer and revealed that gasifier internals had suffered no significant damage during the 48 hours of operation.

4.15 TSP Run 15 Summary

TSP Run 15 was planned to verify gasifier operation on 100 percent Pittsburgh No. 8 coal as demonstrated during TSP Run 13. If gasification on sized (1-1/4" x 1/4") Pittsburgh No. 8 coal was satisfactory, the concentration of fines (material less than 1/4") in the coal feed would be increased stepwise. As a final step, unscreened coal would be fed to the gasifier. Recycle tar feed trials were also planned during this run to investigate the effect of tar feed to the top of the gasifier with a modified tar feed system. Heat and material balance data and effluent material samples would be collected during periods of steady operation.

Besides the tar feed system, the only other modification to the gasifier made prior to TSP Run 15 was a partial relining of the hearth.

After a standard start-up on August 11, 1978, slagging gasification was established on Frances coal fluxed with blast furnace slag at 160,000 SCFH oxygen, 1.35 steam/oxygen ratio, and 350 psig system pressure. Although operation was stable while gasifying Frances coal, the stirrer/distributor tripped as a result of high torque on two occasions. In both cases, the stirrer/distributor was restarted quickly.

The load was reduced to 135,000 SCFH oxygen, and sized (1 1/4" x 1/4") Pittsburgh No. 8 coal was charged to the gasifier at 0952. The transition to the new feedstock was satisfactory and steady gasification continued for four hours.

Three attempts were made to increase the load to the levels established during TSP Run 13. In each case the stirrer/distributor system tripped at the higher loads as a result of torque overload. After the third incident, the rates were adjusted to 135,000 SCFH oxygen and 1.35 steam/oxygen ratio. Gasification continued steadily under these conditions for 17 hours.

Feed of recycle tar to the top of the distributor was started at 2007 on August 12. The amount of recycle tar feed was systematically varied. The trials showed that the sensitivity to tar feed observed during TSP Run 13 had been considerably improved.

The fines content of the Pittsburgh No. 8 coal feedstock was steadily increased beginning at 0900 on August 13. The fines content was increased from 6 to 23 percent in stepwise fashion over the next 36 hours. Gasifier operation during this period was stable with bright tuyeres and good slag tapping but was marked by frequent stirrer/distributor trips.

Gasification continued steadily on Pittsburgh No. 8 coal with an average of 23 percent fines during the final 24 hours of operation. This period was marked by only one trip of stirrer/

distributor system. The gasifier was shut down in controlled fashion at 2208 on August 15.

Post-run inspection revealed a bed of predominantly loose Pittsburgh No. 8 char. Some 6 to 12 inch agglomerates of caked coal/char were found at the tuyere level.

The hearth showed some wear. The shaft bricks and tuyeres did not wear significantly during the run. The quench chamber and slag tap systems were in good condition.

Operation during TSP Run 15 confirmed the long-term ability of the gasifier to process untreated Pittsburgh No. 8 coal. Gasification was satisfactory with feed fines concentrations as high as 23 percent, on average. Tar recycle trials confirmed the usefulness of tar recycle to the top of the gasifier to minimize carbon losses in the form of dust carryover. Heat and material balance data and effluent samples were collected during gasification periods on both screened and unscreened coal. TSP Run 15 concluded with a scheduled voluntary shutdown after programmed run duration had been achieved. Post-run bed inspection confirmed the absence of massive caking below the stirrer and revealed that no significant damage had been sustained by internal equipment during 113 hours of gasification.

4.16 Compendium

A tabular summary of the operating history of the Westfield program is presented in Table 1. In addition to detailing feedstock conditions and hours of operation for each run, Table 1 highlights the operating variables that were studied and the technical achievements that were realized.

As the table indicates, TSP Run 1 was the only run made with Frances coal alone as the primary feedstock. The purpose of this run was to commission the gasifier and its systems - both of which had undergone considerable overhaul and modifications since the last test series. The successful operation of TSP Run 1 was duplicated later in the program during TSP Run 6. Frances coal was used as start-up feed during seven of the 14 runs with eastern bituminous caking coals. Blast furnace metallurgical coke was used as start-up feed during the other seven runs.

After the first run, the next five runs were devoted to gasification of undiluted Ohio No. 9 coal. Blast furnace slag was used as the fluxing agent in each of these runs except TSP Run 4. Limestone was used as the flux in TSP Run 4. Because of the operating difficulties experienced during these runs as a result of caking coal in the lower bed, a decision was made to gasify mixtures of Ohio No. 9 coal and non-caking blast furnace metallurgical coke. Layered mixtures of these feedstocks were gasified during TSP Runs 7, 8, and 12. Blended mixtures were also gasified during TSP Run 8. After modifications to the gasifier and its system, 100 percent Ohio No. 9 coal was successfully gasified for 31 hours during TSP Run 15.

Blast furnace metallurgical coke was gasified as a primary feedstock during TSP Runs 7, 9, and 10. TSP Run 7 demonstrated the ability of the gasifier to process a non-caking feed. TSP Run 9 was terminated shortly after start-up due to a plugged slag tap. TSP Run 10 demonstrated the gasifier's tolerance to fines while operating on a non-caking feedstock.

As indicated in Table 1, only one slag tap failure occured during the program. That occurred at the end of TSP Run 5. Two other slag tap plugs occured, but these appeared to be caused by inadvertent reductions in the flux/ash ratio. Deposits in the quench chamber were effectively eliminated after TSP Run 8 by modifying proprietary equipment and streamlining the quench chamber. TSP Run 10 was the only occasion when operation of downstream equipment became unsteady. This was due entirely to high dust carryover from processing wide-size blast furnace coke. TSP Run 10 also the only run to terminate due to failure to recover from standby, after five previous successes. An unfortunate delay, before standby was initiated, resulted in the blockage of several tuyeres when gasifier operations were resumed. This forced the run termination.

The many technical achievements of the Westfield Technical Support Program are summarized on a run-by-run basis in Table 2. The success of the Westfield program is clearly illustrated in Tables 1 and 2. After overcoming numerous problems that plagued early operation on Ohio No. 9 coal, the final three runs demonstrated the long-term operability of the British Gas/Lurgi slagging gasifier while feeding both 100 percent untreated Pittsburgh No. 8 and Ohio No. 9 coals. Heat and material balance data and samples of effluent materials were collected for both of these eastern U.S. coals. These data provided the information base required by British Gas and Lurgi to complete the process, engineering, and mechanical design of the gasifier, downstream gas processing units, coal and flux preparation facilities, oxygen plant, and steam generation facilities for the Demonstration Plant. Additionally, useful performance data were collected for operation with non-caking blast furnace metallurgical coke and weakly caking Frances coal.

Table 1 Tabular Summary of the Westfield Program

RUN NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
DATES															
START	8/17/77	9/7/77	9/27/77	10/19/77	11/11/77	12/4/77	12/18/77	2/26/78	3/15/78	3/20/78	3/25/78	5/29/78	6/19/78	6/27/78	8/11/78
END	8/26/77	9/9/77	9/28/77	10/20/77	11/12/77	12/8/77	12/21/77	3/1/78	3/15/78	3/22/78	3/31/78	5/31/78	6/23/78	6/29/78	8/15/78
FEEDSTOCK, HOURS OF OPERATION															
FRANCES COAL	(97)	(23)	(8)	(10)	(15)	(55)								(17)	(7)
BLAST FURNACE COKE							(46)	(25)	14	50	(8)	(11)	(8)		
OHIO 9 COAL		23	3	13	25	20		1						31	
PITTSBURGH 8 COAL													(88)		(106)
LAYERED OHIO 9 COAL:COKE							(33)	15				54			
LAYERED PGH. 8 COAL:COKE											(121)				
BLENDED OHIO 9 COAL:COKE								(22)							
TOTAL RUN DURATION	(97)	46	11	23	40	75	(79)	62	14	50	(129)	65	(96)	(48)	(113)
VARIABLES STUDIED															
O_2 LOAD RANGED	X			X	X	X	X						X		X
STEAM/OXYGEN RATIO RANGED	X			X			X							X	
FLUX RATE OF ADDITION RANGED									X					X	
USED LIMESTONE FLUX				X											
ADD FINES TO FEEDSTOCK										X					X
STUDY OF TAR RECYCLE TO GASIFIER TOP													X	X	X
ACHIEVEMENTS															
AUTOMATIC CONTROL OF SLAG TAPPING	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PLANNED ORDERLY SHUTDOWN	X										X	X	X	X	X
MAF FEED RATE EXCEEDED 800 LB/HR/FT^2	X						X						X		
OBTAINED HEAT & MATERIAL BALANCE DATA	X	X		X	X	X	X	X			X	X	X	X	X
COLLECTED DRUM SAMPLES OF PLANT EFFLUENT											X	X	X		X
RECOVERED FROM STANDBY	X	X	X					X							
PROBLEMS															
MASSIVE CAKING IN BED (MONOLITH)		X	X	X	X	X		X				X *			
SLAG QUENCH CHAMBER DEPOSITS		X (T)		X (T)	X		X (T)	X (T) *							
SLAG TAP FAILURE					X (T)										
SLAG TAP PLUGGED						X (T)			X (T) *						
PLUGGED DOWNSTREAM WITH FINES										X *					
STOPPED STIRRER			X (T)					X					X		X
FAILED TO RECOVER FROM STANDBY										X (T) *					

( ) SATISFIED PROGRAM REQUIREMENT

(T) LED TO RUN TERMINATION

* LAST INCIDENT OCCURRING IN PROGRAM

Table 2

SUMMARY OF TECHNICAL ACHIEVEMENTS DURING THE WESTFIELD TECHNICAL SUPPORT PROGRAM

Run No.	Achievements
1	Commissioned refurbished gasifier. Demonstrated gasifier integrity. Confirmed operability on Frances coal. Demonstrated operability of fluxing system. Demonstrated turndown capability on Frances coal. Obtained heat and material balance data. Recovered from standby operation. Scheduled, voluntary shutdown. Operated without significant damage to gasifier internals.
2	Gasified Ohio No. 9 coal for 23 hours. Obtained heat and material balance data. Identified quench system fouling conditions. Recovered from standby operation. Operated without significant damage to gasifier internals.
3	Recovered from standby operation. Identified need to control bed conditions leading to temperature excursions. Identified need for a more rugged stirrer/distributor drive system. Operated without significant damage to gasifier internals.
4	Demonstrated limited operation with limestone flux. Demonstrated effects of temporary load reduction on bed behavior. Caking problems confirmed--uncaked coal passing below stirrer region. Obtained heat and material balance data. Operated without significant damage to gasifier internals.
5	Demonstrated gasifier purging technique with non-caking feedstock using modified coal bunker. Identified threat to hearth components due to prolonged operation with large masses of caked coal in hearth region. Obtained heat and material balance data.
6	Reconfirmed gasifier operability while processing Frances coal. Demonstrated the use of reduced number of tuyeres when operating at low load. Confirmed necessity for redesigned stirrer/distributor system.

Table 2 (cont.)

Run No.	Achievements
6 (cont'd)	Obtained heat and material balance data. Operated without significant damage to gasifier internals.
7	Demonstrated integrity of new hydraulic stirrer/ distributor drive system. Demonstrated smooth operation on blast furnace coke over wide ranges of load and steam/oxygen ratio. Achieved extended operation on Ohio No. 9 coal using layering technique. Obtained heat and material balance data. Achieved programmed run duration. Operated without significant damage to gasifier internals.
8	Demonstrated integrity of extended stirrer system, new hearth, quench chamber modifications, thermocouple branches, and oxygen preheater. Achieved programmed duration feeding layered (1/1) and blended (1/1) Ohio No. 9 and blast furnace coke. Identified need for further slag quench chamber modifications Recovered from standby operation. Obtained heat and material balance data. Operated without significant damage to gasifier internals.
9	Identified lower limit for flux addition. Final quench chamber modifications completed. Operated without significant damage to gasifier internals.
10	Identified system sensitivity to fines while gasifying blast furnace coke. Operated without significant damage to gasifier internals.
11	Demonstrated long-term operation on layered Pittsburgh No. 8 coal and blast furnace coke. No significant quench chamber fouling in this and all subsequent runs. Obtained heat and material balance data. Obtained drum samples of effluent materials. Exceeded programmed run duration. Post-run examination of bed revealed no massive caking below stirrer and confirmed plug flow conditions in gasifier. Operated without significant damage to gasifier internals.

Table 2 (cont.)

Run No.	Achievements
12	Reconfirmed long-term operability of gasifier while processing layered Ohio No. 9 coal and blast furnace coke. Obtained heat and material balance data. Obtained drum samples of effluent material. Planned, orderly shutdown. Bed inspection confirmed plug flow conditions in gasifier. Operated without significant damage to gasifier internals.
13	Demonstrated long-term operability on 100 percent untreated Pittsburgh No. 8 coal. Demonstrated coal throughput of 870 lb (maf)/hr-ft^2, which exceeds proposed Demonstration Plant design. Demonstrated effect of tar recycle to top of gasifier on bed behavior. Obtained heat and material balance data. Obtained drum samples of effluent materials. Achieved programmed run duration. Scheduled, voluntary shutdown. Bed inspection confirmed absence of massive caking below stirrer. Operated without significant damage to gasifier internals.
14	Demonstrated long-term operability on 100 percent untreated Ohio No. 9 coal. Confirmed effects of flux/ash and steam/oxygen ratios on slag tapping performance. Recovered from standby conditions on two occasions. Obtained heat and material balance data. Achieved programmed run duration. Scheduled, voluntary shutdown. Bed inspection confirmed absence of massive caking below stirrer. Operated without significant damage to gasifier internals.
15	Demonstrated system operability while gasifying unscreened, untreated Pittsburgh No. 8 coal with a fines content as high as 23 percent. Reconfirmed long-term operation on 100 percent untreated Pittsburgh No. 8 coal. Confirmed use of tar recycle to the top of the gasifier to minimize carbon losses in the form of dust carry-over. Obtained heat and material balance data. Obtained drum samples of effluent materials.

Table 2 (cont.)

Run No.	Achievements
15 (Cont'd)	Achieved programmed run duration. Scheduled, voluntary shutdown. Bed inspection confirmed absence of massive caking below stirrer. Operated without significant damage to gasifier internals.

5.0 TECHNICAL ACHIEVEMENTS

The technical achievements of the slagging gasifier development program at Westfield have been highlighted in Section 2.0. This section of the report discusses in further detail the history of gasifier operations with emphasis on gasifier bed behavior, quench chamber, slag tap, and feed system operations. The effects of oxygen loading, steam/oxygen ratio, tar injection, and fines content of the feedstock on gasifier performance also are detailed. Equipment life during the Westfield program is summarized.

5.1 Design Data and Information

The primary purpose of the Westfield Technical Support Program (TSP) was to obtain the requisite data base for designing the Demonstration Plant to process Ohio No. 9 and Pittsburgh No. 8 coals. The TSP accomplished this goal.

Process design data including gasifier operating conditions, product yields, and product compositions were needed to design the Gasification Section and most upstream and downstream processing units and off-site facilities. TSP Run 2 and TSP Run 14, in particular, provided the requisite process design data base for Ohio No. 9 coal. TSP Run 13 and TSP Run 15 provided the process design data base for Pittsburgh No. 8 coal. Other runs provided supplementary data for the plant design.

TSP Run 15 confirmed that bituminous caking coals fed to the gasifier can contain a high percentage of coal fines (¼" x 0)--at least 23 percent. This tolerance for coal fines eliminates a potential "fines problem" in processing bituminous caking coals in the British Gas/Lurgi slagging gasifier. The fines appear to agglomerate upon entering the gasifier so that few fines are entrained in the crude synthesis gas leaving the gasifier.

The TSP indicated that a washed coal is the preferred feed for the slagging gasifier. A comparision between operations on washed Pittsburgh No. 8 coal with operations on unwashed Ohio No. 9 coal suggests that the gasifier operates better on a washed coal feed.

The TSP disclosed that the mechanical configuration of the gasifier and some of the associated proprietary equipment require modified designs in order to process bituminous caking coals. This disclosure was not completely unexpected because the pilot plant gasifier had been designed and developed primarily for processing weakly caking Scottish Frances coal. TSP Runs 2-7 provided British Gas and Lurgi with the information which enabled them to make some changes in the proprietary equipment so that the suitability of the gasifier for processing Pittsburgh No. 8 and Ohio No. 9 coals could be demonstrated in TSP Runs 13-15. This experience will permit British Gas and Lurgi to design an improved gasifier for the Demonstration Plant.

5.2 Gasifier Bed Behavior

Gasifier bed instabilities and quench chamber fouling during the early runs were directly related to the caking properties of Ohio No. 9 coal. The use of load reduction and layering with metallurgical coke prolonged operations to allow analysis of the chemical and physical phenomena occuring in the bed. Modifications were made to the hearth, stirrer, and quench chamber that allowed steady, reliable operation on both caking coals (Ohio No. 9 and Pittsburgh No. 8) as well as weakly caking Frances coal.

The slagger is a fixed bed gasifier in the sense that the upper and lower extremities of the bed are fixed in space, the bed is supported internally and maintained at a constant depth above that support. (9) Fuel moves slowly from the top of the bed through the gasification zone and the residue, mostly ash and flux, is discharged as slag from the bottom. Because of this arrangement, a number of chemical and physical processes occur simultaneously throughout the bed, often overlapping and interacting. Included among these processes are:

Preheating, drying, and devolatilization of coal at the top of the bed.

Countercurrent flow of reacting gases and solids with heat exchange.

For agglomerating coals, heating, swelling, and passage of coal particles through their plastic stage, with subsequent resolidification and contraction.

Reaction of steam with fixed carbon and carbon monoxide and reaction of carbon dioxide with fixed carbon.

Heat release from the reaction of oxygen with fixed carbon.

Phase change associated with melting of ash and flux to form slag.

Bed Behavior Indicators

In order to quantify the effects of these processes and relate them to overall operability of the gasifier, instrumentation on the gasifier was modified and upgraded prior to undertaking the TSP. These instruments were monitored continuously during the TSP runs to assess bed behavior. While all instrumentation on the panel board was vital to gasifier and associated equipment operations, several key parameters were used to assess bed stability. These indicators are discussed below with emphasis on their relation to the chemical and physical processes cited earlier.

Temperature measurements were recorded for both streams of crude synthesis gas leaving the top of the gasifier. Changes in the solids flow rate, gas flow rate, or gas-solids contacting efficiency manifest themselves in swings in offtake temperature.

Gas-side pressure drop (DP) was recorded for the top and bottom halves of the gasifier as well as the overall bed. In fixed bed gasifiers, pressure drop is primarily a function of gas distribution, solid particle size and density, bed void fraction, and gas flow rate. For caking coals, void fraction can be altered drastically by swelling, plastic coal particles.

The torque required to rotate the distributor-stirrer assembly was monitored as hydraulic pressure on the drive mechanism. The required torque increased with increasing caking characteristics of the feed coals since the caking process affects the mechanical resistance of the bed material to stirring. Likewise, increased fines loading was found to affect bed permeability and hence stirrer torque. These trends are shown in Figure 2.

Like temperature, the carbon dioxide content of the offgas is a function of gas distribution and gas-solids contacting. Carbon dioxide is generated by combustion of carbon with oxygen. It is consumed, however, by reaction with fixed carbon to form carbon monoxide and by the reverse water-gas shift reaction. Thus, carbon dioxide content in the offgas is also a function of steam decomposition and gas temperature since these factors affect shift equilibrium.

The brightness of the zone just in front of the tuyeres was monitored during most of the Westfield program. Tuyere brightness was an indicator of raceway conditions.

While these instrument readings were important in assessing bed behavior during the runs, the post-run bed inspection was the most direct evidence of what had happended in the gasifier bed. After each run, the bed was allowed to cool for one to three days while being purged with nitrogen and then systematically removed by sections from the top downward. These inspections provided physical evidence regarding the flow of solids down the bed, gas distribution pattern, the location of the caking zone and caked material, and the location of the raceway and slag pool.

Caking Problems During Early Runs

The early runs of the Westfield program on Ohio No. 9 coal were plagued with unsatisfactory bed and hearth conditions which were directly linked to the caking properties of the feedstock. Table 3 summarizes the operability of the gasifier with respect to the key bed behavior indicators described earlier.

With the exception of TSP Run 1, which was made with weakly caking Frances coal, the first six runs showed all the symptoms of large masses of caked fuel below the stirrer. These included offtake temperatures that either fluctuated widely due to uneven solids flow and sudden, intermittent movements of large fractions of the bed (referred to as "hang-slip" phenomena), or were alarmingly steady and unresponsive perhaps as a result of channeling of gas up the annulus surrounding a caked pillar of coal in

Figure 2 - Effect of Coal Swelling Index and Feed Fines Concentration on Distributor Torque

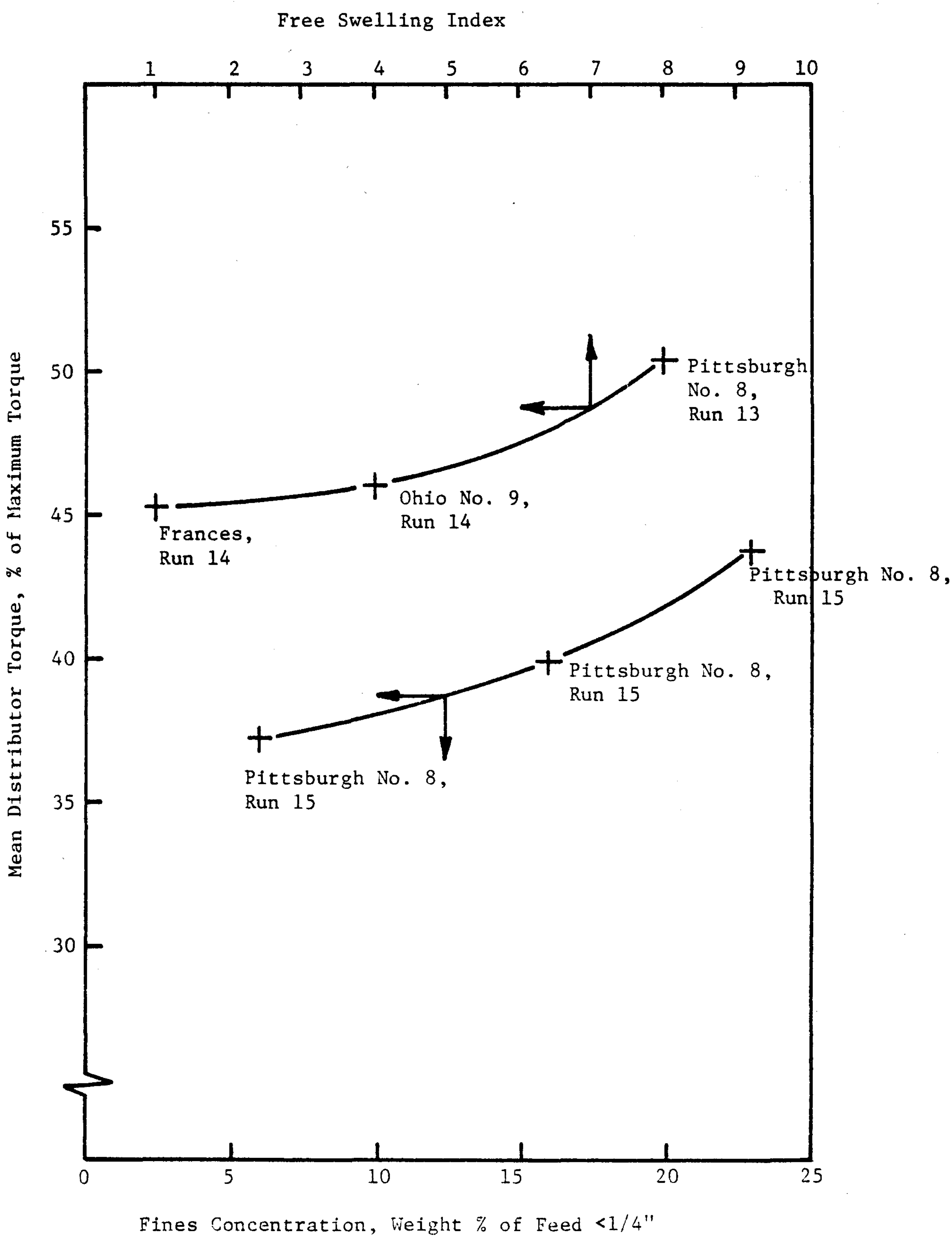


Table 3 Summary of Bed Behavior Indicators and Post-Run Bed Conditions

Run Number	1	2	3	4	5
Primary Feedstock-Coal Flux	Sized Frances BFS	Sized Ohio 9 BFS	Sized Ohio 9 BFS	Sized Ohio 9 Limestone/BFS	Sized Ohio 9 BFS
Bed Behavior Indicators					
Offtake Temperature	Lively, frequent hang-slip	Steady, frequent hang-slip	Large fluctuations	Reasonably steady frequent hang-slip	Very steady, lazy cycles
Bed DP's	Steady	Lively, occasional spikes	Large fluctations	Reasonably steady occasional spikes	Reasonably steady occasional spikes
Stirrer Torque	Steady	Lively, occasional spikes	High,tripped Just before shutdown	Steady,occasional spikes	Steady, occasional spikes
CO_2 Level	Steady, low range	Fluctuating, high range	Very high level prior to shutdown	High range, occasional spikes	High range, occasional spikes
Tuyere Brightness	Bright	2 black tuyeres, others dim, flashing	Dim, flashing	2 black tuyeres, others dim, flashing	Black, flashing
Post-Run Bed Conditions	Good char, even flux distribution	Cakes mass in middle bed region, remainder char & large lumps, even flux distribution	Caked plug at bottom,middle section of char & large lumps, even flux distribution	Pillar of caked fuel below stirrer, annulus of loose char, limestone distributed in loose char	Pillar of caked fuel below stirrer, annulus of loose char, BFS distributed in annulus

BFS refers to blast furnace slag

Table 3 Summary of Bed Behavior Indicators and Post-Run Bed Conditions Continued

Run Number	6	7	8	10	11
Primary Feedstock-Coal	Sized Ohio 9	Layered Ohio 9/BFC	Ohio 9/BFC Layered & Blended	Wide-Range BFC	Layered Pgh. 8/BFC
Flux	BFS	BFS	BFS	BFS	BFS
Bed Behavior Indicators					
Offtake Temperature	Very steady	Cyclic but steady	Steady, cyclic on layered feed-stock	Erratic, fre-quent spikes	Cyclic but steady
Bed DP's	Top DP spik-ing, bottom DP steady	Erratic at 2:1 & 3:1 layering	Erratic especially top DP	Erratic	Cyclic but steady
Stirrer Torque	Steady occa-sional spikes	Steady, occa-sional spikes	Frequent spikes	Occasional spikes	Steady
CO_2 Level	High range, occasional spikes	Steady, middle range	Steady, low range	Erratic	Steady, low range
Tuyere Brightness	Dim, flash-ing	Dim, flashing at 2:1 & 3:1 layering	Dim, flashing	Dim, flashing	Alternating dim & bright
Post-Run Bed Conditions	Pillar of caked fuel below stir-rer, annulus of loose char, BFS distribu-ted in annulus	Loose bed of BFC (bed purged prior to shut-down)	Partially coked coal below stirrer (undiluted Ohio 9 in last two locks)	Pillar of coke dust in center of bed, little dust elsewhere	Alternating layers of BFC & Pgh 8 char, no evidence of caking, even flux distribution

BFS refers to blast furnace slag
BFC refers to blast furnace coke

Table 3 Summary of Bed Behavior Indicators and Post-Run Bed Conditons Continued

Run Number	12	13	14	15
Primary Feedstock-Coal	Layered Ohio 9/BFC	Sized Pgh. 8	Sized Ohio 9	High Fines Content Pgh. 8
Flux	BFS	BFS	BFS	BFS
Bed Behavior Indicators				
Offtake Temperature	Cyclic but steady	Steady	Stable, frequent fluctuations	Lively, frequent fluctuations
Bed DP's	Cyclic but steady	Steady, higher at high load	Lively, frequent fluctuations	Lively, frequent fluctuations
Stirrer Torque	Steady, occasional spikes	Steady, occasional spikes	Steady, occasional spikes	Erratic, frequent stirrer stoppages
CO_2 Level	Occasional spikes, middle range	Steady, middle range	Fluctuating, middle range	Steady, middle range
Tuyere Brightness	Dim, flashing	Bright	Black, flashing	Bright
Post-Run Bed Conditions	Alternating layers of BFC & Ohio 9, Ohio 9 layer was caked mass of coal in center surrounded by annulus of loose char	Loose char mixed with small, caked lumps below stirrer, even flux distribution	Loose char, dust & pocket of flux below stirrer, slag shrouding tuyeres	Bed of loose char with small caked lumps, even flux distribution

BFS refers to blast furnace slag
BFC refers to blast furnace coke

the center of the bed. Bed DP's fluctuated widely probably due to channeling of gases through the bed and the presence of caked masses of coal, especially in the upper reaches of the gasifier. The stirrer torque operated at high levels during most of the runs, spiking occasionally to even higher levels and, on a few occasions, tripping out entirely. Sudden increases in carbon dioxide levels were often experienced, probably due to channeling of gases through the bed.

Raceway conditions were unstable during these runs, as indicated by black and flashing tuyeres. These conditions are thought to be the result of large pillars of caked coal impinging on the raceway area, diverting the blast of oxygen and steam away from the frontof the tuyeres, and causing pressure and slag level fluctuations in the hearth. These last two effects were also related to quench chamber fouling, which was a contributing factor to termination of five of the first seven runs on Ohio No. 9 coal.

Gasifier Modifications to Accommodate Caking Coals

Prior to TSP Run 6, it was concluded by British Gas, Lurgi, and Continental Oil personnel that modifications to the gasifier might be required to permit sustained operations on caking coals. Before these modifications could be put into effect, however, two partial solutions to the problem were tested and met with modest success. The first of these was the use of temporary load reductions to offset the effects of hang-slip phenomena in the bed. The oxygen loading was reduced in TSP Run 4 by 10 to 20 percent for about one minute whenever offtake temperatures and bed DP's indicated hanging bed conditions. The load was returned to its previous setting when conditions improved. This technique proved very successful in limiting the number of offtake temperature excursions and was used often in subsequent runs.

Because of the successful operation achieved during TSP Run 1 with Scottish Frances coal, a compromise solution to the problems of caking coals was proposed, whereby caking and non-caking feedstocks would be charged to the gasifier in layers. It was postulated that the layer of non-caking feed, in this case blast furnace metallurgical coke, would allow the gasifier sufficient time to recover from the effects of the caking feed, Ohio No. 9 coal. This technique was successful for 1:1 coal to coke layering, as experienced during TSP Run 7, but did not appear operable at 2:1 or 3:1 ratios. Quench chamber fouling with slag continued to be a problem at these higher ratios and ultimately led to gasifier shutdown. Because the bed was purged with five locks of metallurgical furnace coke prior to shutdown, no signs of a coked pillar or monolith were found during the post TSP Run 7 bed inspection. Although layering did not lead to long-term operation during TSP Run 7, it did prolong operation long enough to provide useful information related to the caking process and its effect on gasifier bed stability.

While both load reduction and layering offered partial solutions to the problem of gasifying caking coals, they did not address the fundamental causes of poor bed behavior and quench chamber fouling. Since monolithic formations of caked coal were found after each of the early runs on Ohio No. 9 coal, it seemed clear that a portion of the fresh coal feed was falling through the stirred zone before passing completely through its plastic, caking phase. As a consequence, coal was caking in the middle and lower sections of bed, agglomerating into large masses, and falling into the raceway and hearth as large lumps of caked fuel. These conditions, in turn, aggravated problems with quench chamber fouling.

To combat these effects, two major gasifier design changes were made during the month of January, 1978. The first change was to extend the stirrer in the upper section of the gasifier shaft to provide better gas-solids contacting. A sophisticated drive was also installed for the stirrer-distributor system between TSP Runs 6 and 7. This drive allowed the stirrer to operate at more suitable speeds. These two stirrer modifications increased the probability that coal particles would pass through their caking phase and be broken up into smaller, more manageable bits before reaching the raceway region.

The second major modification accomplished during January, 1978 was a revision of the hearth geometry in an attempt to isolate hearth conditions from bed behavior.

After these modifications were accomplished, TSP Run 8 was made with a combination of layered and blended Ohio No. 9 coal/metallurgical coke feedstocks. Bed behavior improved, but quench chamber fouling continued to be a problem and again led to shutdown.

Prior to TSP Run 9, modifications were made to proprietary equipment in the quench chamber to eliminate fouling. TSP Run 9 was shut down shortly after start-up with a plugged slag tap due to underfluxing, and TSP Run 10 was performed with a wide-size range blast furnace coke.

The feedstock was switched from moderately-caking Ohio No. 9 coal to strongly-caking Pittsburgh No. 8 coal for TSP Run 11. Gasifier operation was very steady during this run as evidenced by the bed behavior indicators. Gasification of layered Pittsburgh No. 8 coal/metallurgical coke continued for over five days with no major upsets and only a few minor process problems before the run was brought to a close with a controlled shutdown. Post-run bed conditions revealed alternating layers of metallurgical coke and Pittsburgh No. 8 char with no evidence of heavy caking in the bed. Only slight fouling had occurred in the quench chamber and these deposits never interfered with slag tapping during the run.

After the successful operation during TSP Run 11, it was still uncertain that the gasifier could process Ohio No. 9 coal in the same reliable manner. The results of TSP Run 12 proved that the gasifier is also capable of processing layered Ohio No. 9 coal, although operations were not quite as steady as during TSP Run 11. The most significant difference was the dim and flashing tuyeres in TSP Run 12 versus the alternating bright and dim tuyeres in TSP Run 11. A partial explanation for this difference was found during the post TSP Run 12 bed inspection when the Ohio No. 9 coal layer was found to contain a caked mass of coal in the center surrounded by an annulus of loose char. Further analysis showed that the flashing tuyere period corresponded to the flow of the Ohio No. 9 layer, with its caked mass, into the raceway region. Despite slight raceway instability, gasification continued uninterrupted on layered Ohio No. 9 with no significant quench chamber fouling.

Undiluted Pittsburgh No. 8 coal was the feedstock in two of the final three runs. A total of 194 hours of operation was achieved using this feedstock without requiring a shutdown or standby. The operation of the gasifier during TSP Run 13 and 15 was stable and reliable, although it should be noted that bed behavior was less steady during the high load period of TSP Run 13 and high fines content periods of TSP Run 15. The tuyeres remained consistently bright in both runs, and there was no significant quench chamber fouling.

The only worrisome aspect of operation on undiluted Pittsburgh No. 8 coal was the tendency for torque overload on the stirrer/distributor drive. In the extreme, the torque overload caused the stirrer to stop--once during TSP Run 13 and eleven times during TSP Run 15. It is important to note, however, that in all cases in which stirrer rotation stopped due to torque overload, it was possible to reestablish stable operation, and that at no time did these incidents threaten continued operation.

The post-run bed conditions for TSP Run 13 and 15 were similar in that the region below the stirrer was filled with loose char mixed with a few small lumps of caked fuel. These small lumps apparently caused little or no problems when they reached the raceway.

The gasifier operated on undiluted Ohio No. 9 coal during TSP Run 14. The bed behavior indicators were nearly as steady during TSP Run 14 as during TSP Run 13--the only significant difference being periods of reduced tuyere brightness. Post-run inspection showed that frozen slag had shrouded some of the tuyeres. This was probably due to a mechanical failure which led to a low flux addition rate during portions of the run. Slag quench chamber deposits were again minimal.

Another factor that warrants consideration when comparing the bed behavior of TSP Run 14 with that of TSP Run 13 is variablity of coal feed. Appendix B points out that Pittsburgh No. 8 coal was washed prior to its shipment to Westfield whereas Ohio No. 9 coal was not. As a consequence, the composition of Ohio No. 9 coal was more variable than that of Pittsburgh No. 8 coal, especially with respect to moisture content, ash content, and ash composition.

This variability may account for some of the irregularities observed during TSP Run 14.

Gasification of Non-Caking and Weakly Caking Feedstocks

The slagging gasifier processed both non-caking blast furnace metallurgical coke and weakly caking Frances coal during the Westfield program. These fuels were used primarily as start-up feedstocks to verify the integrity of the gasifier and to allow the water jacket, hearth, and cooling systems to "heat up" before admitting a highly caking feedstock. Non- and weakly caking feedstocks were also useful as corrective feeds. During early runs in which massive caking led to the formation of a monolithic block, it was found that the monolith could be eliminated by feeding either Frances coal or blast furnace coke for short periods of time. The symptoms of massive caking generally disappeared after one or more gasifier inventories of the corrective feed had been admitted. Although unnecessary during the runs at the end of the program, corrective feed in the form of blast furnace coke was immediately available as gasifier purge.

Frances coal was the standard feedstock used in the privately-funded gasifier development program. Periods of continuous operation of up to 23 days had been demonstrated in that program. This operability was reconfirmed during the Westfield program. Frances coal was fed for 232 hours in eight separate runs without an incident which resulted in termination. Three standby periods were required while feeding Frances coal, and in each case a satisfactory recovery was made. The longest continuous period of operation was 97 hours during TSP Run 1. A second verification of operability on Frances coal was made during TSP Run 6 during which 48 hours of continuous operation on this coal was completed successfully. Operation with Frances coal was demonstrated over a range of oxygen feed rates (loading) from 100,000 SCFH to 160,000 SCFH and steam/oxygen ratios from 1.15 to 1.35. The nature of the Frances coal ash allowed operation without flux addition, but since primary use of this coal was a start-up transition fuel, blast furnace slag was added as flux in all of the runs. The size of the Frances coal was nominally 1" x 5/8", but the feed material contained up to 15 percent of 1/4" x 0 coal fines.

Bed behavior during TSP Run 1 was quite steady as indicated by key operating parameters. It was also noted that operation during fluxed periods was much smoother than during unfluxed periods. This result was reconfirmed during start-up periods of subsequent runs. The smoothing qualities of flux addition appear to be related to its role as a heat sink in the gasifier, both at the top in the form of sensible heat and at the bottom in the form of heat of fusion.

Gasification of non-caking blast furnace metallurgical coke was also demonstrated during the Westfield program.

coke in the eastern U.S. coal producing areas makes it a desirable start-up material and corrective feedstock. Metallurgical coke was fed for 162 hours during 7 runs. The longest continuous operation was 48 hours during TSP Run 7. The nature of the metallurgical coke ash required fluxing, and blast furnace slag was added as flux during all operation with this fuel.

Two runs, TSP Runs 9 and 10, were terminated while feeding coke. In the first, the flux feed rate was halved, the slag viscosity became too high, and the slag pool became frozen. In the second, the gasifier failed to recover from a standby caused by a plant mechanical failure. Frozen slag in the hearth was the reason that the gasifier could not recover from standby. It should be noted, however, that in a previous run, TSP Run 8, the gasifier did successfully recover from a standby during a period in which coke was being fed. The nominal size of the blast furnace coke feed during the program was 1 1/2" x 3/4", but it contained about four percent of 1/4" x 0 fines. An attempt to feed a fines-laden coke feedstock containing 15 percent of 1/4" x 0 fines was abandoned when the downstream equipment became choked with fines.

In general, plant operation while feeding metallurgical coke was smooth. This smooth operation was demonstrated over a range of oxygen load from 130,000 SCFH to 160,000 SCFH and steam/oxygen ratio from 1.15 to 1.45.

The transition from start-up fuel to caking coal was clearly smoother when Frances coal was used as the start-up material vis-a-vis blast furnace coke. This, however, may be entirely due to the disparity between the size consist of the coke and the caking coal. The results of the program show that either material is acceptable as a start-up and corrective fuel.

5.3 Quench Chamber Operation

Fouling of the quench chamber with slag deposits was a problem during the first half of the Westfield program. This was not surprising because the original quench chamber in the pilot plant was not designed to handle the large quantities of ash in Ohio No. 9 coal. Modifications to the proprietary equipment effectively eliminated this problem after TSP Run 8.

Molton slag flowing from the bottom of the British Gas/Lurgi slagging gasifier is quenched with water in a pressurized chamber to form a dense, glassy frit. The dense slag frit settles to the bottom of the chamber and is periodically removed via a lockhopper. A transition zone is located at the top of the quench chamber where the chamber walls narrow to join the bottom of the gasifier.

A summary of quench chamber operations is listed in Table 4. The primary effects of slag deposition in the quench chamber were to restrict the view of the slag tapping operation, which is

TABLE 4
QUENCH CHAMBER OPERATION

TSP Run	Fouling & Effects	Role in Shut Down	Modifications Prior To Run
1	No fouling[(a)]	None	None
2	Deposits divert slag stream and restrict visibility	Contributory	None
3	Minimal fouling[(b)]	None	None
4	Deposits restrict visibility	Contributory	None
5	Deposits divert slag stream	Contributory	New Internals Design
6	Deposits restrict visibility	None	None
7	Deposits divert slag stream and restrict visibility	Primary cause	None
8	Deposits divert slag stream and restrict visibility	Primary cause	None
9	Minimal fouling	None	Equipment Modifications and Streamlining
10	Minimal fouling	None	None
11	Minimal fouling	None	None
12	Minimal fouling	None	None
13	Minimal fouling	None	None
14	Minimal fouling	None	None
15	Minimal fouling	None	None

Notes

(a) TSP Run 1 was made with weakly caking Frances coal
(b) TSP Run 3 operation included only 3 hours on Ohio No. 9 coal

critical to gasifier operation, and to interfere with the free fall of slag from the slag tap to the quench water. The table also indicates that quench chamber fouling was the primary cause of shutdown for two of the first seven runs on Ohio No. 9 coal and a contributory cause for three other runs.

5.4 Slag Tapping Performance

Fundamental to the performance of the slagging gasifier is the ability to maintain and control a sufficiently high temperature in the hearth area so that the coal ash and flux form a pool of liquid slag in the hearth, and tapping of slag from the gasifier is readily achieved. The proper temperature level is dependent upon the melting point and the viscosity-temperature behavior of the slag. This in turn is a function of its chemical composition. The geometry of the hearth can also affect the gasifier performance with respect to slag removal.

Throughout the Westfield program experience was gained in achieving reliable slag tapping while feeding eastern U.S. caking coals. Over 15,000 slag taps were performed in the 15 runs made during the program. Fully automatic control of slag removal was demonstrated in every run. In general, the tapping performance in terms of slag removal rates and slag level control was good to excellent. In three runs, TSP Runs 4, 6, and 9, the flux addition rate was too low, and poor slag tapping resulted. Significantly, there were no problems with slag removal during TSP Runs 11-15 which were made at the end of the program. The slag tapping performance for selected runs is shown in Table 5. These selected runs include the three runs in which difficulties were encountered and other runs representative of the experience during the program. The effects of slag composition and steam/oxygen ratio for these runs are shown in Figure 3.

The chemical composition of the slag determines its melting point and its viscosity-temperature behavior. The effect of chemical composition on slag viscosity has been studied extensively.

A standard method used to characterize slag viscosity as a function of composition is the silica ratio. The silica ratio is defined as follows:

$$\text{Silica Ratio} = \frac{SiO_2}{SiO_2 + CaO + MgO + Fe_2O_3} \times 100$$

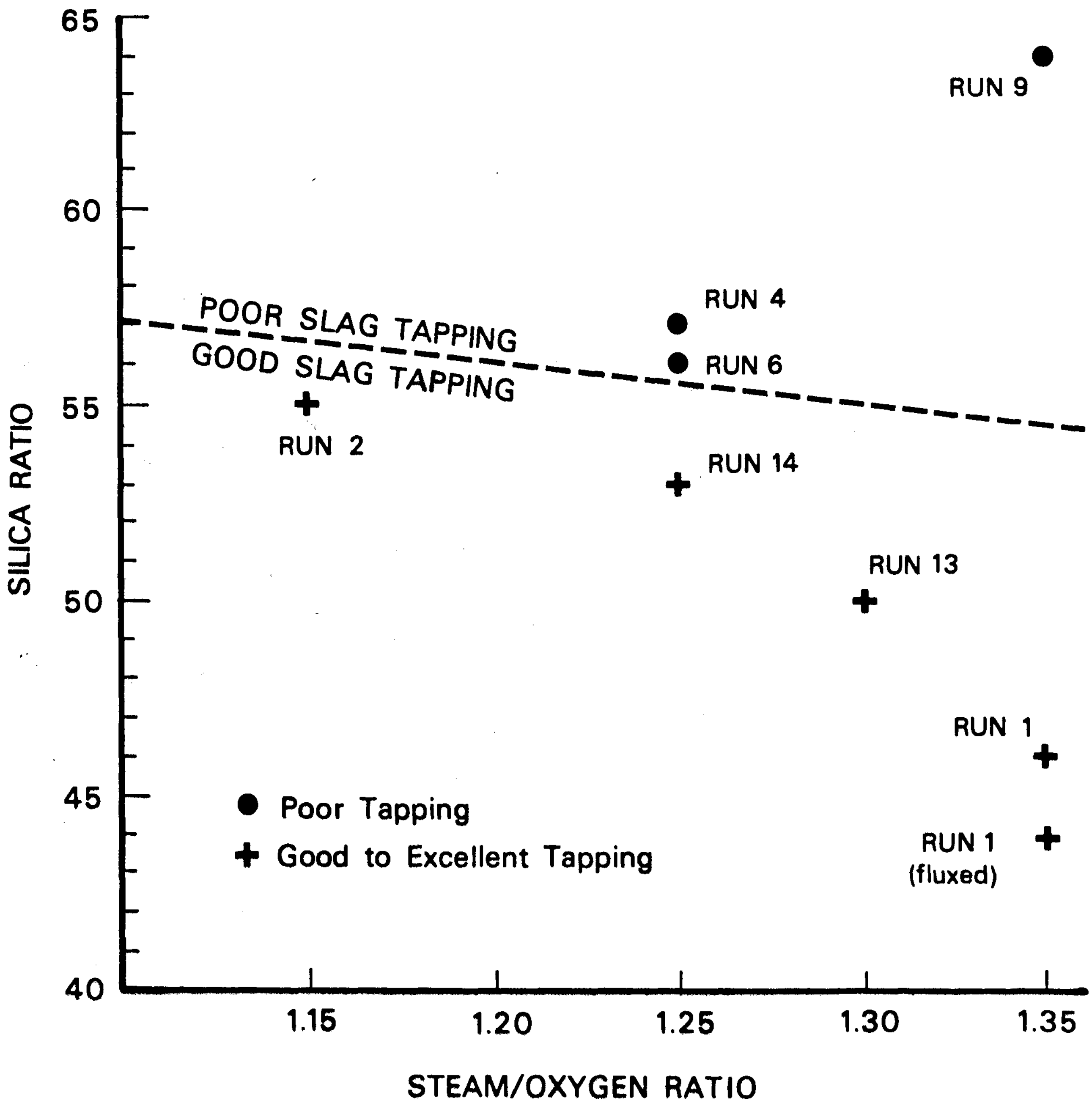
A high silica ratio gives a viscous slag. The ash in eastern U.S. bituminous coals is generally rich in SiO_2, Al_2O_3 and Fe_2O_3 and poor in CaO and MgO. These coal ashes require the addition of a flux to alter the slag chemical composition and give a reasonably low viscosity for slag removal from the slagging gasifier. The flux is rich in CaO or MgO and lowers the silica ratio.

TABLE 5
SLAG TAPPING PERFORMANCE FOR SELECTED RUNS

Run No.	1	1	2	4	6	9	13	14	15
Feedstock	Frances Coal	Frances Coal	Ohio 9 Coal	Ohio 9 Coal	Ohio 9 Coal	B.F. Coke	Pgh 8 Coal	Ohio 9 Coal	Pgh 8 Coal
Flux	None	B.F. Slag	B.F. Slag	Limestone	B.F. Slag	B.F. Slag	B.F. Slag	B.F. Slag	B.F. Slag
Steam/O_2 Ratio	1.35	1.35	1.15	1.25	1.25	1.35	1.30	1.25	1.30
Slag Composition, Wt. %									
CaO	14.4	30.5	17.0	13.2	15.0	16.8	26.5	20.4	26.5
MgO	7.4	11.6	6.1	1.3	4.9	5.8	7.8	5.6	7.2
SiO_2	33.0	37.1	43.4	40.7	38.6	46.7	40.1	43.0	40.7
Al_2O_3	22.5	14.8	19.5	18.2	17.3	23.0	18.0	19.0	17.8
Fe_2O_3	14.5	4.7	12.4	16.3	10.1	4.1	5.7	9.7	5.4
Silica Ratio	48	44	55	57	56	64	50	53	50
Hearth Geometry	Normal →				→	Deep →			→
Slag Tapping Performance	Good	Excellent	Good	Poor	Fair to Poor	Poor	Very Good	Fair to Good	Very Good

Figure 3

EFFECT OF SLAG COMPOSITION AND STEAM/OXYGEN RATIO ON SLAG TAPPING



During the Westfield program blast furnace slag was used as flux for all the runs except TSP Run 4. It is shown in Table 5 and Figure 3 that, in general, silica ratios below 55 give free flowing slags. In the three runs in which slag tapping problems were encountered, the silica ratios were above 55. The flux addition rate was too low in each of these runs. The low flux addition rate in TSP Runs 4 and 6 was due to change in the size consist or particle density of the flux. The flux level was decreased purposely in Run 9. It is important to note that low flux rate rather than the use of limestone flux was responsible for the slag tapping problems in TSP Run 4.

The silica ratio, as expressed above, does not allow adequately for the effect of iron. Essentially all of the iron oxide in the coal ash is reduced to ferrous oxide and metallic iron.

Metallic iron is denser than the slag and will tend to separate to the bottom of the hearth. The iron in solution probably contributes as a flux, whereas separated iron does not.

The viscosity of a slag is a function of both chemical composition and slag temperature. The higher the temperature, the less viscous the slag. The temperature of the slag can be increased by reducing the steam/oxygen ratio. The steam/oxygen ratio was reduced slightly in order to improve slag tapping in several runs during the Westfield program. Heat from the tuyere blast maintains the slag as a liquid in the hearth. Bed irregularities such as hang-slip and channeling can lead to periods of poor slag tapping. Bed behavior and slag tapping are interdependent.

Slag tapping also will suffer if the momentum of the raceway blas is insufficient to distribute the raceway heat across the cross section of the gasifier. The gasifier load was systematically reduced in TSP Run 1 to determine the load at which slag tapping was affected. The information obtained from this run was used in forming programs for the succeeding runs, and problems of this type were avoided. Further reductions in load were possible by reducing the number of active tuyeres.

The heat losses to the hearth are also important in considering slag tapping performance. Excessive heat loss could cause the slag to cool and ultimately freeze. Although the heat losses varied to some extent, depending on the condition of the hearth bricks and the nature of the feedstock, there were no instances where slag tapping problems could be attributed to excessive heat losses.

The slag tap burner properly fulfilled its role in preventing the slag from freezing and plugging the tap hole.

Changes in hearth geometry can affect the slag tapping performance by changing the slag retention time and/or the interaction between the raceway and the slag pool. The ability to tailor the hearth geometry to the feedstock is important. During the TSP, it was demonstrated that a given hearth geometry is tolerant of a range of coals, e.g. Pittsburgh No. 8, Ohio No. 9, and Frances coals. Two different hearth geometries were used in the Westfield program, and both worked satisfactorily.

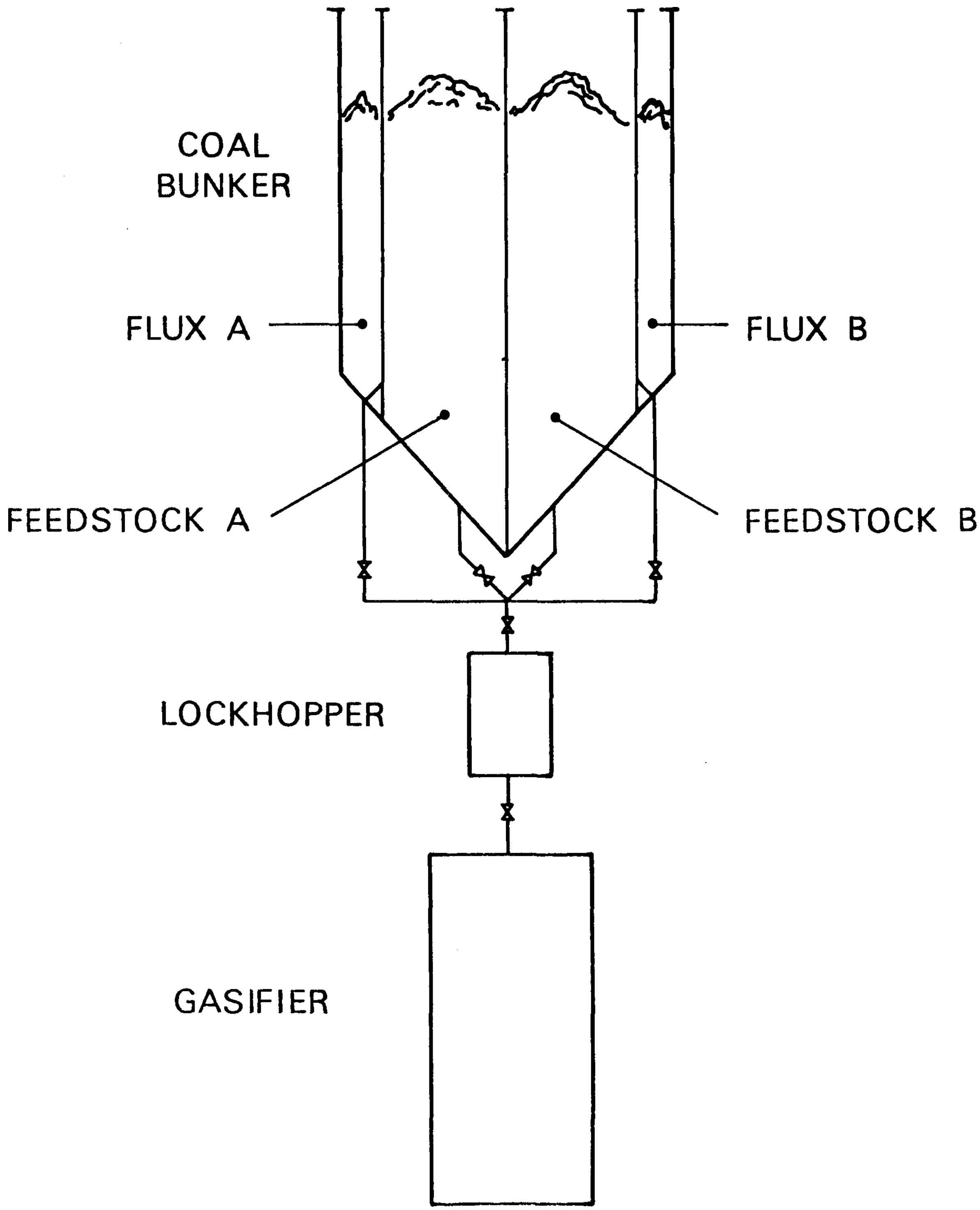
5.5 Coal and Flux Feeding Systems

The top portion of the slagging gasifier, including the coal feed system, is quite similar to commercial Lurgi dry bottom gasifiers. However, the increased coal throughput of the slagging gasifier coupled with the highly-caking properties of eastern U.S. coals dictated several desirable modifications to the pilot plant coal feed system. As described in Section 5.4, the ash composition of eastern U.S. coals is such that flux addition system was required. The coal feed system to the gasifier was modified as suggested by Lurgi to improve its operating reliability, and a flexible, reliable flux addition system was added. The Westfield pilot plant coal/flux feed system is shown schematically in Figure 4.

Because of the caking properties of eastern U.S. coal, gasifier start-up on these coals is best accomplished by initially feeding a non- or weakly caking feedstock. If caking coal is fed to the gasifier during start-up, this can lead to caking deep in the gasifier bed. A non- or weakly caking fuel should be fed until the gasifier is "warmed up", and smooth baseline conditions are established. Then the caking feedstock can be introduced. With the original pilot plant feed system, the switch from start-up feed to caking coal could only occur when the feed bunker was empty. The emptying of the bunker did not always coincide with the readiness of the gasifier to accept caking feedstocks; therefore, a simple system to switch feeds was desirable.

Figure 4

WESTFIELD COAL/FLUX FEED SYSTEM



The concept of modifying the bunker to allow a simple change from a caking feedstock to a non- or weakly caking feedstock (or the reverse) was further supported by two additional factors. These were:

a. The ability to recover from standby condition (the temporary cessation of steam and oxygen feed) would be improved if a non- or weakly caking feedstock could be fed.

b. Non- or weakly caking feed could be fed as an interim feed when sustained operation was threatened by problems related to the caking properties of the primary feedstock.

Based on these justifications, the gasifier feed system was modified following TSP Run 4.

As shown in Figure 4, the coal bunker was split in two with each half having its own outlet to the lockhopper. A simple valving arrangement allowed feeding from either bunker to the lockhopper. This modification proved to be very useful in ultimately demonstrating the operability of the slagging gasifier while feeding highly caking eastern U.S. coals. The advantages of this system are as follows:

a. Simplified start-up.

b. Provided a means of eliminating undesirable symptoms by purging with non- or weakly caking feed.

c. Allowed extended operation to study gasifier bed behavior using a layering technique.

d. Decreased the sensitivity to standby conditions.

The change from a start-up feedstock to a caking feedstock was dictated by the gasifier conditions. The start-up times could be shortened or lengthened depending on the gasifier conditions alone.

Purges of non- or weakly caking fuel were used during TSP Run 5-8 to eliminate symptoms resulting from feeding caking coal. In general, poor bed conditions improved immediately when purge feed was initiated and disappeared entirely after two to three hours of such feed. Although not required, this feature was available during the later stages of the program. Both Frances coal and metallurgical coke were used as fuels.

As described in Section 5.2, the use of the technique of layering caking and non-caking feedstocks was a key to achieving extended gasifier operation which in turn led to successful performance with caking feedstocks. The modified system allowed the use of this procedure by providing a simple means of changing feedstocks. Layered feeds were fed during TSP Runs 7, 8, 11, and 12.

The ability to recover from standby while feeding non-or weakly caking fuel was demonstrated five times during the program; twice in TSP Run 1, and once each in TSP Runs 2, 3, and 8. A sixth standby during TSP Run 10 resulted in a shutdown, but that resulted from too much slag in the hearth rather than bed conditions. This experience suggests that recovery from a standby in which the coal lockhopper is empty could be accomplished by charging non-or weakly caking feed.

As discussed in Section 5.4 flux addition is required with the refractory ash composition common to eastern U.S. coals. Recognizing this, a number of approaches were considered for the Westfield program. The system shown schematically in Figure 4 was chosen for the following reasons:

- A controlled amount of flux is added to each lockhopper of feedstock ensuring reasonable uniformity of flux feed.
- The system was flexible in that the flux rate could be changed almost instantaneously by adding more or less flux to the next lockhopper.
- Plant modification was readily accomplished.
- Operation of flux addition could be accomplished in conjunction with that of the coal lockhopper.

The system consists of a separate flux bunker, a calibrated variable-rate feeder, and appropriate piping and valving. Flux and feed are fed concurrently and mixed prior to introduction to the lockhopper. The flux feeder was timed so that the prescribed dose of flux had entered the lockhopper before it became full of feedstock. The sytem was commissioned in TSP Run 1. Subsequently, prior to TSP Run 5, the flux system was duplicated to provide security in the event of a mechanical failure and to allow the use of two different fluxes such as limestone and blast furnace slag in the same run.

Operation of this flux addition system was satisfactory except when changes in flux characteristics altered the calibration of the feeder. The other disadvantage in the system was that large step changes in the feeder setting could not be made precisely. Large step changes could be made accurately by cutting the flux feed time, but this led to a large flux concentration gradient in the lockhopper. These disadvantages led to slag tapping problems during TSP Runs 4, 6, and 9. Use of a feeder which feeds a specified weight of material would have prevented these incidents.

5.6 Process Variables

The oxygen feed rate (oxygen load) was ranged widely during the Westfield program. Coal feed rate is directly proportional to oxygen load. The steam/oxygen ratio was ranged to a lesser extent during the program. The ranging of these variables proved to affect only the smoothness of plant operations and in no instance did ranging a variable lead to termination of the run. This ranging had no substantial effect on product yields, thermal efficiency, or oxygen and steam consumption on a unit throughput basis.

Oxygen loading was varied from 130,000 to 170,000 SCFH while the gasifier was operating on Pittsburgh No. 8 coal during TSP Runs 13 and 15. Higher oxygen loads during TSP Run 13 were associated with proportionately higher coal gasification rates and more varied distributor torque, offtake temperatures and bed DP's. Bed behavior was slightly less smooth at high loads than at low loads, with operation approaching instability at 170,000 SCFH.

While gasifying Ohio No. 9 coal, the oxygen load was ranged from 80,000 to 130,000 SCFH during TSP Runs 6 and 14, respectively. Steady gasification of Frances coal was demonstrated for much longer periods at 160,000 and 100,000 SCFH of oxygen during TSP Runs 1 and 6, respectively. It must be noted that during TSP Run 6 the number of tuyeres was reduced from the normal number to accommodate the lower flow rates of steam and oxygen.

The primary limiting factors for turndown capability of the British Gas/Lurgi slagging gasifier appears to be the mass flow rate and the blast velocity of the gases emerging from the tuyeres. A minimum value for these variables is required for gases to penetrate into the raceway region and to insure adequate gas distribution across the bottom of the bed.

During the Westfield program the normal (or rated) load was considered to be 160,000 SCFH oxygen. Gasification at this loading was demonstrated over extended periods of time with both Pittsburgh No. 8 and Frances coal. During TSP Run 13, sustained operation on Pittsburgh No. 8 coal was demonstrated at 130,000 SCFH oxygen (or approximately 80 percent of rated load) by cutting back the load on all tuyeres. Operation at 122,000 SCFH oxygen (or approximately 75 percent of rated load) was demonstrated for Frances coal during TSP Run 1. For Ohio No. 9 coal gasification, a reduction in load to 50 percent of rated capacity was demonstrated during TSP Run 6 using a reduced number of tuyeres. A return to normal load from this condition was not attempted. Additionally, on several occasions during the program, the gasifier was placed on standby operation. Effectively complete turndown capability was demonstrated on these occasions when return from standby conditions to normal load was completed.

The steam/oxygen ratio was ranged from 1.25 to 1.35 while gasifying Ohio No. 9 coal during TSP Run 13. Operation with ratios as low as 1.15 were investigated during TSP Runs 2 and 3. As discussed in Section 5.4, the primary impact of this parameter appears to be on the temperature of the hearth region and slag viscosity. Steam/oxygen ratio did not appear to have a significant effect on bed behavior.

Each of the runs during the Westfield program was made at 350 psig gasifier pressure. This pressure was very close to design limits for the pilot plant gasifier and related equipment.

5.7 Tar Recycle

Feeding of solids-laden tar recycled from the sump of the Westfield Tar Separator into the top of the gasifier was practiced throughout the Westfield program. In the final three runs, TSP Runs 13-15, the effects of tar recycle were studied systematically. The results show that:

> The solids content of the recycle tar reaches an equilibrium level if solids-laden tar is fed to the top of the gasifier.
>
> The level of the solids content is a function of the amount of fines produced in the gasifier and the feed rate of solids-laden tar.
>
> When solids-laden tar is added to the top of the gasifier, the coal feed rate decreases.

Feed of recycled solids-laden tar was practiced routinely at Westfield during its days as a commercial plant. The solids content of the tar is controlled at a level which permits trouble-free pumping. When the solids level in the tar increases, the tar feed rate to the top of the gasifier is increased and the equilibrium solids concentration drops. The feeding of solids-laden recycle tar to the top of the gasifier reduces the coal feed requirement. This is demonstrated in Figure 5 where coal feed rates from TSP Run 13 are plotted against oxygen loading. Data are shown with and without recycle tar feed. The coal feed rate is clearly lower when solids-laden tar is fed to the top of the gasifier. The presence of tar feed did not have a significant effect on the gas composition, as shown in Table 6. The effectiveness of this procedure has been thoroughly demonstrated during the Westfield program. The practice of recycle tar feed to the top of the gasifier is a means of eliminating carbon losses in the form of dust carryover.

Feed of solids-laden tar to the top of the gasifier was thought to be detrimental in the A.G.A. trials when feeding Pittsburgh No. 8 coal.(1) Operation with this coal was reliably achieved only after the recycle tar feed was stopped. In TSP Runs 2

Figure 5 - Coal Feed Rate Versus Oxygen Loading With and Without Feed of Recycle Solids-Laden Tar

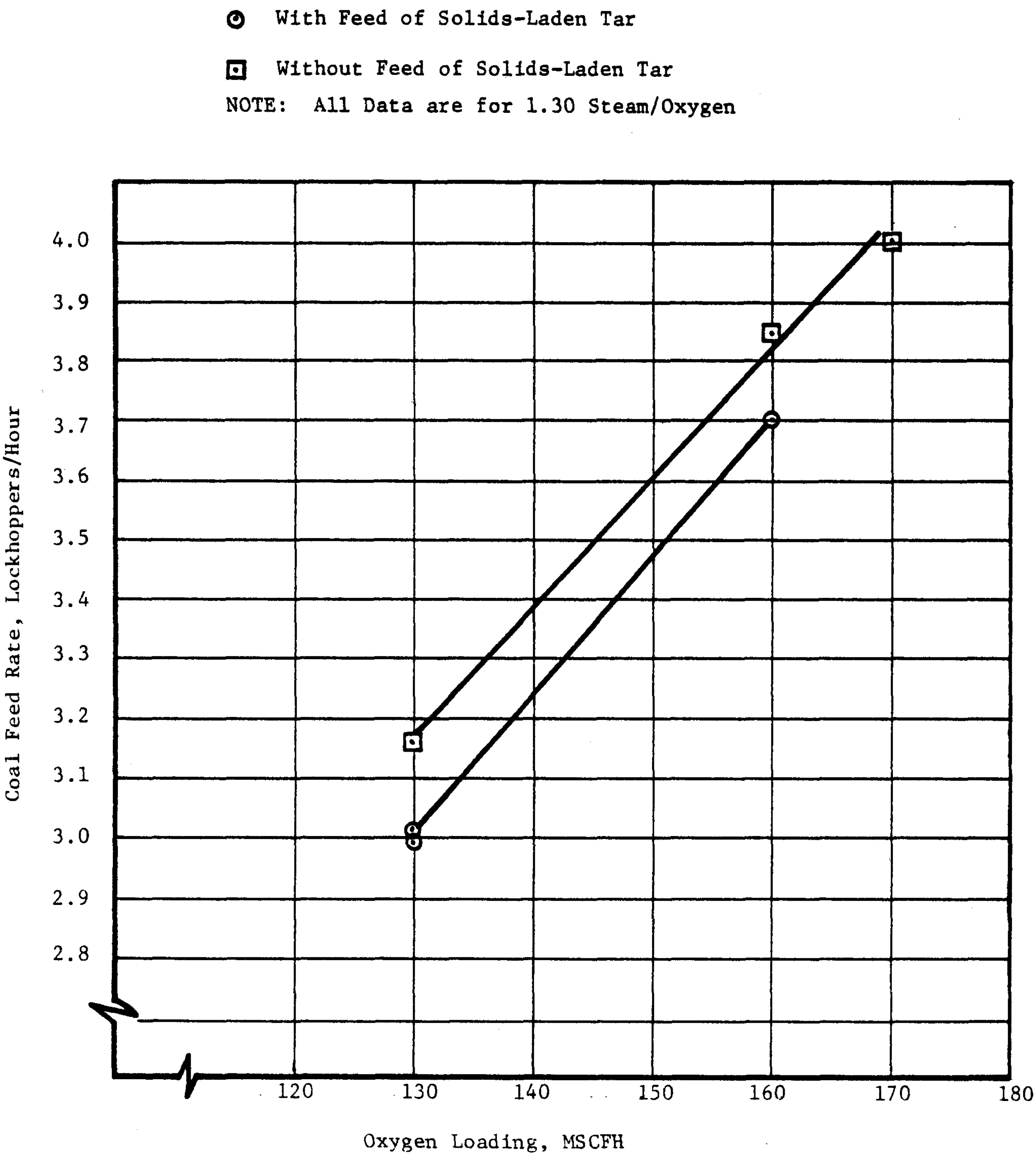


TABLE 6
EFFECT OF TAR RECYCLE ON PRODUCT GAS COMPOSITION DURING TSP RUN 13

A. Flare Gas Analysis During Periods of Tar Recycle to the Gasifier

Date	6/19/78	6/20/78	6/20/78	6/20/78	6/20/78	6/21/78	6/21/78	6/21/78	Mean Value	Standard Deviation	75% Mean Confidence Limits
Time	2240	0030	0445	0640	0900	0440	0730	1030			
CH_4	7.85	6.80	6.57	7.40	7.54	7.05	7.74	6.74	7.21	0.487	± 0.22
CO_2	3.11	3.19	3.08	3.50	3.55	3.65	3.76	4.32	3.52	0.412	± 0.18
C_2H_4	0.10	0.15	0.19	0.19	0.19	0.27	0.20	0.20	0.19	0.048	± 0.02
C_2H_6	0.85	0.47	0.50	0.45	0.46	0.77	0.47	0.49	0.56	0.158	± 0.07
H_2S	0.47	0.43	0.53	0.51	0.51	0.55	0.59	0.53	0.52	0.049	± 0.02
H_2	27.95	28.76	28.33	28.46	29.54	28.32	28.55	28.82	28.59	0.471	± 0.21
O_2	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	-	-
Ar	0.71	0.68	0.99	0.93	0.92	0.84	0.83	0.92	0.85	0.110	± 0.05
N_2	3.39	2.70	3.43	3.70	3.49	3.66	3.68	3.29	3.42	0.326	± 0.15
CO	52.92	53.74	54.13	53.33	52.40	52.47	52.52	52.67	53.02	0.645	± 0.29
Recovery	97.35	96.92	97.75	98.47	98.60	97.58	98.34	97,98		-	-

B. Flare Gas Analysis During Periods of No Tar Recycle to the Gasifier

Date	6/20/78	6/20/78	6/20/78	6/21/78	6/21/78	6/21/78	Mean Value	Standard Deviation	75% Mean Confidence Limits
Time	1310	1634	2240	0040	1510	1400/1600			
CH_4	7.04	6.82	7.72	7.27	7.04	6.73	7.10	0.357	± 0.10
CO_2	3.64	3.71	3.89	3.52	3.70	3.78	3.71	0.125	± 0.07
C_2H_4	0.33	0.13	0.20	0.19	0.29	0.14	0.21	0.081	± 0.04
C_2H_6	0.58	0.53	0.53	0.46	1.25	0.46	0.64	0.305	± 0.16
H_2S	0.53	0.50	0.51	0.67	0.57	0.53	0.55	0.063	± 0.03
H_2	26.76	29.45	28.34	28.88	27.54	28.85	28.30	0.991	± 0.53
O_2	Nil	Nil	Nil	Nil	Nil	Nil	Nil	-	-
Ar	0.90	0.90	0.83	0.93	0.88	0.82	0.88	0.043	± 0.02
N_2	3.00	2.56	3.18	2.83	2.73	3.77	3.01	0.429	± 0.23
CO	54.50	53.38	52.25	53.79	54.48	52.76	53.53	0.913	± 0.49
Recovery	97.28	97.98	97,45	98.54	98.48	97.84	-	-	-

NOTE: All data are for 130,000 SCFH Oxygen and 1.30 Steam/Oxygen.

through 5 of the Westfield program , the tar feed rate ranged from 1.5 to 9.0 percent of MAF coal feed rate. During the A.G.A. trials, the tar feed rate for Illinois No. 5 and Illinois No. 6 coals was about five percent of the MAF coal feed rate.

During TSP Run 13 (Pittsburgh No. 8 feed coal), the feed of recycle tar was stopped during periods in which heat and material balance data were obtained. A general smoothing of the gasifier bed behavior was noted during these periods. There were alternate periods with and without tar feed throughout the run. Each time it was noted that gasifier operation was less smooth with tar feed.

In view of this experience tar feed to the top of the gasifier was not practiced during TSP Run 14, and smooth bed conditions were observed.

The recycle tar feed system was modified at Lurgi's suggestion between TSP Run 14 and TSP Run 15. Tar feed to the top of the gasifier again was studied systematically during TSP Run 15. The results of this study showed that the sensitivity to tar feed observed during TSP Run 13 had been effectively reduced. This was particularly important since TSP Run 15 featured the introduction of coal fines with the coal feed.

5.8 Coal Feed Size Consist

The tolerance of the British Gas/Lurgi slagging gasifier for fines (¼" x 0) in the feed material was demonstrated during TSP Run 15 for caking coal and during TSP Run 10 for non-caking coal. The fact that operation with Pittsburgh No. 8 was satisfactory in TSP Run 15 while operation with metallurgical coke resulted in excessive dust carryover in TSP Run 10 suggests the importance of fines capture by highly caking coals. Both strongly caking and non-caking coals were processed during the A.G.A. trials with a dry-bottom Lurgi gasifier, but at much lower coal throughput rates. (1)

The fines content (fraction less than 1/4-inch) of Pittsburgh No. 8 coal feed material was successively increased from six percent to 23 percent during TSP Run 15 without encountering the operating limit of the gasifier or overwhelming downstream equipment with dust carryover. Bed behavior was slightly less stable, however, than that for sized Pittsburgh No. 8 coal gasified during TSP Run 13. Operation during TSP Run 15 was characterized by several stirrer stoppages which occasionally required temporary load reductions while the stirrer was being restarted. In all cases the stirrer was restarted without undue difficulty, and good bed conditions were re-established quickly. Lumps of caked fuel were found at the top of the bed after shut-down of the run. When these lumps were broken apart, a good deal of fine material was found to be trapped inside. These observations suggest that caking coals may act to agglomerate fines at the top of the bed as the coal passes through its plastic range.

Gasifier performance on caking coals can be compared with performance on metallurgical coke, a non-caking fuel, during TSP Run 10. Operation while feeding the fines-laden feedstock containing 15 percent of material less than 1/4-inch was abandoned shortly after the line-out period because excessive dust carry-over caused problems for downstream equipment. The waste heat boiler sump level control became erratic because of solids build-up, and the wash cooler recirculation pump had to be continuously backflushed to avoid pluggage. The rotation rate of the stirrer was decreased, and tar injection rate increased, but these changes had little positive effect. Since the situation was intolerable, operation on wide range coke was terminated.

During the A.G.A. trials at Westfield in 1974, both caking and non-caking coals with high fines content were gasified in a Lurgi dry-bottom gasifier (1). Pittsburgh No. 8 coal containing 24 percent fines (1/4" x 0) was successfully gasified at a steady rate of 160 lb/hr-ft^2, and the top-of-bed gas velocities were comparable to those in TSP Run 15. Non-caking Rosebud subbituminous coal containing 45 percent fines was gasified at a rate of 250 lb/hr-ft^2. These gasification rates can be compared with a rate of 740 lb/hr-ft^2 during the final period of TSP Run 15 when gasifying Pittsburgh No. 8 coal with 23 percent average fines content.

5.9 Fluxes

The type and amount of flux used in the slagging gasifier is a factor in the economic evaluation of the gasifier. As stated in Section 5.4, the composition of the ash of eastern U.S. caking coals in such that flux addition is required to achieve satisfactory slag tapping. Flux is typically rich in calcium and magnesium and is used to adjust the slag to a composition with sutiable viscosity-temperature characteristics.

Two types of flux were used during the Westfield program. These were limestone and blast furnace slag. Typical analyses of these fluxes are shown in Table 7.

Although both types of fluxes perform the same role in the gasifier, they function differently. The blast furnace slag melts at gasifier temperatures to form a free flowing liquid. It is less rich in calcium and magnesium, and more flux is required, but the slag composition is not sensitive to small changes in the rate of addition. Limestone, on the other hand, has a very high melting point and must react with the coal ash in order to form a low viscosity slag. It is rich in calcium which reduces the addition level required, but increases the sensitivity to variation in the addition rate. Increasing the calcium level above a certain point is detrimental. Therefore, it is possible to add too much flux while using limestone.

Blast furnace slag was used as flux during all 15 runs made during the program. It performed well in all but two runs (TSP Runs 6 and 9) when the level of addition was too low. The use of blast furnace slag as flux has been fully demonstrated.

TABLE 7
TYPICAL ANALYSES OF FLUXES

Type	Blast Furnace Slag	Limestone	
Composition, Wt. %		As Received	Calcined Basis[1]
CaO	37.2	49.8	81.7
MgO	11.0	4.8	7.9
SiO_2	33.4	4.0	6.6
Al_2O_3	13.4	1.1	1.8
Fe_2O_3	0.7	1.2	2.0
Others	4.3	39.1[2]	0

(1) $CaCO_3$ converted to $CaO + CO_2$

(2) CO_2

Limestone flux was used in only one run, TSP Run 4. Poor slag tapping was observed during this run, but factors other than the type of flux were involved. First, due to feeder calibration error the amount of limestone added was too low to achieve good slag tapping, and, second, the slag tap burner did not function normally due to a restriction in the supply piping. No further attempts were made to use limestone as flux. Although the results from TSP Run 4 is inconclusive, the experience from blast furnace technology and other slagging gasifiers indicates that limestone is an acceptable flux.

5.10 Materials and Equipment Life

Materials usage was limited in the TSP to that necessary to achieve equipment life adequate to demonstrate the feasibility of the slagging gasifier and to obtain the data necessary to design the Demonstration Plant. No effort has been made to obtain the very best performance from the various types of proprietary equipment. However, the experience within the context of the Westfield program gives encouragement that reasonable commercial life can be expected. In addition, steel industry experience gives considerable confidence that adequate materials of construction can be obtained within the present state of the art.

Westfield Experience

The important items of proprietary equipment are listed below:

Slag tap

Tuyeres

Hearth refractory

Burner

Stirrer

The only failure of a piece of proprietary equipment occured during TSP Run 5 when the slag tap failed. This failure was entirely a result of poor bed conditions in front of the tuyeres and the failure to recognize the associated potential problems. Extended operation with poor bed conditions was avoided in subsequent runs. Ultimately, the problems leading to poor conditions were solved (see Section 5.2).

Throughout the program, pieces of proprietary equipment were modified as required to solve problems which were encountered with the use of eastern U.S. caking coals. With the exception of hearth refractory changes, which were made as a precautionary measure, 670 hours operation were achieved during eight runs of the DOE program and two runs privately-financed by British Gas

Corporation. At the completion of the program, all of the proprietary equipment remained operable. Table 8 summarizes the experience with respect to the life of proprietary equipment.

TABLE 8
Summary of Experience of Life of Proprietary Components

Components	Number of Failures	Demonstrated Hours of Service	Still Usable
Slag tap	1	670	Yes
Tuyeres	0	1465	Yes
Burner	0	825	Yes
Stirrer	0	670	Yes
Shaft Refactory	0	670	Yes
Hearth Refactory	0	524	Yes

Steel Industry Experience

In addition to the Westfield experience, experience in the steel industry give considerable confidence that adequate materials of construction can be obtained within the present state of the art. Two examples of this are blast furance components and continuous casting of steel.

A blast furnace has much in common with the slagging gasifier, and materials problems in the hearth are similar. It is important to note that the amount of iron, the single most aggressive element, is in much greater abundance in a blast furnace than in the slagger. The blast furnace relies on water-cooled copper (tuyeres and slag notch) and cooled high conductivity refractories (carbon hearth) and obtains reasonable commercial life from its components.

6.0 HEAT AND MATERIAL BALANCES

The technical support program at Westfield was designed to develop the necessary data for design of the Demonstration Plant. Consistent heat and material balances around the slagging gasifier are required for each design coal in order to size correctly both the downstream gas processing facilities and the utility requirements. To this end, the data required to generate heat and material balances were obtained in most of the runs.

The Westfield slagging gasifier pilot plant was not completely equipped with sophisticated data measuring devices for all input and output streams. The measurement of several streams is less accurate than for other streams. Among the less-accurate measurements were those for the fuel (coal or coke) feed rate, the gas liquor yield, and the yield of tar and oil. However, these values can be improved by detailed inspection of such things as individual component analysis and closure of heat balances.

The coal or coke feed rate was calculated using the number of lockhoppers fed per hour, the volume of the lockhopper, and the bulk density of the feed. A correction was made for the presence of flux in each lockhopper. Each truck carrying coal from its storage pile to the charge hopper for the belt conveyor was weighed. These weights can be used to obtain a rough estimate and check on the calculated feed rate.

The source of tar and liquor yields is from side stream analyses. A side stream sample of the overhead product is taken from the gasifier. The side stream sampling apparatus and procedure are reported in Appendix C. The side stream sampling provided a combined, representative sample of the gas, tar, oil, gas liquor, naphtha (condensibles), and dust (powdery char and coal) in the primary gasifier product. In order to reliably obtain a sample of the primary gasifier product stream, a sample point was chosen which may not have always produced a truly representative sample.

The tar, oil, gas liquor, and dust in the side stream sample are condensed at ambient conditions, separated, and weighed. Gas volume is measured and condensibles are removed via the St. Clair De Ville Method.

Heat and material balances were prepared by British Gas engineers for many of the TSP Runs and are reported in Appendix A. Despite potential inaccuracies in the plant data, these balances generally close to within five percent on the overall mass balance, the heat balance and the carbon, hydrogen and oxygen elemental balances. The nitrogen and sulfur balances are less accurate. This is due in part to the low concentrations of the sulfur and nitrogen compounds which increase the impact of the analytical inaccuracies. The variations in the coal sulfur levels and the hydrogen sulfide and nitrogen levels in the product gas were great enough to account for the lack of closure. Thus the data from the TSP heat and material balances are of sufficient accuracy to confidently design the Demonstration Plant. This statement is confirmed in the assessment by Lurgi in Section 2.4.

Continental Oil Company engineers have taken data from TSP Run 13 (Pittsburgh No. 8 coal at 870 MAF coal/hr/ft^2 throughput) and TSP Run 14 (Ohio No. 9 coal at 780 LB MAF coal/hr/ft^2) and constructed fully closed heat and material balances. These fully closed balances are called rationalized heat and material balances.

To fully close the elemental balances and the heat balances, the gas rate and composition, coal rate and composition, input oxygen, inlet steam, and heat loss are permitted to float within carefully defined limits. These limits are based on the variation of the plant data. A Least Squares Technique is used to minimize the movement of each variable within the range allowed. The changes required to close the balances were small and within observed experimental variations.

The rationalized balances prepared by Continental Oil engineers are summarized in Tables 9-12. The overall mass balances are shown in Table 9 on a basis of one ton of moisture, ash-free (MAF) coal or coke feed to the gasifier. The heat balances are shown in Table 10 on a percentage basis using a 100 percent for the higher heating value of the coal. Thermal efficiencies and product yields for any rate of coal feed to the gasifier can be calculated using Tables 9 and 10.

Comparison of the rationalized heat and material balances shows them to be quite similiar in terms of yields and overall thermal efficiency. The dry gas efficiency, however, is lower with Ohio No. 9 coal than with PittsburghNo. 8 coal (80.3 versus 84.7). This is due to the difference in coal composition. The Ohio No. 9 coal is higher in sulfur, and ash than the Pittsburgh No. 8 coal and higher in volatile matter when expressed on a MAF basis.

The coal compositions are shown in Table 13 in Section 7.1. The slight increases in liquid hydrocarbon yields (volatile matter) and sulfur compounds (sulfur content) reduce the dry gas efficiency. The higher ash content reflects itself by giving a lower offtake temperature and higher sensible heat duty.

TABLE 9

SUMMARY OF RATIONALIZED MATERIAL BALANCES
Basis: One Ton of MAF Coal or Coke Feed

Run Number	TSP Run 13	TSP Run 14
Feedstock	Pittsburgh No. 8 coal	Ohio No. 9 coal
Flux	Blast Furnace slag	Blast Furnace slag
Throughput, lb maf Feed/hr/ft^2	868	670
Offtake Temperature, °F	958	770
Input, pounds		
MAF Feedstock	2000	2000
Ash & Flux	551	1009
Oxygen & Air		
O_2	1123	1128
N_2	187	190
Steam	851	813
Fuel Gas	8	10
Total Input	4720	5150
Output, pounds		
Dry Gas		
H_2	108	102
CO	2872	2664
CO_2	319	412
CH_4	214	206
CnHm	38	38
Other compounds	261	317
Subtotal	3812	3739
Gas Liquor less Input Moisture	191	199
Net Tar & Oil	126	137
Naphtha	32	41
Dust	5	7
Slag	554	1027
Total Output	4720	5150
Input-Output, pounds	0	0

TABLE 10

SUMMARY OF RATIONALIZED HEAT BALANCES
Basis: Coal Higher Heating Value = 100.00

Run Number	TSP Run 13	TSP Run 14
Feedstock	Pittsburgh No. 8 coal	Ohio No. 9 coal
Flux	Blast Furnace slag	Blast Furnace slag
Throughput, lb maf Feed/hr/ft^2	868	670
Offtake Temperature, °F	958	770
Input, Higher Heating Value, percent		
MAF Coal	100.00	100.00
Fuel Gas	.61	0.80
Total Inputs	100.61	100.80
Outputs, Higher Heating Value, percent		
Dry Gas		
H_2	22.41	21.17
CO	42.24	39.53
CH_4	17.24	16.74
CnHm	2.82	2.89
Subtotal	84.71	80.33
Other Gas Compounds	1.28	2.66
Net Tar & Oil	6.92	7.82
Naphtha	1.96	2.50
Dust	0.08	0.17
Slag	.16	0.44
Total Output	95.11	93.92
Sensible and Latent Heat (Output-Input)	3.73	4.45
Heat Loss	1.77	2.43
Total Output Heat	100.61	100.80
Input Heat-Output Heat	0	0

TABLE 11

RATIONALIZED PROCESS DESIGN HEAT AND MATERIAL BALANCES - PITTSBURGH NO. 8 COAL WITH BLAST FURNACE SLAG FLUX

Basis: 1 hour Datum: $60^{o}F$ & H_2O (1)

					Elemental Weight Balances							ΔH		Higher Heating Value	
Input	Pounds	Lb-moles	Mol %	SCF	H	C	N	O	S	Ash	Temp., °F	Btu/lb	MM Btu	Btu/lb	MM Btu
MAF Coal	24549	-	-	-	1346	20219	377	2095	512	-	60	-	-	14802	363.37
Coal Moisture	1143	-	-	-	128	-	-	1015	-	-	60	-	-	-	-
Coal Ash & Flux	6762	-	-	-	-	-	-	-	-	6762	60	-	-	-	-
Subtotal															
Steam	10447	579.85	-	219995	1169	-	-	9278	-	-	700	1330.9	13.90	-	-
Oxygen & Air	16077	512.83	-	194568	-	-	2295	13782	-	-	200/60	26.7	0.43	-	-
Fuel Gas	99	5.56	-	2109	23	71	4	1	-	-	60	-	-	22600	2.24
Heat of Reaction		(HHV in - HHV out)											20.03		
TOTAL INPUT	59077				2666	20290	2676	26171	512	6762			34.36		365.61
Output															
Dry Gas															
H_2	1331	660.19	28.71	-	1331	-	-	-	-	-	958	3117.1	4.15	61183	81.43
CO	35255	1258.63	54.73	-	-	15117	-	20138	-	-	958	231.3	8.15	4354	153.50
CO_2	3911	88.85	3.86	-	-	1068	-	2843	-	-	958	220.2	0.86	-	-
CH_4	2622	163.47	7.11	-	659	1963	-	-	-	-	958	654.2	1.71	23885	62.63
C_2H_6	344	11.44	0.50	-	69	275	-	-	-	-	958	688.2	0.23	22323	7.68
C_2H_4	118	4.20	0.18	-	17	101	-	-	-	-	958	500.9	0.06	21640	2.55
N_2	2560	91.41	3.98	-	-	-	2560	-	-	-	958	229.3	0.59	-	-
NH_3	122	7.13	0.31	-	22	-	100	-	-	-	958	544.9	0.07	9671	1.18
HCN	Trace	0.02	Trace	-	Trace	Trace	Trace	-	-	-	958	366.3	0.00	10620	0.01
H_2S	438	12.84	0.56	-	26	-	-	-	412	-	958	237.2	0.10	7093	3.11
COS	85	1.42	0.06	-	-	17	-	23	45	-	958	168.4	0.01	3920	0.33
CS_2	1	0.01	Trace	-	-	Trace	-	-	1	-	958	148.1	0.00	5996	0.01
C_4H_4S	1	0.01	Trace	-	Trace	1	-	-	Trace		958	261.5	0.00	13120	0.01
Subtotal	46788	2299.62	100.00	872476	2124	18542	2660	23004	456	-			15.93		312.44
Gas Liquor	3488	193.66	-	-	390	-	-	3098	-	-	958	1483.6	5.17		-
Tar & Oil	1547	-	-	-	115	1334	15	69	14	-	958	640	0.99	16263	25.16
Naphtha	394	-	-	-	37	335	1	-	1	-	958	650	0.26	18082	7.12
Dust	61	-	-	-	Trace	19	Trace	Trace	Trace	42	958	257	0.02	4588	0.28
Slag	6799	-	-	-	-	40	-	-	39	6720	2950	809.2	5.50	85	0.58
Heat Loss													6.49		
TOTAL OUTPUT	59077				2666	20290	2676	26171	512	6762			34.36		345.58
(Out/In)100, %	Forced				Forced	Forced	Forced	Forced	Forced	Forced			Forced		

TABLE 12

RATIONALIZED PROCESS DESIGN HEAT AND MATERIAL BALANCE - OHIO NO. 9 COAL WITH BLAST FURNACE SLAG FLUX

Basis: 1 hour Datum: $60^{o}F$ & H_2O (1)

					Elemental Balance, Pounds						Temp.,	ΔH		Higher Heating Value	
Input	Pounds	Lb-moles	Mol %	SCF	H	C	N	O	S	Ash	°F	Btu/lb	MM Btu	Btu/lb	MM Btu
MAF Coal	18945	-	-	-	1043	15175	215	1493	1019	-	60	-	-	14671	277.95
Coal Moisture	1699	-	-	-	190	-	-	1509	-	-	60	-	-	-	-
Coal Ash & Flux	9557	-	-	-	-	-	-	-	-	9557	60	-	-	-	-
Subtotal	30201	-	-	-	1233	15175	215	3002	1019	9557					277.95
Steam	7700	427.38	-	162148	862	-	-	6838	-		700	1330.9	10.25	-	-
Oxygen & Air	12486	398.18	-	151069	-	-	1801	10685	-		200/60	25.8	0.32	-	-
Fuel Gas	98	5.52	-	2094	23	70	4	1	-		60	-	-	22600	2.21
Heat of Reaction		(HHV in - HHV out)											19.13		-
TOTAL INPUT	50485				2118	15245	2020	20526	1019	9557			29.70		280.16
Output															
Dry Gas															
H_2	962	477.38	28.04	-	962	-	-	-	-	-	770	2458.8	2.36	61183	58.84
CO	25233	900.82	52.94	-	-	10820	-	14413	-	-	770	180.9	4.56	4354	109.86
CO_2	3899	88.61	5.21	-	-	1064	-	2835	-	-	770	168.9	0.66	-	-
CH_4	1949	121.44	7.14	-	490	1459	-	-	-	-	770	485.4	0.95	23885	46.53
C_2H_6	286	9.52	0.56	-	57	229	-	-	-	-	770	428.1	0.12	22323	6.39
C_2H_4	76	2.72	0.16	-	11	65	-	-	-	-	770	371.5	0.03	21640	1.64
N_2	1941	69.30	4.07	-	-	-	1941	-	-	-	770	179.6	0.35	-	-
NH_3	76	4.48	0.26	-	13	-	63	-	-	-	770	414.1	0.03	9671	0.73
HCN	1	0.04	Trace	-	Trace	Trace	1	-	-	-	770	259.0	0.00	10620	0.01
H_2S	857	25.15	1.48	-	51	-	-	-	806	-	770	183.0	0.16	7093	6.08
COS	139	2.32	0.14	-	-	28	-	37	74	-	770	103.8	0.01	3920	0.55
CS_2	1	0.02	Trace	-	-	-	-	-	1	-	770	114.9	0.00	5996	0.01
C_4H_4S	1	0.01	Trace		Trace	1	-	-	Trace	-	770	-	0.00	13120	0.01
Subtotal	35421	1701.46	100.00	645534	1584	13666	2005	17285	881	-			9.23		230.65
Gas Liquor	3584	198.91	-	-	401	-	-		-	-	770	1389.3	4.98	-	-
Tar & Oil	1302	-	-	-	96	1117	13	3183	18	-	770	505	0.66	16700	21.74
Naphtha	386	-	-	-	36	345	1	58	4	-	770	516	0.20	18000	6.95
Dust	65	-	-	-	1	32	1	-	1	30	770		0.01	7130	0.46
Slag	9727	-	-	-	-	85	-	-	115	9527	2950	809.2	7.87	127	1.23
Heat Loss													6.75		
TOTAL OUTPUT	50485				2118	15245	2020	20526	1019	9557			29.70		261.03
(Out/In) 100, %	Forced				Forced	Forced	Forced	Forced	Forced	Forced			Forced		

7.0 STATUS OF DEVELOPMENT

Operation of the British Gas/Lurgi gasifier during the Westfield program has demonstrated the technical feasibility of the process using high sulfur eastern bituminous caking coals as feedstock. Experience has been gained feeding Ohio No. 9 coal and Pittsburgh No. 8 coals. The results of the 15 pilot plant runs made under the Westfield Technical Support Program confirmed the advantages claimed for the slagging gasifier. Satisfactory solutions to process problems that occurred in the program were found. It is reasonable to conclude that the Demonstration Plant can be designed and constructed with a high degree of confidence that extended operation can be achieved.

7.1 Feedstocks

The major variable studied in the program was the impact of the feed coal properties upon gasifier operations. The feedstocks used during the program included non-caking or lightly-caking feedstocks (Frances coal and blast furance coke) and highly-caking eastern U.S. coals (Pittsburgh No. 8 coal and Ohio No. 9 coal). Typical analyses of these feedstocks are shown in Table 13. In addition, the size consist of the feedstock was varied in several runs.

Non-Caking Feedstocks (Frances Coal and Blast Furnace Coke)

The experience with non-caking feedstocks during the Westfield program is important because the use of such fuels is necessary in a demonstration plant or commercial plant as a start-up feed. Both non-caking feedstocks used during the program (Scottish Frances coal and blast furnace metallurgical coke) were shown to be satisfactory for this purpose. The blast furnace coke size consist was dissimilar to that of the caking coal feed, and for this reason the transition period between feedstocks was less smooth than with Frances coal. Both non-caking feedstocks were also effective as a corrective purge to eliminate symptoms of massive caking.

TABLE 13

Typical Analyses of Feedstock Used in the Westfield Program

Coal	Frances Coal	Blast Furnace Coke	Ohio 9 Coal	Pittsburgh 8 Coal
Proximate Analysis, Wt %				
Moisture	7.6	6.3	5.4	3.2
Ash	5.2	9.6	21.3	7.5
Volatile Matter	32.5	2.2	32.5	35.1
Fixed Carbon	54.7	81.9	40.8	54.2
Ultimate Analysis (Dry Basis), Wt %				
Hydrogen	4.7	0.9	4.2	5.0
Carbon	78.0	86.6	61.9	76.3
Nitrogen	1.4	1.1	0.9	1.4
Oxygen (diff)	9.7	0.0	6.1	7.9
Sulfur	0.6	1.2	4.4	1.6
Ash	5.6	10.2	22.5	7.8
Free Swelling Index	<1	0	3-5	8
Ash Elemental Analysis, Wt%				
Na_2O	0.4	1.1	0.25	0.44
K_2O	0.3	2.2	2.20	1.70
CaO	14.2	4.3	1.82	1.99
MgO	7.0	2.5	1.35	0.66
Fe_2O_3	13.2	14.9	18.4	19.1
TiO_2	0.7	0.8	1.02	1.06
P_2O_5	ND	ND	0.25	0.29
SiO_2	29.7	47.2	50.0	47.9
Al_2O_3	23.8	25.9	21.9	24.5
SO_3	8.5	ND	2.42	1.76

Note: ND means not determined.

Eastern U.S. Caking Coals

An essential purpose of the Westfield program was to demonstrate the operability of the slagging gasifier on high sulfur eastern U.S. caking coals. Much of the program through June of 1978 was devoted to identifying and solving problems related to the caking properties of these coals. Two coals were selected for testing in the Technical Support Program -- raw Ohio No. 9, a moderate to highly-caking coal having a high ash content and high iron content, and washed Pittsburgh No. 8 coal, a very strongly-caking coal with moderate ash and iron contents. Neither coal was pretreated to alter its caking properties.

Beginning with TSP Run 13 starting on June 19, 1978, a series of three successful runs has demonstrated the ability to feed these coals reliably, has provided the heat and material balance data necessary to design the Demonstration Plant, and has supplied information required to further improve operability of the Demonstration Plant. In addition, the final run of the program showed that Pittsburgh No. 8 coal containing an average of 23 percent of 1/4" x 0 coal fines can be fed to the gasifier without fouling the downstream equipment. Although optimum solutions to all the problems have not been found, the gasifier in its present form has operated 224 hours on highly caking eastern U.S. coals in three consecutive runs without a forced shutdown. In each case, the hours of operation were equal to or in excess of programmed duration.

In two of the final three runs, Pittsburgh No. 8 coal was the feedstock. A total of 194 hours of operation have been achieved using this feedstock without requiring a shutdown or standby. A throughput of 870 pounds per hour of MAF coal per square foot of gasifier cross-section exceeds the proposed design rate for the Demonstration Plant. This is despite the fact that the Westfield gasifier operates at 365 psia versus 450 psia for the Demonstration Plant as explained in Section 2.1. Control of slag removal was excellent and slag tapping rates were high in all runs. No problems were encountered with malfunctioning tuyeres, high hearth heat losses, or slag quench chamber deposits while feeding Pittsburgh No. 8 coal.

The only problem experienced while feeding Pittsburgh No. 8 coal was a tendency for the stirrer-distributor torque to overload. It is important to note that these torque overloads were not a threat to continued gasifier operation. Lurgi believes that this tendency can be eliminated by refining the design of the top of the gasifier.

Experience at Westfield with Pittsburgh No. 8 coal demonstrated the following:

- Operation for 194 hours without serious incident and with voluntary shutdowns.
- Throughputs comparable to those achieved on Scottish weakly caking coals and in excess of that proposed for the demonstration plant design (at 85 psi lower pressure).

- Acceptable operation with a feedstock containing as much as 23 percent material finer than 1/4-inch.

Ohio No. 9 coal was fed to the gasifier in nine of the 15 runs in the Westfield program. All but two of these runs were prior to March, 1978, when the solution to plant and process problems began to result in improved gasifier performance. TSP Run 14 made in June, 1978, reflects the results of the problem solving period. During this run, 31 hours of feeding untreated Ohio No. 9 coal were culminated by a planned, orderly shutdown. Examination of the bed after shutdown showed no evidence of massive caking below the stirrer blades as had been observed in the earlier runs. Also, of great significance was the absence of major deposits in the slag quench chamber. This problem had been the cause of several shutdowns early in the program.

The gasifier was operated at a throughput of 675 pounds per hour of MAF coal per square foot of gasifier cross-section during TSP Run 14. The steam/oxygen ratio was lower than that used during the Pittsburgh No. 8 coal runs because of the higher ash content of the Ohio No. 9 coal. The bed behavior during TSP Run 14 was as smooth as that observed during the Pittsburgh No. 8 coal runs at similar load. As expected with the high ash level in the coal, the offtake temperature level was lower than with Pittsburgh No. 8 coal.

The carbon dioxide content of the synthesis gas was higher in TSP Run 14 than in the Pittsburgh No. 8 coal runs. This may reflect a slightly lower steam conversion. The throughput of MAF coal per unit oxygen was higher with the Ohio No. 9 coal than with Pittsburgh No. 8 coal.

In summary, TSP Run 14 demonstrated that Ohio No. 9 coal can be fed to the Westfield gasifier without encountering bed problems related to the caking properties of the coal or slag quench chamber deposits. The run stresses the role of adequate fluxing in maintaining trouble-free operation at the bottom of the gasifier. Further improvements in the operability and performance of Ohio No. 9 coal can be expected by improving the design of the gasifier and by washing the coal prior to feeding.

An Illinois coal was not fed to the pilot plant gasifier during the Westfield program. A short run on Illinois No. 5 coal was completed during an earlier privately-funded program. Illinois No. 5 coal fluxed with blast furnace slag was fed to the gasifier for 9.5 hours without evidence of impending inoperability. Inspection of the bed after shutdown revealed that no monolith of coke had formed.

The properties of the Illinois No. 5 and No. 6 coals with respect to caking properties, ash level, ash composition, and volatile matter content fall within the range of the coals which were successfully processed during the Westfield Technical Support Program. It is concluded that these coals would be completely acceptable as feedstock for a slagging gasifier demonstration plant.

7.2 Adequacy of Data Base

The results of the Westfield program have confirmed the advantages of the slagging gasifier in processing low reactivity eastern U.S. bituminous coals. Table 14 lists the operating results from slagging gasifier runs using Frances coal, Ohio No. 9 coal, and Pittsburgh No. 8 coal. The results from operation of a Lurgi dry bottom gasifier during the Westfield A.G.A. trials (1) are included for comparison. These results clearly demonstrate the following advantages of the slagging gasifier as compared to the Lurgi dry bottom gasifier for low reactivity coals such as eastern bituminous coals:

- The slagging gasifier offers a dramatic increase in throughput per unit cross section.
- The amount of steam required per unit of MAF coal in gasification is an order of magnitude less. As much as half of this advantage may be lost, however, because some steam is required downstream in the Shift Conversion Unit to produce the desired H_2/CO ratio for methanation.
- The amount of oxygen required per unit of MAF coal is significantly lower.
- In the slagging gasifier, the steam and oxygen requirements and level of throughput are essentially the same regardless of the properties of the coal feedstock. The results with Pittsburgh No. 8 coal, a low reactivity, highly-caking eastern U.S. coal, are equivalent to those produced with Frances coal, a higher reactivity, mildly-caking coal. As shown in the table, the results from operation on Ohio No. 9 coal are similar, although at a slightly lower demonstrated throughput per unit cross-sectional area.

It should be noted that the A.G.A. trials did not attempt to maximize coal throughput nor optimize steam and oxygen requirements, but nevertheless the advantages of the slagging gasifier are clearly apparent.

The data necessary to calculate heat and material balances were obtained during 12 of the 15 runs. At least one set of data for heat and material balances for each of the feedstocks used during the program was obtained. These balances confirm the balances prepared by Lurgi for the commercial and demonstration plant designs.

Of particular interest to Lurgi were data on the concentrations of minor components in the gas stream, such as COS, which could have an impact on the downstream design. Throughout the program, data as required by Lurgi have been obtained, and all outstanding requests have been fulfilled.

TABLE 14

SUMMARY OF WESTFIELD OPERATING RESULTS

Gasifier Type	Dry Bottom	Slagging Gasifier		
Coal	Phg. No. 8 (1)	Pgh. No. 8	Frances (2)	Ohio 9 Coal
Operating Conditions				
Pressure, psig	364	350	350	350
Rates, Ton/Ton MAF Coal				
Oxygen	0.70	0.562	0.564	0.564
Steam	3.54	0.423	0.406	0.407
Coal Rate, Lb (MAF)/Hr/Sq Ft	145	870	852	670
Yeilds, Per Ton MAF Coal				
Tar + Oils, Lb	92	126	119	137
Net Gas Liquor, Lb (3)	5,610	191	200	199
Raw Gas, MSCF	84.7	71.1	70.3	68.1
SNG Equivalent, MSCF (4)	21.6	21.8	21.6	20.6
Raw Gas Composition, mol %				
CO_2	30.7	3.86	2.28	5.21
CO	17.8	54.73	57.20	52.94
CH_4	8.4	7.11	6.70	7.14
C_2H_6	0.7	0.05	0.45	0.56
C_2H_4	0.3	0.18	0.16	0.16
H_2	38.6	28.71	28.53	28.04
H_2S	0.7	0.56	0.11	1.48
N_2 + Ar	2.4	3.98	4.22	4.48
COS	-	0.06	-	0.14
NH_3	0,4	0.31	0.35	0.26
Gas Gross HV, Btu/SCF	286	358	357	357
Gas Offtake Temp	1230	958	900	770
Run Duration, Hrs.	48	88	524	31
Post-Run Inspection	-	Good	Good	Good

(1) AGA trials
(2) Privately-funded program.
(3) Liquor less coal moisture.
(4) SNG = 94% CH_4, 3% H_2, 1% CO_2, 2% N_2; assumes no losses in downstream gas processing units; and N_2 + Ar content is adjusted for 95% oxygen feed purity.

A major effort during the Westfield program was made to ensure that data necessary to determine the environmental impact of the slagging gasifier effluent streams were obtained. To accomplish this, samples of all major effluent streams were obtained. These samples are as follows:

a. Slag frit;

b. Tar (dusty recycle tar and clean product tar);

c. Oil;

d. Gas liquor (from the tar separator and from the oil separator);

e. Naphtha;

f. Product gas; and

g. Slag quench water.

In addition, samples of the inputs to the gasifier, coal feedstocks, flux and slag quench water make-up were obtained routinely. Five organizations are participating in evaluation of these samples. These organizations are listed below:

1. British Gas Corporation-Westfield Development Centre

2. Conoco Coal Development Company, Library, Pennsylvania

3. Oak Ridge National Laboratory

4. British Gas Corporation-London Research Station

5. Lurgi Kohle und Mineraloeltechnik

Some data relative to the environmental aspects of the slagging gasifier were produced in every run. A major effort is underway to thoroughly analyze samples obtained from TSP Runs 13 and 15, both made using Pittsburgh No. 8 coal as feedstock.

All of the samples listed above are analyzed by British Gas Corporation at Westfield. For selected runs, including TSP Runs 13 and 15, a thorough characterization of the input and effluent samples will be accomplished.

Drum sized samples of all the listed samples except the product gas and naphtha have been shipped to Conoco Coal Development Company at Library, Pennsylvania. The use of these samples will be three-fold:

a. To duplicate and reconfirm the data produced at Westfield.

b. To do additional work where necessary to fill any data gaps -- long-term leaching studies are an example of this; and

c. To provide samples where necessary to organizations interested in purchase of plant by-products.

A large batch (35 drums) of slag frit from TSP Run 15 has been obtained and will be shipped to Oak Ridge National Laboratories. An independent set of slag leaching studies will be conducted there.

Samples of phenolic waste water produced from the slagging gasifier during TSP Run 15 were collected by British Gas Corporation's London Research Station personnel for a waste treatment study. This study is part of a program funded by the International Energy Agency, and the results obtained will be available to the slagging gasifier project.

It must be noted that with the exception of the slag frit and the slag quench system effluents, the environmental problems occurring with the slagging gasifier are essentially identical to those which exist with the standard Lurgi dry-bottom gasifier. The analytical results from the Westfield program and from the outside parties, combined with Lurgi's expertise in this field, should provide a comprehensive view of the environmental aspects of the Demonstration Plant.

The results of the Westfield program have provided confidence that the technology is available to design and construct a gasification plant which will be operable on a wide range of eastern U.S. coals. However, more must be learned before the optimum design parameters can be established for a commercial facility. This will be the function of the Demonstration Plant program.

8.0 BIBLIOGRAPHY

1. Woodall-Duckham, Ltd., Report on the Trials of American Coals in a Lurgi Gasifier at Westfield, Scotland for the American Gas Association and Office of Coal Research, Department of the Interior, United States Government, June, 1974, Crawley, Sussex, U.K. (June 1974).

2. Hebden, D., Edge R. F., and Foley, K. W., "Investigations with a Small Pressure Gasifier," Research Communication GC14, The Gas Council of Great Britain, London, U.K. (November 1954).

3. Hebden, D., Lacey, J. A., and Horsler, A. G., "Further Experiments with a Slagging Pressure Gasifier," Research Communication GC112, The Gas Councial of Great Britian, London, U.K. (November 1964)

4. Lacey, J.A., "Gasification of Coal in a Slagging Pressure Gasifier," Fuel Gasification, R. F. Gould, ed., pp 31-49, Advances in Chemistry Series 69, ACS, Washington, D.C. (1967)

5. Sudbury, J. D., Bowden, J. R., and Watson, W. B., "A Demonstration of the Slagging Gasifier, " Proceedings of Eighth Synthetic Pipeline Gas Symposium, Chicago, Illinois (October 18-20, 1976).

6. Ricketts, T. S., "High-Pressure Coal Gasification Plants in Scotland and Abroad," J. Inst, Fuel, 34, 177-188 (May 1961).

7. Ricketts, T. S., Publication No. 567, The Institute of Gas Engineers, London (1960).

8. Sobbett, J. M., and Goodman, M. C., "Pressure Gasification of Coal: The Design of a Town Gas Plant," The Chemical Engineer, No. 164, A55-A64 (December 1962).

9. Lowry, H. H. (Editor), Chemistry of Coal Utilization: Supplementary Volume, John Wiley & Sons: New York (1963).

10. Bowden, J. R., and Sudbury, J. D., "The British Gas/Lurgi Slagging Gasifier For Production of Pipeline Quality Gas," Paper presented at The American Institute of Chemical Engineers, New York, New York (November 15, 1977).

11. Sudbury, J. D., Curran, G. P., and Phinney, J. A., "Gasification of Caking Coals in the BGC/Lurgi Slagging Gasifier," Paper presented at the Fifth International Conference on Coal Gasification, Liquefaction, and Conversion To Electricity, Pittsburgh Pennsylvania (August 2, 1978).

APPENDIX A

PILOT PLANT RUN DIARY AND RAW DATA

A total of 15 pilot plant runs was completed at Westfield Development Centre under the original Westfield and the Westfield II Agreements between Continental Oil Company and British Gas Corporation. These runs are identified in this Appendix and the body of this report in a numerical sequence beginning with TSP Run 1 and ending with TSP Run 15. In previous correspondence, technical progress reports, interim run reports, Program Committee minutes, and the Westfield II Agreement some runs were given a different designation. The previous run designations compared with the run identities used in this Appendix and the body of this report are shown below:

Task IX Report, Run Identity	Previous Run Designation
TSP Run 1	Run 1
TSP Run 2	Run 2
TSP Run 3	Run 3
TSP Run 4	Run 4
TSP Run 5	Run 5
TSP Run 6	Run 6
TSP Run 7	Run 7
TSP Run 8	Run 8
TSP Run 9	Run 9-A
TSP Run 10	Run 9-B
TSP Run 11	Run 9-C
TSP Run 12	Run A
TSP Run 13	Run B-1
TSP Run 14	Run B-2
TSP Run 15	Run C

This Appendix gives a run diary (date, time, and event) and reports the raw data and heat and material balances for each of the pilot plant runs. This information was extracted from the reports submitted by British Gas Corporation for each pilot plant run, and no evaluation of the data or the heat and material balances to exclude erroneous results, if any, has been made. Most, if not all, the data are believed to be within the accuracy of the analytical procedures. The analytical procedures are summarized in Appendix C. The term "ND" in the analyses means "not determined."

TSP Run 1

Feed Coal: Scottish Frances Coal
Date of Run: August 17-21, 1977

1. Run Diary

Date	Time	Event
Aug 17	0740	Began start up procedure.
	0845	14,000 SCFH of air introduced to the gasifier through the tuyeres.
	1107	Air feed stopped, and steam/oxygen introduced into the gasifier through the tuyeres.
	1405	Gasifier settled down with oxygen loading of 160,000 SCFH; steam/oxygen ratio equal to 1.35; and pressure equal to 350 psig.
	1445	Standby period caused by loss of hydraulic pressure at coal lock. No adverse effect upon gasifier performance.
	1525	Gasifier back on line with full conditions restored.
Aug 18	1025	A brief standby period caused by a problem at the coal lock.
	1120	Gasifier returned to planned conditions with no problems.
Aug 19	1106	Fluxing established to the gasifier. Ash content of Frances coal increased from 5% to approximately 20% by addition of blast furnace slag.
	1935	Fluxing discontinued.
	2235	Oxygen loading reduced to 150,000 SCFH.
Aug 20	0330	Oxygen loading reduced to 140,000 SCFH.
	0820	Oxygen loading reduced to 135,000 SCFH.
	1126	Oxygen loading reduced to 130,000 SCFH.
	1425	Oxygen loading reduced to 122,000 SCFH.
	2035	Oxygen loading raised to 130,000 SCFH.
Aug 21	0259	Fluxing re-established to approximate 15% ash content.
	0525	Steam/oxygen ratio trimmed to 1.15 with oxygen loading raised to 140,000 SCFH.
	0825	Oxygen loading reduced to 130,000 SCFH.
	1200	Began standard shutdown procedure.

2. Raw Data

a. Frances Coal

Proximate Analysis (Air Dried), Wt. % Date	Time	Moisture	Ash	Volatile Matter	Fixed Carbon
Aug 17-18	1300-1200	5.59	5.19	33.43	55.79
Aug 18-19	1300-1200	5.68	5.55	33.00	55.77
Aug 19-20	1100-1000	5.72	6.05	32.74	55.49
Aug 20-21	1100-1200	6.44	6.25	32.85	54.46
Aug 17-19	Comp. A	4.35	5.56	35.46	54.63
Aug 19-21	Comp. B	4.50	5.94	35.03	54.53

Ultimate Analysis (Air Dried), Wt. %	Composite A	Composite B
Carbon	72.5	71.2
Hydrogen	5.1	5.0
Nitrogen	1.4	1.3
Sulfur	0.51	0.51
Chlorine	0.34	0.34

Heating Value (Air Dried), Btu/lb. 12,565

Size Analysis, Wt. %	Aug 17	Aug 18	Aug 19	Aug 20	Aug 21
over 3/4"	23	32	26	29	22
1/2"-3/4"	28	44	44	50	41
3/8"-1/2"	26	14	16	12	20
1/8"-3/8"	12	8	10	6	11
under 1/8"	11	2	4	3	6
Bulk Density, Lbs/CF	49.5	48.0	48.0	48.0	ND

Moisture Content, Wt. % Date	Time	Moisture
Aug 17	1400	7.5
Aug 18	0330	8.0
Aug 19	0800	7.5
Aug 19	0245	8.0
Aug 19	0915	8.5
Aug 20	0315	9.0
Aug 21	0300	9.0

b. Flux - Blast Furnace Slag

Component, Wt. %	Composite
SiO_2	35.47
Al_2O_3	13.40
CaO	34.20
MgO	12.08
Fe_2O_3	1.42
Carbon	0.06
	96.63

b. Flux continued

Component, Wt. %	Composite
Free Iron as Fe	0.14
FeO	0.54
Total Iron as Fe	0.99
Fe^{+2}	0.42
Fe^{+3}	0.43

Silica Number	42.6
Loss on Ignition, Wt. %	+0.1 (gain)

Size Analysis, Wt. %	Aug 19	Aug 21
over 1/2"	65.5	11.0
3/8"-1/2"	29.5	78.0
1/8"-3/8"	3.5	10.5
under 1/8"	1.5	0.5

Moisture Content, Wt. %	Aug 19	Aug 21
	1.5	2.5

c. Slag

Date:	Aug 18	Aug 19	Aug 19	Aug 20	Aug 20	Aug 21
Time:	2130	1545	1545	1115	2115	Comp.
Component, Wt. %						
SiO_2	32.49	37.06	32.9	31.81	32.99	32.47
Al_2O_3	20.78	14.77	16.6	24.56	22.50	17.28
CaO	16.02	30.46	30.8	15.62	14.40	29.66
MgO	7.25	11.60	10.5	7.73	7.41	12.25
Fe_2O_3	20.73	4.69	7.1	10.18	14.47	6.48
Carbon	0.05	0.06	0.5	0.06	-	-
	97.32	98.64	98.4	89.96	91.77	98.14
Free Iron as Fe	8.82	1.95	1.7	3.46	5.55	1.28
FeO	7.18	3.09	2.96	5.60	4.67	2.29
Total Iron as Fe	14.51	3.28	5.0	7.13	10.13	4.54
Fe^{+2}	5.58	2.4	2.3	4.36	3.63	1.7
Fe^{+3}	0.11	-	1.0	-	0.95	1.4
Silica No.	43	44	40	49	48	40
Loss on Ignition, %*	+1.03	+0.65	+0.1	-1.04	-1.0	-0.2

* +is a gain.

d. Oxygen Purity

Date	Time	O_2 Vol. %
Aug 17	0740	94.5
	1120	95.5
	1720	96.8
	2130	95.55
Aug 18	0230	94.2
	0715	95.6
	1200	95.4
	1510	94.1
	1900	93.6
	2300	93.0
Aug 19	0300	94.2
	0715	94.8
	1130	93.9
	1930	97.55
	2330	94.2
Aug 20	0300	96.0
	0750	94.8
	1100	96.0
	1530	94.8
	1845	96.0
	2315	96.8
Aug 21	0300	96.6
	0910	94.9

e. Recycle Tar (No recycle until Aug 19)

Ultimate Analysis (Dry, Dust Free)	Wt. %
Carbon	86.30
Hydrogen	7.00
Nitrogen	1.10
Sulfur	0.34
Chlorine	0.22
Oxygen	5.04
	100.00

Heating Value, Btu/lb. 16,310

Moisture Content	Wt. %
Aug 19	4.5
Aug 20	3.5
Aug 21	9.5

e. Recycle Tar continued

Dust Content

Date	Time	Wt. %
Aug 16	1240	12
	1610	32
Aug 17	0340	27
	0800	50
Aug 19	0915	30
	1300	30
Aug 20	0630	8
Aug 21	0500	39

Dust Proximate Analysis (Air Dried)	Wt. %
Moisture	1.0
Ash	13.3
Volatile Matter	6.4
Fixed Carbon	79.3
	100.0

Dust Ultimate Analysis (Air Dried)	Wt. %
Carbon	80.8
Hydrogen	1.7
Nitrogen	1.1
Sulfur	1.1
Chlorine	0.2
Oxygen	0.8
Ash	13.3
Water	1.0

Dust Heating Value, Btu/lb. 12,655

f. **Crude Synthesis Gas (Main Stream Samples)**

Analysis (Dry Basis), Vol. %

Date:	Aug 17			Aug 18					Aug 19			Aug 20				Aug 21	
Time:	1120	1620	2300	0400	0715	1405	1615-2100	2245	0400	0900	2300	0330	0910	Composite	2130	0300	0730
CH_4	5.79	6.76	6.13	6.91	7.69	6.00	6.76	6.99	6.97	6.23	6.50	6.14	6.18	6.39	6.30	6.60	6.36
CO_2	1.71	2.84	2.08	2.72	2.77	3.45	2.71	3.18	2.29	2.80	2.30	2.60	3.11	2.51	1.50	2.30	1.42
C_2H_4	0.04	0.07	0.12	0.07	0.14	0.09	0.07	0.03	0.13	0.14	0.07	0.19	0.19	0.07	0.33	0.12	0.14
C_2H_6	0.15	0.44	0.52	0.29	0.55	0.43	0.41	0.30	0.43	0.32	0.35	0.36	0.35	0.19	0.47	0.42	0.40
H_2S	0.04	0.02	0.02	0.02	0.02	0.10	0.10	0.02	0.14	0.12	0.13	0.14	0.11	0.14	0.10	0.15	0.13
H_2	30.84	29.73	29.42	28.02	28.67	30.70	28.53	28.87	30.99	27.83	28.30	29.00	30.36	28.85	28.30	29.60	27.86
O_2	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0.20	Nil	Nil	Nil	Nil
Ar	1.05	0.80	0.83	0.82	0.80	0.80	1.21	0.82	0.80	0.84	0.88	0.83	0.51	0.31	0.54	0.53	0.58
N_2	3.73	2.90	2.91	3.50	3.00	2.98	3.38	3.30	2.10	2.72	2.10	2.17	2.89	3.39	3.30	3.20	2.64
CO	52.38	56.75	56.90	55.79	55.32	54.27	56.55	56.49	58.90	57.14	57.40	58.50	55.72	58.15	58.20	56.50	58.86
	95.73	100.31	98.93	98.14	98.96	98.82	99.72	100.00	102.75	98.14	98.03	99.93	99.62	100.00	99.04	99.42	98.39

f. Crude Synthesis Gas continued

Minor Constituents

Date	Time	NH_3 g/m^3	HCN g/m^3	Condensate mls/m^3
Aug 17	1500-1800	0.07	0.092	12.18
Aug 18	0900-1200	0.035	0.046	11.21
Aug 19	0925-1210	0.194	0.039	12.81
Aug 20	0100-0400	0.017	0.004	11.30

Total Organic Sulfur Date	Time	g/m^3
Aug 19	0400	0.21
Aug 21	0515	0.24

g. Coal Lock Hopper Gas

Analysis, Vol. %

Date:	Aug 17	Aug 18	Aug 19	Aug 19	Aug 21
Time:	1330	0725	0910	2300	0300
CH_4	3.31	3.85	3.58	4.00	3.70
CO_2	1.29	1.13	1.13	1.10	0.62
C_2H_4	0.13	0.04	0.05	0.16	0.08
C_2H_6	0.20	0.31	0.12	0.22	0.14
H_2S	0.02	0.02	0.03	0.10	0.03
H_2	17.62	16.0	17.00	17.50	17.20
Ar	1.03	1.02	1.01	1.06	0.65
N_2	44.83	42.40	36.88	38.60	36.80
CO	32.16	34.06	33.44	35.10	35.00
	100.59	98.83	93.24	97.84	94.22

h. Flash Gas From Tar Separator

Analysis, Vol. %

Date:	Aug 18	Aug 19	Aug 19	Aug 21
Time:	0100	0100	2300	0300
CH_4	5.98	6.10	8.30	7.30
CO_2	19.00	2.15	3.40	1.40
C_2H_4	0.42	0.14	0.42	0.42
C_2H_6	0.29	0.39	0.88	0.76
H_2S	0.02	0.02	0.04	0.05
H_2	23.91	30.21	29.60	28.43
Ar	0.82	1.11	0.96	0.73
N_2	2.78	4.20	2.70	9.40
CO	39.44	58.90	52.20	50.30
	92.66	103.22	98.50	98.79

i. Side Stream Samples

Sample	S/S 1	S/S 2
Date	Aug 18	Aug 19
Time Period	1500-2100	1145-1700
Gas Volume, SCF	1,284	1,149
Tar Product, grams	) 973	198
Oil Product, grams	)	842
Gas Liquor Product, grams	3,675	3,750
Dust, grams	46	33
Dust in Tar, Wt. %	2.8	8.0
Water in Tar, Wt. %	37.0	35.0
Dust in Oil, Wt. %	ND	0.3
Water in Oil, Wt. %	ND	Nil

j. Crude Synthesis Gas Composition (Side Stream Sample)

Analysis, Vol. %	S/S 2
CH_4	6.75
CO_2	2.71
C_2H_4	0.09
C_2H_6	0.29
H_2S	0.10
H_2	28.42
Ar	1.11
N_2	2.77
CO	55.71
	97.95

Minor Constituents, g/m^3	S/S 1	S/S 2
NH_3	ND	0.042
HCN	0.039	0.014
Naphtha	5.01	4.47

k. Combined Tar and Oil (Side Stream Samples)

Ultimate Analysis, Wt. %	S/S 1	S/S 2
Nitrogen	1.0	1.1
Carbon	86.7	86.9
Hydrogen	7.8	7.8
Ash	Nil	0.01
Water	Nil	Nil
Sulphur	0.34	0.24
Chlorine	0.22	0.16
Oxygen (Diff.)	3.94	3.79
	100.00	100.00
Heating Value, Btu/lb.	16,255	16,360

l. Gas Liquor Analysis (Side Stream Samples)

mg/l	S/S 1	S/S 2
Total Dissolved Solids	14,020	16,417
Total Sulfur	16,508	11,081
Total Ammonia	19,371	14,752
Free Ammonia	16,410	12,226
Fixed Ammonia	2,960	2,526
Carbonate as CO_2	15,332	15,310
Chloride as Cl	12,385	7,954
pH	9.18	9.0
Specific Gravity	1.027	1.017

m. St. Clair de Ville Condensate

Ultimate Analysis, Wt. %	Main Stream Sample	S/S 2 Sample
Carbon	90.6	88.8
Hydrogen	9.6	9.2
Nitrogen	0.1	0.1
Sulfur	ND	ND
Chlorine	ND	ND

3. Heat and Material Balance - Unfluxed Frances Coal

Material Balance, Pounds per Hour									Heat Balance
Input	Rate	Carbon	Hydrogen	Nitrogen	Sulfur	Oxygen	Chlorine	Ash	Therms/Hr.
Coal	28269	19916	1622	384	141	4566	94	1546	3558
Steam	9890		1107			8783			135
Fuel Gas	98	70	23	4		1			22
Recycle									
Tar	0								0
Oxygen	12667					12667			) -1
Air	2742			2177		565			)
	53666	19986	2752	2565	141	26582	94	1546	3714
Output									
Heat Loss									64
Methane	2472	1851	621						606
Carbon Monoxide	36125	15489				20636			1651
Hydrogen	1312		1312						840
Carbon Dioxide	2719	742				1977			6
Inert Gas	2930			2930					7
Ethylene	45	38	7						10
Ethane	281	224	57						64
Ammonia	93		17	76					1
Hydrogen Sulfide	78		5		73				6
Carbonyl Sulfide	20	4			11	5			
Tar	1437	1249	112	14	5	57			250
Naphtha	483	422	45	2		14			105
Phenols	110	84	7			19			16
Fatty Acids	167	105	15			47			23
Liquor	5083	17	546	2	8	4375	135		72
Slag	1544	1						1543	11
	54899	20226	2744	3024	97	27130	135	1543	3732
Input-Output Error, %	+2.3	+1.2	-0.3	+17.9	-31.2	+2.1	+43.6	-0.2	+0.5

4. Data Used in Balances - Unfluxed Frances Coal

Coal Heating Value, Btu/lb.	12,586

Coal Proximate Analysis	Wt. %
Moisture	6.98
Ash	5.47
Volatile Matter	32.55
Fixed Carbon	55.00
	100.00

DAF Coal Ultimate Analysis	Wt. %
Carbon	80.47
Hydrogen	5.66
Nitrogen	1.55
Oxygen	11.37
Sulfur	0.57
Chlorine	0.38
	100.00

Moisture of Decomposition	107 lb/ton DAF Coal
DAF Coal Consumption	24,760 lb/hour

Gas Composition	Vol. %
Methane	6.76
Carbon Monoxide	56.58
Hydrogen	28.54
Carbon Dioxide	2.71
Inert Gas	4.59
Ethylene	0.07
Ethane	0.41
Hydrogen Sulfide	0.10
Ammonia	0.24
	100.00

Crude Gas Offtake Temperature	516°C
Gasifier Pressure	350 psig
Heat Loss from Jacket & Hearth	23.35 therms/hour*
Jacket Steam Production	3000 lb/hour*

*Estimated

Byproducts

Composition Wt. %	Naphtha	Tar	Phenols	Fatty Acid	Minor Liquor Comp.
Carbon	87.24	86.70	76.57	63.13	8.36
Hydrogen	9.36	7.80	6.43	8.84	-
Nitrogen	0.50	1.00	-	-	0.92
Sulfur	-	0.34	-	-	3.83
Chlorine	-	-	-	-	66.70
Oxygen	2.90	3.94	17.00	28.03	20.19
Ash	-	0.22	-	-	-
	100.00	100.00	100.00	100.00	100.00

Heating Value	Btu/lb.
Naphtha	20,942
Tar	16,255
Phenols	14,024
Fatty Acid	12,895
Minor Liquor Components	0

5. Performance Data - Unfluxed Frances Coal

Crude Gas Flow *	20,710,000 SCFD	
Steam Consumption	3.26 lb/therm gas	
Steam Decomposition	84.01%	
Oxygen Consumption	51.62 SCF/therm gas 12,646 SCF/ton DAF coal	
Crude Gas Production*	241.8 therms/ton DAF coal 3,031 therms/hour	
DAF Coal Consumption	24,760 lb/hour	
Gas Liquor Yield	1.61 lb/therm gas	
Thermal Efficiencies, %	Gas Only	Gas, Tar, Oil & Naptha
Crude Gas / Coal	85.21	94.84
Crude Gas / Coal, Steam & Oxygen	74.61	83.03

*Includes coal lock gas.

6. Heat and Material Balance - Fluxed Frances Coal

Material Balance, Pounds per Hour

Input	Rate	Carbon	Hydrogen	Nitrogen	Sulfur	Oxygen	Chlorine	Ash	Heat Balance Therms/Hr.
Coal/Flux	32284	19262	1605	351	146	5033	92	5795	3483
Steam	9848		1102			8746			135
Fuel Gas	96	69	22	4		1			22
Recycle Tar	843	711	49	9	5	69			148
Oxygen	12858					12858			)
Air	2680			2114		566			) -1
	58609	20042	2778	2478	151	27273	92	5795	3787
Output									
Heat Loss									64
Methane	2316	1734	582						567
Carbon Monoxide	36779	15770				21009			1674
Hydrogen	1313		1313						838
Carbon Dioxide	2499	682				1817			5
Inert Gas	2344			2344					5
Ethylene	44	38	6						10
Ethane	129	103	26						29
Ammonia	73		13	60					-
Hydrogen Sulfide	107		6		101				8
Carbonyl Sulfide	20	4			11	5			
Tar	1704	1483	133	19	4	65			295
Naphtha	483	422	45	2		14			104
Phenols	110	84	7			19			16
Fatty Acids	167	105	15			47			23
Liquor	5127	17	551	2	8	4414	135		70
Slag	5822	27						5795	46
Dust	34							34	
	59071	20469	2697	2427	124	27390	135	5829	3754
Input-Output Error, %	+0.8	+2.1	-2.9	-2.1	-17.9	+0.4	+46.7	+0.6	-0.9

7. Data Used In Balances - Fluxed Frances Coal

Coal Heating Value, Btu/lb.	10,788*
Coal Proximate Analysis	**Wt. %***
Moisture	7.0
Ash	17.95
Volatile Matter	27.85
Fixed Carbon	47.2
	100.00

*Includes flux

DAF Coal Ultimate Analysis	**Wt. %**
Carbon	79.51
Hydrogen	5.58
Nitrogen	1.45
Oxygen	12.48
Sulfur	0.60
Chlorine	0.38
	100.00
Moisture of Decomposition	107 lb/ton DAF Coal
Crude Gas Composition	**Vol. %**
Methane	6.38
Carbon Monoxide	58.03
Hydrogen	28.79
Carbon Dioxide	2.51
Nitrogen	3.70
Ethylene	0.07
Ethane	0.19
Hydrogen Sulfide	0.14
Ammonia	0.19
	100.00
Crude Gas Offtake Temperature	474° C
Gasifier Pressure	350 psig
Heat Loss from Jacket & Hearth	23.35 therms/hr**
Jacket Steam Production	3000 lb/hr**

* Includes flux.
** Estimated.

Byproducts

Composition, Wt. %	Naphtha	Product Tar	Recycle Tar	Phenols	Fatty Acid	Minor Liquor Comp.
Carbon	87.24	86.90	80.77	76.57	63.13	8.36
Hydrogen	9.36	7.80	5.63	6.43	8.84	-
Nitrogen	0.50	1.10	1.05	-	-	0.92
Sulfur	-	0.24	0.56	-	-	3.83
Chlorine	-	-	-	-	-	66.70
Oxygen	2.90	3.79	7.79	17.00	28.03	20.19
Ash	-	0.17	4.20	-	-	-
	100.00	100.00	100.00	100.00	100.00	100.00

Heating Value	Btu/lb.
Naphtha	20,942
Product Tar	16,360
Recycle Tar	16,360
Phenols	14,024
Fatty Acid	12,895
Minor Liquor Comp.	0

8. Performance Data - Fluxed Frances Coal

Crude Gas Flow*	20,550,000 SCFD
Steam Consumption	3.30 lb/therm gas
Steam Decomposition	86.16%
Oxygen Consumption	53.1 SCF/therm gas 13,130 SCF/ton DAF coal
Crude Gas Production*	243.7 therms/ton DAF coal 2,989 therms/hour
DAF Coal Consumption	24,228 lb/hour
Gas Liquor Yield	1.65 lb/therm gas

Thermal Efficiencies, %	Gas Only	Gas, Tar, Oil & Naptha
Crude Gas / Coal	85.86	94.20
Crude Gas / Coal & Steam & Oxygen	74.93	82.22

*Includes coal lock gas.

TSP Run 2

Feed Coals: Ohio No. 9 & Scottish Frances Coals
Date of Run: September 7-9, 1977

1. Run Diary

Date	Time	Event
Sept 7	0840	Began start-up procedure.
	1115	Introduced Frances coal. Air turned off, and steam/oxygen admitted to tuyeres.
	1215	Standard operating conditions reached; pressure at 350 psig; oxygen loading at 160,000 SCFH: steam/oxygen ratio at 1.35.
	1545	Oxygen loading reduced to 155,000 SCFH.
	1615	Oxygen loading reduced to 150,000 SCFH.
	1645	Oxygen loading reduced to 145,000 SCFH.
	1715	Oxygen loading reduced to 140,000 SCFH.
	1745	Oxygen loading reduced to 135,000 SCFH.
	1815	Oxygen loading reduced to 130,000 SCFH; steam/oxygen ratio reduced to 1.15. Some instabilities were encountered.
	2227	Steam/oxygen ratio returned to 1.35; gasifier performance became stable.
Sept 8	0100	Fluxing with blast furnace slag began.
	0305	Steam/oxygen ratio reduced to 1.15. Gasifier was steadied for introduction of Ohio No. 9 coal feed.
	0450	Complete loss of oxygen from oxygen plant; tuyeres were isolated; and gasifier was put on standby at 300 psig.
	0816	Gasifier was brought back on line, but steam/oxygen flow to one tuyere was restricted, and it was turned off. Running continued on the remaining tuyeres.
	1130	Steam/oxygen ratio at 1.15; steady conditions for introduction of Ohio No. 9 coal.
	1148	Ohio No. 9 coal was charged to the bunker.
	1245	The first lock of Ohio No. 9 coal arrivedin the gasifier as evidenced by a higher CO_2 level in the crude synthesis gas.
	1315	Increased frequency of slag tapping required because of higher ash content of Ohio No. 9 coal. There were some periods of erratic bed DP, but the gasifier recovered. No changes were made.

Date	Time	Event
Sept 9	0300	Restricted flow to a second tuyere was noted. Attempts were made to restore the flow.
	0348	The second tuyere was turned off, but this did not seem to affect gasification, which continued smoothly. There was evidence of slag buildup in the quench chamber.
	1029	The gasifier was shut down because of slag fouling the quench chamber.

2. Raw Data

a. Ohio No. 9 Coal

Proximate Analysis (Air Dried), Wt. %		Moisture	Ash	Volatile Matter	Fixed Carbon
Date	Time				
Sept 8-9	1200-0530	6.03	20.79	32.33	42.18
Sept 9	0600-1000	6.32	20.86	33.08	41.26

Ultimate Analysis (Air Dried), Wt. %	Sept 8-9 1200-0530	Sept 9 0600-1000
Carbon	57.1	58.6
Hydrogen	4.2	4.4
Nitrogen	0.6	0.7
Sulfur	4.8	4.5
Chlorine	0.04	0.04
Heating Value (Air Dried), Btu/lb.	9,840	10,460

Size Analysis, Wt. %	Sept 7 1600*	Sept 8 1300	Sept 9 0200	Sept 9 0800
over 1-1/4"	-	-	6	-
1"-1-1/4"	-	10	16	10
3/4"-1"	11	42	50.5	41
1/2"-3/4"	36	24	20	36
3/8"-1/2"	16	10	4	4
1/8"-3/8"	35	11	2.5	6
under 1/8"	2	3	1	3
Bulk Density, Lbs/CF	ND	53.5	ND	ND

Moisture Content, Wt. %

Date	Time	Moisture
Sept 7	1600	12.0*
Sept 8	1300	5.5
Sept 9	0200	6.0
Sept 9	0800	4.0

*Frances Coal

b. **Flux - Blast Furnace Slag**

Component, Wt. %	Composite
SiO_2	35.6
Al_2O_3	14.2
CaO	37.1
MgO	12.5
Fe_2O_3	0.1
Carbon	ND

Loss on Ignition, Wt. % +0.31 (gain)

Size Analysis, Wt. %	Sept 8 0100	Sept 8 1130	Sept 9 0200	Sept 9 0800
over 3/4"	2	-	-	-
1/2"-3/4"	9.5	3	4.5	4
3/8"-1/2"	75.0	72	74.5	65.5
1/8"-3/8"	13.0	24	20	30
under 1/8"	0.5	1	1	0.5
Moisture Content, Wt. %	3.0	ND	5.5	5.5

c. **Slag**

Date	Sept 8-9		Sept 9	Sept 9	
Time	1430 - 0230		0330-0930	Final Lock	
Component, Wt.%	Smpl 1	Smpl 2		Smpl 1	Smpl 2
SiO_2	43.1	43.0	44.2	43.6	44.1
Al_2O_3	19.3	18.7	19.7	19.9	19.1
CaO	17.9	18.1	15.4	16.0	15.6
MgO	6.4	5.8	6.2	5.9	5.3
Fe_2O_3	12.1	13.1	12.4	12.8	13.2
Carbon	ND	0.6	ND	ND	0.5
	98.8	99.3	97.9	98.2	97.8
Free Iron as Fe	1.8	1.8	1.9	1.5	1.0
FeO	8.8	7.3	8.6	9.4	9.0
Total Iron as Fe	8.6	9.1	8.7	9.0	9.2
Fe^{+2}	6.8	5.7	6.7	7.3	7.0
Fe^{+3}	Nil	1.6	0.1	0.2	1.2
Silica No.	54	54	56	56	56
Loss on Ignition,%*	+1.9	+1.7	+1.9	+2.8	+1.3

* + is a gain.

d. Oxygen Purity

Date	Time	O_2, Vol. %
Sept 7	1325	90.5
	1410	93.0
	1715	95.0
	2000	93.5
Sept 8	0115	97.1
	0315	94.2
	0930	97.1
	1315	95.1
	1700	96.0
	2130	94.1
Sept 9	0300	94.4
	0945	95.4

e. Recycle Tar

Ultimate Analysis (Air Dried), Wt. %	Dust Free Tar	Dust In Tar
Carbon	85.90	72.80
Hydrogen	6.80	1.50
Nitrogen	1.10	1.00
Sulfur	0.46	1.26
Chlorine	0.22	0.16
Ash	Nil	14.30
Water	Nil	1.21
Oxygen (Diff.)	5.52	7.77
	100.00	100.00
Heating Value, Btu/lb.	16,020	12,095

Moisture and Dust Content, Wt. %

Date	Time	Moisture	Dust
Sept 7	1515	ND	4
	2040	ND	1
Sept 8	0355	ND	4
	1540	13.4	4
	2215	ND	5
Sept 9	0545	4.6	2
	0840	ND	2

f. **Crude Synthesis Gas (Main Stream Sample)**

Analysis (Dry Basis), Vol. %

Date:	Sept 7		Sept 8									Sept 9		
Time:	1515	2115	0300	0910	1155	1255	1412	1510	1730	1300-1900	2330	0500	0530	0615-0825
CH_4	6.2	6.09	6.15	6.83	7.03	6.01	5.43	7.10	7.26	6.33	7.66	6.84	7.19	6.86
CO_2	2.1	1.52	3.02	2.74	2.46	3.73	5.32	7.52	3.42	5.13	4.88	4.76	4.84	4.56
C_2H_3	0.2	0.13	0.07	0.16	0.14	0.14	0.11	0.12	0.18	0.10	0.14	0.29	0.12	0.11
C_2H_6	0.4	0.43	0.44	0.49	0.49	0.45	0.40	0.47	0.46	0.43	0.49	0.46	0.45	0.41
H_2S	0.2	0.11	0.17	0.20	0.21	1.24	1.54	1.72	1.8	2.0	2.24	1.8	1.56	1.64
H_2	27.8	28.4	27.23	26.84	25.97	25.28	26.53	26.53	25.1	26.67	25.88	26.7	26.58	26.48
Ar	0.9	0.86	0.89	0.8	0.72	0.81	0.67	0.67	0.77	0.86	0.76	-	0.8	0.91
N_2	3.2	3.38	3.27	3.4	3.99	3.07	3.68	3.41	2.4	3.2	3.2	3.66	3.63	3.11
CO	54.3	58.18	57.23	58.58	55.44	58.05	56.32	49.74	56.16	56.12	55.71	54.57	53.81	54.35
	95.3	99.1	98.47	100.04	96.45	98.78	100.00	97.28	97.55	100.84	100.96	99.08	98.98	98.43

f. Crude Synthesis Gas continued

Minor Constituents, g/m^3

Date	Time	Ammonia	Condensate
Sept 8	1940-2330	ND	5.66
Sept 9	0530	1.14	ND

Organic Sulfur Compounds

Date	Time	Total g/m^3	COS, PPM	CS_2, PPM	Thiophenes, PPM
Sept 7	1505	-	180	1.7	11.0
	1740	-	172	1.2	8.9
Sept 8	0910	-	194	1.9	5.4
	1255	-	1,030	17.0	10.4
	1315	-	1,183	22.2	22.4
	1410	-	1,395	22.5	26.1
	1510	-	1,230	21.8	38.4
	1720	-	1,190	22.4	34.5
Sept 9	0100	1.47	1,159	34.5	31.1
	0630	-	1,143	31.4	30.9
	0915	-	1,271	24.0	29.9

g. Flash Gas From Tar Separator

Analysis - Sept 8 at 2230

	Vol.%
CH_4	3.68
CO_2	38.11
C_2H_4	0.01
C_2H_6	0.03
H_2S	6.84
NH_3	24.94
H_2	10.46
Ar	0.71
N_2	1.16
CO	20.28
	106.22

h. Side Stream Samples

Sample	S/S 1	S/S 2
Date	Sept 8	Sept 9
Time Period	1245-1909	0445-1010
Gas Volume, SCF	1,829	1,653
Tar/Oil Product, grams	2,196	2,089
Gas Liquor Product, grams	5,989	5,053
Dust Grams	10	25

i. Crude Synthesis Gas Composition (Side Stream Sample)

Analysis, Vol. %	S/S 1	S/S 2
CH_4	6.32	7.15
CO_2	5.37	4.81
C_2H_4	0.14	0.12
C_2H_6	0.44	0.43
H_2S	1.58	1.68
H_2	27.04	25.93
Ar	0.60	1.57
N_2	3.57	1.90
CO	54.53	52.88
	99.59	96.47

Minor Constituents, g/m^3		
NH_3	0.054	0.088
HCN	0.16	ND
Naphtha	5.02	ND

j. Combined Tar and Oil (Side Stream Sample)

Ultimate Analysis, Wt. %	S/S 1	S/S 2
Carbon	85.6	86.1
Hydrogen	7.3	7.4
Nitrogen	0.8	0.8
Sulfur	1.05	1.04
Chlorine	0.16	0.23
Ash	Nil	Nil
Water	Nil	Nil
Heating Value, Btu/lb.	16,100	16,000

k. Gas Liquor Analysis (Side Stream Samples)

mg/l	S/S 1	S/S 2
Tar/Oil Content	6,972	5,403
Total Dissolved Solids	6,394	5,467
Total Sulfur	824	1,065
Total NH_3	18,003	17,255
Free NH_3	15,980	15,385
Fixed NH_3	2,023	1,870
Carbonate as CO_2	23,540	21,560
Chloride	2,660	2,837
pH	8.5	8.7
Specific Gravity	1.013	1.013

l. St. Clair de Ville Condensate

Ultimate Analysis, Wt. %	Main Stream	S/S 1
Carbon	87.9	86.5
Hydrogen	8.8	10.0
Nitrogen	< 0.1	< 0.1

3. Heat and Material Balance - Ohio No. 9 Coal & Blast Furnace Slag Flux

Material Balance, Pounds per Hour

Input	Rate	Carbon	Hydrogen	Nitrogen	Sulfur	Oxygen	Chlorine	Ash	Heat Balance Therms/Hr.
Coal/Flux	31000	15262	1307	161	1283	3708	10	9269	2727
Steam	6837		765			6072			93
Oxygen	10433					10433			-
Fuel Gas	102	73	24	4		1			23
Recycle Tar	330	257	23	3	1	45		1	55
Air	2440			1848		592			-
	51142	15592	2119	2016	1284	20851	10	9270	2898
Output									
Methane	1658	1241	417						405
Carbon Monoxide	25552	10956				14596			1162
Hydrogen	874		874						557
Carbon Dioxide	3674	1003				2671			7
Nitrogen	1845			1845					3
Ethylene	46	39	7						10
Ethane	213	170	43						48
Hydrogen Sulfide	1101		65		1036				81
Ammonia	81		14	67					-
Carbonyl Sulfide	118	24			63	31			
Carbon Disulfide	3				3				
Thiophene	4	2			2				
Tar	1646	1409	120	13	17	84		3	285
Naphtha	220	192	21	1		6			47
Liquor	4432	29	482		4	3905	12		61
Slag	9323	56						9267	76
Heat Loss									65
	50790	15119	2043	1926	1125	21293	12	9270	2807
Input-Output Error, %	-.7	-3.0	-3.6	-4.4	-12.4	+2.1	+20.0	0	-3.1

4. Data Used in Balances - Ohio No. 9 Coal

Coal Heating Value, Btu/lb.	8,798*

Coal Proximate Analysis	Wt. %*
Moisture	5.32
Ash	29.90
Volatile Matter	28.10
Fixed Carbon	36.68
	100.00

DAF Coal Ultimate Analysis	Wt. %
Carbon	76.0
Hydrogen	5.59
Nitrogen	0.80
Oxygen	11.17
Sulphur	6.39
Chlorine	0.05
	100.00

Crude Gas Composition	Vol. %
Methane	6.29
Carbon Monoxide	55.51
Hydrogen	26.32
Carbon Dioxide	5.08
Nitrogen	4.01
Ethylene	0.10
Ethane	0.43
Hydrogen Sulfide	1.97
Ammonia	0.29
	100.00

Gas Offtake Temperature	469°C
Gasifier Pressure	350 psig
Heat Loss from Jacket & Hearth	24 therms/hour**
Jacket Steam Production	3,000 lb/hour**

* Includes flux.
** Estimated.

Byproducts

Composition Wt. %	Naphtha	Product Tar	Recycle Tar	Minor Liquor Comp.
Carbon	87.24	85.60	77.77	23.76
Hydrogen	9.36	7.30	7.07	-
Nitrogen	0.50	0.80	1.00	-
Sulfur	-	1.05	0.44	3.05
Chlorine	-	-	-	9.84
Oxygen	2.90	5.09	13.49	63.35
Ash	-	0.16	0.23	-
	100.00	100.00	100.00	100.00

Heating Value	Btu/lb.
Naphtha	20,942
Product Tar	16,100
Recycle Tar	16,100
Minor Liquor Components	0

5. Performance Data - Ohio No. 9 Coal

Crude Gas Flow*	14,930,000 SCFD	
Steam Consumption	3.26 lb/therm gas	
Steam Decomposition	80.74%	
Oxygen Consumption	62.21 SCF/therm gas 12,988 SCF/ton DAF coal	
Crude Gas Production*	208.8 therms/ton DAF coal 2097 therms/hour	
DAF Coal Consumption	20,090 lbs/hr.	
Gas Liquor Yield	2.06 lb/therm gas	
Thermal Efficiencies, %	Gas Only	Gas, Tar, Oil & Naphtha
Crude Gas / Coal	76.86	88.73
Crude Gas / Coal & Steam & Oxygen	67.20	75.74

*Includes coal lock gas.

TSP Run 3

Feed Coals: Ohio No. 9 and Scottish Frances Coals
Date of Run: September 28-29, 1977

1. Run Diary

Date	Time	Event
Sept 28	1507	Steam/oxygen injected after start-up with petroleum coke. Conditions of gasifier-pressure of 350 psig, steam/oxygen ratio of 1.35, and 160,000 SCFH of oxygen on Frances coal - were reached within one hour.
	1730	Oxygen loading starting to be reduced.
	2005	Oxygen loading of 130,000 SCFH reached with no problems. Blast furnace slag flux added. Steam/oxygen ratio trimmed to 1.15. Bed DP begins to rise. A problem external to the gasifier causes the gasifier to be placed on standby at 275 psig.
	2105	Gasifier back on line at 160,000 SCFH oxygen loading. Fluxing continued. Oxygen loading starting to be reduced.
Sept 29	0045	Oxygen loading of 130,000 SCFH. Steam/oxygen ratio at 1.15.
	0117	Ohio No. 9 coal fed to gasifier.
	0215	Slag tapping frequency increased and less variation in offtake temperature than with Frances coal feed. Bed DP low.
	0300	Bed DP drops to zero then rises sharply. Gasifier offtake temperature rises sharply. High torque on stirrer/distributor system.
	0320	Offtake temperature and Bed DP drop.
	0330	Offtake temperature and Bed DP rise.
	0340	Offtake temperature rise is more severe than previous rise. CO_2 level in offtake gas rises from 5% to 12%. Stirrer/distributor drive over loaded and shut off automatically.
	0350	Gasifier put on standby. Run terminated shortly thereafter.

2. Raw Data

a. Ohio No. 9 Coal

Proximate Analysis (Air Dried), Wt. % Date	Time	Moisture	Ash	Volatile Matter	Fixed Carbon
Sept 29	0130-0400	3.05	17.51	38.88	40.56

Size Analysis, Wt. %	Sept 29 0230
over 1-1/4"	11.5
1"-1-1/4"	18
3/4"-1"	39
1/2"-3/4"	21.5
3/8"-1/2"	4
1/8"-3/8"	4
under 1/8"	2
Bulk Density, Lbs,CF	52.0
Moisture Content, Wt. %	5.5

b. Flux - Blast Furnace Slag

Component, Wt. %	Composite
SiO_2	33.1
Al_2O_3	13.5
CaO	35.3
MgO	12.2
Fe_2O_3	0.9
Carbon	Nil
	95.0
Silica Number	41
Loss on Ignition, Wt. %	-0.2

Size Analysis, Wt. %	
over 1/2"	4.5
3/8"-1/2"	70.5
1/4"-3/8"	22.5
1/8"-1/4"	2
under 1/8"	0.5
Moisture Content, Wt. %	5.0
Bulk Density, Lbs/CF	73.0

c. Slag

Date:	Sept 29		
Time:	0230	0330	0430
Component, Wt. %			
SiO_2	39.6	39.6	40.5
Al_2O_3	17.8	17.5	18.2
CaO	19.9	19.0	18.6
MgO	7.1	6.8	6.6
Fe_2O_3	10.9	11.5	10.6
Carbon	0.6	0.8	0.8
	95.9	95.2	95.3
Free Iron as Fe	1.8	2.0	1.5
FeO	7.3	7.5	7.5
Total Iron as Fe	7.6	8.1	7.4
Fe^{+2}	5.7	5.8	5.8
Fe^{+3}	0.1	0.3	0.1
Silica No.	51	51	53
Loss on Ignition, %*	+1.9	+1.8	+1.5

d. Oxygen Purity, Vol. %

Date	Time	Oxygen	Nitrogen	Argon
Sept 28	1630	97.7	ND	ND
	2100	93.5	1.5	5.0
Sept 29	0045	95.5	ND	ND

e. Recycle Tar

Dust Content

Date	Time	Wt. %
Sept 29	0315	15

* + is a gain.

f. Crude Synthesis Gas (Main Stream Samples)

Analysis (Dry Basis), Vol. %

Coal Feed:	Frances	Ohio No. 9
Date:	Sept 28	Sept 29
Time:	1640	0315
CH_4	6.40	7.04
CO_2	2.46	4.15
C_2H_4	0.29	0.07
C_2H_6	0.24	0.36
H_2S	0.03	1.63
H_2	27.42	25.07
Ar	0.69	1.01
N_2	3.20	3.06
CO	56.48	57.61
	97.21	100.00

Minor Constituents, g/m^3

Date	Time	NH_3	HCN
Sept 29	0100-0350	0.924	0.022

NOTE: No other analyses were made because TSP Run 3 was terminated after a short time on stream.

3.0 Heat and Material Balance

The run was too short and the data insufficient to permit making a heat and material balance.

TSP Run 4

Feed Coals: Ohio No. 9 and Scottish Frances
Date of Run: October 19-20, 1977

1. Run Diary

Date	Time	Event
Oct 19	0720	Gasifier full of petroleum coke at 100 psig. Gasifier pressure raised to 350 psig and Frances coal introduced. Conditions indicated some form of blockage at the burner. Coal locking delayed for removal of large pieces of concrete from above top of cone.
	1156	Steam/oxygen injected into gasifier at oxygen loading of 160,000 SCFH.
	1340	Slag tapping poor; burner problem remains.
	1650	Oxygen load reduction started.
	1840	Lower loading reached with slag tapping still poor.
	1940	Fluxing with blast furnace slag started on the Frances coal. Slag tapping improved.
	2247	Ohio No. 9 coal introduced into gasifier.
	2304	Gasifier outlet temperature rose and bed DP increased and was erratic. Loading cut back momentarily and temperature came down.
Oct 20	0043	One tuyere appeared to be blocked but maintained full flow.
	0213	The tuyere returned to normal.
	0300	Flux changed to limestone. Slag tapping deteriorated with bed DP raising and falling immediately after completion of each slag tap.
	0415	Steam/oxygen ratio trimmed slightly.
	0600	Frozen slag on the quench chamber internals interfering with slag tapping. Attempts to reduce the problem were made.
	0800	Slag tapping improved but increased slag dribble and quench chamber fouling continued.
	0925	One tuyere appeared to be blocked.
	0945	A second tuyere appeared to be blocked. Steam/oxygen ratio reduced.
	1130	One blocked tuyere shut off.
	1155	A third tuyere appeared to be blocked.
	1226	Run terminated.

2. Raw Data

a. Ohio No. 9 Coal

Proximate Analysis (Air Dried), Wt. % Date	Time	Moisture	Ash	Volatile Matter	Fixed Carbon
Oct 19-20	2330-0530	4.41	20.39	33.38	41.82
Oct 20	0530-1226	4.10	20.12	33.34	42.44

Ultimate Analysis (Air Dried), Wt. %	Oct 19-20 2330-0530	Oct 20 0530-1226
Carbon	60.3	60.9
Hydrogen	4.3	4.5
Nitrogen	0.8	0.9
Sulfur	3.18	3.72
Chlorine	0.10	0.12
Water	4.05	3.63
Heating Value (Air Dried), Btu/lb.	10,730	10,901

Size Analysis, Wt. %	Oct 20 0010	Oct 20 1200
over 1-1/4"	27	29
1"-1-1/4"	23	23
3/4"-1"	29	26.5
1/2"-3/4"	14.5	12
3/8"-1/2"	3.5	3
1/8"-3/8"	2	3
under 1/8"	1	3.5
Bulk Density, Lbs/CF	54.5	51.5
Moisture Content, Wt. %	4.5	4.5

Forms of Sulfur in Coal	Wt. %
Total Sulfur	3.18
Pyritic Sulfur	2.50
Sulphase	Trace
Organic Sulfur	0.68

Caking Properties	
Free Swelling Index	4-1/2
Grey King Coke	F

Ash Analysis, Wt. %	Oct 19-20 2230-0530
SiO_2	43.6
Al_2O_3	22.5
CaO	2.8
MgO	1.1
Fe_2O_3	16.2
Na_2O	0.3
K_2O	2.1
TiO_2	0.9
Mn_3O_4	0.1
	89.6

b. **Flux - Limestone**

Component, Wt. %	Smpl 1	Smpl 2
SiO_2	4.0	3.0
Al_2O_3	1.1	0.8
CaO	50.0	49.9
MgO	4.8	3.1
Fe_2O_3	1.2	1.0
Carbon	Nil	Nil
	61.1	57.8
Free Iron as Fe	Nil	ND
FeO	0.11	ND
Total Iron as Fe	0.70	ND
Fe^{+2}	0.08	ND
Fe^{+3}	0.62	ND
Silica Number	7	5
Loss on Ignition, Wt.%	ND	-40.4
	Oct 20 0330	Oct 20 0930
Moisture Content, Wt. %	1.5	1.5
Bulk Density, Lbs/CF	88.5	86

c. Slag

Flux:	B.F. Slag	Limestone		
Date:	Oct 20	Oct 20		
Time	0030-0130	0600-1220	0600-1220	1220
Component, Wt. %				
SiO_2	40.7	40.7	42.8	43.1
Al_2O_3	17.0	18.2	18.8	23.8
CaO	14.7	13.2	12.8	9.9
MgO	4.6	1.3	1.5	1.6
Fe_2O_3	12.6	16.3	17.4	14.2
Carbon	1.5	1.0	1.1	1.0
	91.1	90.7	94.4	93.6
Free Iron as Fe	2.03	2.89	3.1	2.09
FeO	8.84	10.98	9.5	8.19
Total Iron as Fe	8.80	11.40	12.2	9.93
Fe^{+2}	6.58	8.51	7.4	6.35
Fe^{+3}	0.19	Nil	1.7	1.49
Total Sulfur	1.4	3.4	2.3	1.5
Sulfide	1.3	1.5	1.5	1.3
Silica No.	56	57	57	63
Loss on Ignition, %*	+1.4	+2.5	+3.0	+2.1

* + is a gain.

d. Slag Leaching Studies

Twelve 25 gram samples of slag (Ohio No. 9 fluxed with limestone) were placed in 12 beakers in 250 mls. of de-ionised water. Three groups of four were then made up for tests after:

Group 1 - 1 week
Group 2 - 2 weeks
Group 3 - 4 weeks.

Each of the four samples in each group were treated as follows:

A. Lying still in cold de-ionised water.
B. Lying in cold de-ionised water with stirring.
C. Lying still in hot de-ionised water (60-80^{o}C).
D. Lying in hot de-ionised water with stirring.

At the end of each time period the samples were filtered and made up to constant volume with de-ionised water and the filtrates tested for total dissolved solids. Results are given below:

	Sample	T.D.S.,PPM
	A	20.5
Group 1	B	158
1 week	C	64.3
	D	64.4
	A	76
Group 2	B	254
2 weeks	C	62
	D	70
	A	63
Group 3	B	98
4 weeks	C	71.3
	D	125

Slag Quench Water (Limestone Flux)

	Smpl 1	Smpl 2
Total Sulfur, mg/l	22.5	24.7
Total Sulfide, mg/l	Nil	Nil
Total Dissolved Solids, mg/l	264	395

e. Oxygen Purity

Date	Time	O_2 Vol. %
Oct 19	1000	96.4
	1630	95.8
	1915	95.8
Oct 20	0015	97.4
	0900	97.0

f. Recycle Tar

No analyses were made.

g. Crude Synthesis Gas (Main Stream Samples)

Analysis (Dry Basis), Vol. %

Date:	Oct 20	Oct 20	Oct 20
Time:	0015	0400	1115
CH_4	6.79	6.35	6.57
CO_2	5.96	7.22	1.86
C_2H_4	0.14	0.15	0.18
C_2H_6	0.53	0.32	0.66
H_2S	1.44	ND	1.36
H_2	29.77	31.14	30.18
Ar	0.76	0.72	0.60
N_2	2.42	1.45	1.64
CO	54.69	54.00	56.01
	102.50	101.35	99.06

Minor Constituents

Date	Time	Naphthalene g/m^3	COS PPM	CS_2 PPM	Thiophenes PPM
Oct 20	0415	-	923	23.7	7.6
	1200	-	1360	2.6	20.8
	0800-1115	0.0035	-	-	-

h. Crude Synthesis Gas Composition (Side Stream Sample)

Minor Constituents

	Oct 20 0415-0930
NH_3, g/m^3	0.037
HCN, g/m^3	0.23
COS, PPM	712
CS_2, PPM	4.2
Thiophenes, PPM	Nil

i. Gas Liquor Analysis

Source:	After-Cooler	Sidestream
Date:	Oct 20	Oct 20
Time:	0400-1230	0415-0930
Component, mg/l		
Tar/Oil Content	3,800	1,580
Total Dissolved Solids	5,465	10,800
Total Sulfur	2,268	6,618
Total Ammonia	31,603	20,600
Free Ammonia	9,537	19,244
Fixed Ammonia	22,066	1,356
Carbonate as CO_2	22,000	38,500
Chloride	3,009	3,369
pH	8.45	8.8
Specific Gravity	1.015	1.026

j. Oil Analysis (Main Stream Sample)

Density at 20°C	0.968 g/ml
Toluene Insolubles	1.8 Wt. %
Viscosity, Redwood No. 1 at 20°C	32.8 Seconds
Redwood No. 1 at 40°C	30.0 Seconds
Phenols (Wet)	8.7 Wt. %

Distillation

Vol. % OH	°C
IBP	76
5	106
10	125
20	151
30	174
40	190
50	200
60	218
70	229
80	240
90	274
95	320

j. Oil Analysis continued

PNA Analysis on IBP - 200°C Fraction

Component	Wt. %
P3-P7	Nil
P8	0.61
P9	0.85
P10	1.03
P11 & N11	1.76
P12 & N12	0.30
	4.25
N5	Nil
N6	0.09
N7	0.24
N8	0.54
N9	0.78
N10	1.38
	3.03
A6	11.4
A7	12.8
A8	16.6
A9	13.1
A10	18.0
Naphthalene	12.5
A11	8.0
	92.4

3. Heat and Material Balance - Ohio No. 9 Coal & Limestone Flux

Material Balance, Pounds (Basis: 1,000 pounds dry coal and flux)

Input	Rate	Carbon	Hydrogen	Nitrogen	Sulfur	Oxygen	Chlorine	Ash	Heat Balance Therms/Hr.
Coal/Flux	1049	577	48	9	35	100	1	279	2651
Steam	293		33			260			102
Fuel Gas	4	3	1						22
Recycle Tar	10		1			1			30
Oxygen/Air	523			71		452			-
	1879	588	83	80	35	813	1	279	2805
Output									
Calcination									17
Heat Loss									65
Methane	63	47	16						396
Carbon Monoxide	938	402				536			1095
Hydrogen	39		39						638
Carbon Dioxide	197	54				143			11
Nitrogen	38			38					2
Ethylene	3	3	-						15
Ethane	6	5	1						35
Ammonia	3		1	2					-
Hydrogen Sulfide	29		2		27				54
Carbonyl Sulfide	3	1	1			1			-
Tar	65	55	5	1	1	3			285
Naphtha	8	7	1						46
Liquor	127	1	14		1	111	1		45
Slag	248	2						246	55
	1767	577	80	41	29	794	1	246	2759
Input-Output Error, %	-6.0	-1.9	-3.6	-48.8	-17.1	-2.3	-	-11.8	-1.6

4. Data Used in Balances

Coal Heating Value, Btu/lb.	9,894*
Coal Proximate Analysis	**Wt. %***
Moisture	4.60
Ash	26.62
Volatile Matter	30.26
Fixed Carbon	38.52
	100.00
DAF Coal Ultimate Analysis	**Wt. %**
Carbon	81.35
Hydrogen	5.80
Nitrogen	1.21
Oxygen	7.06
Sulfur	4.42
Chlorine	0.16
	100.00
Moisture of Decomposition	134 lb/ton DAF Coal
DAF Coal Consumption	8.84 lb/therm gas
Gas Composition	**Vol. %**
Methane	6.17
Carbon Monoxide	52.45
Hydrogen	30.25
Carbon Dioxide	7.01
Inert Gas	2.11
Ethylene	0.15
Ethane	0.31
Hydrogen Sulfide	1.32
Ammonia	0.23
	100.00
Crude Gas Offtake Temperature	510°C
Gasifier Pressure	350 psig
Heat Loss from Jacket & Hearth	0.012 therms/therm gas
Jacket Steam Production	1.44 lbs/therm gas

* Includes limestone flux.

Byproducts

Composition Wt. %	Naphtha	Product Tar	Recycle Tar	Minor Liquor Comp.
Carbon	87.24	85.50	80.11	21.65
Hydrogen	9.36	7.40	4.95	-
Nitrogen	0.50	0.90	1.04	-
Sulfur	-	1.29	0.86	13.65
Chlorine	-	-	-	6.95
Oxygen	2.90	4.75	7.33	57.75
Ash	-	0.16	5.71	-
	100.00	100.00	100.00	100.00

Heating Value	Btu/lb.
Naphtha	20,942
Product Tar	16,240
Recycle Tar	10,709
Minor Liquor Components	0

5. Performance Data - Ohio No. 9 Coal

Steam Consumption	3.6 lb/therm gas
Steam Decomposition	91.65%
Oxygen Consumption	65.66 SCF/therm gas 14,847 SCF/ton DAF coal
Crude Gas Production*	226.1 therms/ton DAF coal
DAF Coal Consumption	8.84 lb/therm gas

Thermal Efficiencies, %	Gas Only	Gas, Tar, Oil & Naphtha
Crude Gas / Coal	78.6	89.6
Crude Gas / Coal, Steam & Oxygen	67.9	77.4

* Includes coal lock gas.

TSP Run 5

Feed Coals: Ohio No. 9 and Scottish Frances Coals
Date of Run: November 10-12, 1977

1. Run Diary

Date	Time	Event
Nov 10	2355	Gasifier charged with coke and pressurized with nitrogen to 100 psig.
Nov 11	0110	Air admitted to tuyeres.
	0316	Air switched off and steam/oxygen at start up rates admitted to gasifier with Frances coal.
	0350	Full oxygen loading of 160,000 SCFH was reached. Bed behaved erratically with high offtake temperatures due to wet and dusty Frances coal.
	0800	Oxygen loading was being reduced towards projected conditions for Ohio No. 9 coal.
	0935	Planned oxygen loading for Ohio No. 9 coal was reached.
	1016	Fluxing with blast furnace slag was started. Performance on fluxed Frances coal was much steadier than unfluxed.
	1509	First lock of Ohio No. 9 coal was charged to the gasifier, and the stirrer speed was increased.
	1603	Ohio No. 9 coal had reached the raceway of the gasifier, and slag tapping continued to be good.
	1754	Two tuyeres showed some abnormality.
	1930	The tuyeres appeared to be restored.
	2040	The two tuyeres became abnormal once more.
	2220	Frances coal was introduced to purge the gasifier.
	2305	The oxygen rate was increased briefly, and all tuyeres were functioning once more.
Nov 12	0020	Ohio No. 9 coal was recharged to the gasifier. Operation was good except tuyeres were flashing and were dimmer than usual.
	1200	Gasification rates were increased with steam/oxygen ratio remaining the same.
	1300	Gasification rates were further increased.
	1315	Tuyeres were flashing; hearth area became much hotter.
	1815	Growths of slag in quench vessel were interfering with slag tapping. Conditions in gasifier bed deteriorated.

Run Diary continued

Date	Time	Event
Nov 12	1850	Frances coal was charged to the gasifier to improve conditions.
	1923	Gasifier bed conditions returned to normal.
	1925	There was an equipment failure within the gasifier; so the steam/oxygen feed was switched off at the tuyeres, and cooldown with nitrogen commenced.

2. Raw Data

a. Ohio No. 9 Coal

Proximate Analysis (Air Dried), Wt.% Date	Time	Moisture	Ash	Volatile Matter	Fixed Carbon
Nov 11	1530-2220	3.12	22.35	31.61	42.92
Nov 12	0035-1850	2.64	23.23	33.31	40.82

Ultimate Analysis (Air Dried), Wt. %	Nov 11 1530-2230	Nov 12 0035-1850
Carbon	60.4	60.3
Hydrogen	4.3	4.3
Nitrogen	0.9	0.9
Sulfur	4.05	3.28
Chlorine	0.10	0.12
Ash	22.35	23.23
Water	3.12	2.64
Heating Value (Air Dried), Btu/lb.	10,440	10,460

Size Analysis, Wt. %	Nov 11 1530	Nov 12 0200	Nov 12 1330
over 1"	6	2.5	3
3/4"-1"	32	27.5	32.5
1/2"-3/4"	40	40.5	44
3/8"-1/2"	14	15.5	14
1/4"-3/8"	2.5	4	4
1/8"-1/4"	1	2	0.5
under 1/8"	4.5	8	2
Bulk Density, Lbs/CF	54.0	51.0	54.0
Moisture Content, Wt. %	6.5	9.0	8.5

Ash Analysis

Component, Wt. %	
SiO_2	43.6
Al_2O_3	22.5
CaO	2.8
MgO	1.1
Fe_2O_3	16.2
Carbon	Nil
	86.2

b. Flux - Blast Furnace Slag

	Nov 11	Nov 12	
	1530	0200	1330
Moisture Content, Wt.%	9.5	7.0	14.5
Bulk Density, Lbs/CF	78	71	71

c. Slag

Date:	Nov 11	Nov 12	Nov 12		Quench
Time:	1740-2200	0240-1340	1440-1840	Final	Chamber
Component, Wt. %				Lock	Deposit
SiO_2	43.6	41.7	42.1	41.2	16.7
Al_2O_3	19.2	18.1	18.9	18.3	7.8
CaO	14.0	15.2	14.4	15.0	7.4
MgO	3.7	4.3	4.3	4.6	2.0
Fe_2O_3	12.6	13.1	12.7	12.5	60.4
Carbon	0.9	1.0	0.5	0.5	ND
	94.0	93.4	92.9	92.1	94.3
Free Iron as Fe	1.8	1.5	0.9	1.1	ND
FeO	8.5	8.9	8.5	7.1	ND
Total Iron as Fe	8.8	9.2	8.9	8.7	ND
Fe^{+2}	6.6	6.9	6.6	5.5	ND
Fe^{+3}	0.4	0.8	1.4	2.1	ND
Total Sulfur	1.5	2.9	0.9	ND	ND
Sulfide	1.1	1.1	0.6	0.6	ND
Silica No.	59	56	57	56	ND
Loss on Ignition,%*	+2.7	+2.3	+2.1	+2.2	+13.6

* + is a gain.

d. Oxygen Purity, Vol. %

Date	Time	Oxygen	Nitrogen	Argon
Nov 11	0600	95.2	3.3	1.5
	1115	96.55	2.72	0.73
	2040	98.5	0.63	0.87
Nov 12	0130	96.1	3.9	Nil
	0600	97.8	2.2	Nil
	0900	98.1	1.0	0.1
	1500	95.2	4.1	0.55

e. Recycle Tar

Ultimate Analysis (Dry, Dust Free), Wt. %	Dry Tar	Dust in Tar
Carbon	85.2	76.5
Hydrogen	6.9	2.2
Nitrogen	1.0	0.9
Sulfur	1.06	1.42
Chlorine	0.10	0.12
Ash	0.6	16.94
Water	Nil	1.52
Heating Value, Btu/lb.	16,020	12,060

Moisture Content		Wt. %
Nov 11	2000	3.9
Nov 12	1030	3.4

f. Crude Synthesis Gas (Main Stream Samples)

Analysis (Dry Basis), Vol. %

Date:	Nov 11				Nov 12			
Time:	0415*	1540	1930	1630-1930	0230	0400 0600	0930	1530
CH_4	4.4	6.4	6.0	5.7	7.25	5.5	5.65	4.65
CO_2	2.3	4.1	2.0	3.5	5.6	5.1	5.95	5.0
C_2H_4	0.05	0.14	0.23	0.4	0.15	0.14	0.13	0.13
C_2H_6	0.24	0.45	0.41	0.39	0.54	0.47	0.51	0.40
H_2S	0.2	0.75	1.64	1.12	1.38	1.09	1.40	1.60
H_2	28.0	27.4	27.5	28.0	28.0	29.0	29.0	29.0
Ar	0.71	0.76	0.90	2.00	0.74	0.71	0.56	0.78
N_2	4.3	4.3	3.4	8.9	2.67	3.7	2.8	3.9
CO	60.0	55.7	57.5	49.2	49.3	50.0	49.5	50.0
	100.2	100.0	99.6	99.2	95.6	95.7	95.5	95.5

*Frances coal being fed.

f. Crude Synthesis Gas continued

Minor Constituents, g/m^3

Date	Time	NH_3	HCN	Naphthalene	Condensate
Nov 11	1740-2140	0.026	0.0065	0.0004	ND
Nov 12	0230-0700	0.044	0.0039	ND	12.54
Nov 12	1145-1445	0.043	0.0044	0.0010	6.42

Sulfur Compounds, PPM

Date	Time	COS	CS_2	Thiophene
Nov 11	2000	1,160	27.1	6.0
Nov 12	1030	1,332	10.8	8.7

g. Flash Gas From Tar Separator

Analysis, Vol. %

Date:	Nov 12
Time:	1830
CH_4	4.35
CO_2	7.60
C_2H_4	0.14
C_2H_6	0.37
H_2S	5.53
H_2	17.00
Ar	0.70
N_2	2.70
CO	46.00
NH_3	0.29
O_2	0.09
	84.77

Condensate	g/l
NH_3	25.57
H_2S	15.53
CO_2	11.26

h. Side Stream Samples

Sample	S/S 1	S/S 2
Date	Nov 11	Nov 12
Time Period	1600-2130	0345-0900
Gas Volume, SCF	2,049	1,902
Tar/Oil Product, grams	3,454	2,815
Gas Liquor Product, grams	13,412	7,429
Dust, grams	189	65

i. Crude Synthesis Gas Composition (Side Stream Sample)

Analysis, Vol. %	S/S 1	S/S 2
CH_4	6.7	5.4
CO_2	4.2	5.1
C_2H_4	0.11	0.13
C_2H_6	0.48	0.48
H_2S	1.03	1.36
H_2	28.0	28.4
Ar	0.95	0.64
N_2	4.4	3.75
CO	51.0	49.0
Minor Constituents		
Naphthalene, g/m^3	0.0093	ND
NH_3, g/m^3	0.069	0.097
HCN, g/m^3	0.0085	0.010
Condensibles, g/m^3	8.43	12.1
COS, PPM	1250	ND
CS_2, PPM	28.6	ND
Thiophenes, PPM	6.0	ND

j. Combined Tar and Oil (Side Stream Samples)

Ultimate Analysis, Wt. %	S/S 1	S/S 2
Carbon	85.9	84.4
Hydrogen	7.3	7.3
Nitrogen	1.1	0.9
Sulfur	1.50	1.27
Chlorine	0.07	0.06
Ash	0.06	0.02
Heating Value, Btu/lb.	15,930	16,270

k. Gas Liquor Analysis (Side Stream Samples), mg/l

	S/S 1	S/S 2
Total Dissolved Solids	7,799	3,907
Total Sulfur	1,190	1,605
Total Ammonia	17,255	14,654
Free Ammonia	15,334	13,413
Fixed Ammonia	1,921	1,241
Carbonate as CO_2	15,180	15,136
Chloride	1,773	3,635
Tar/Oil Content	3,900	7,700
ph	9.0	8.85
Specific Gravity	1.02	1.014

l. Gas Liquor Analysis (Main Stream Samples)

mg/liter	Liquor from Oil Separator	Liquor from Tar Separator
Flourine	30	190
Acetone	10	22
Methanol	Nil	Nil
Iso-propanol	12	Nil
N-propanol	Nil	Nil
Acetonitrile	395	29
Pyridine	116	23

m. St. Clair de Ville Condensate

Ultimate Analysis, Wt. %	Main Stream Sample	Side Stream Sample
Carbon	89.9	89.2
Hydrogen	9.0	9.4
Nitrogen	0.1	0.1
Sulfur	1.48	ND
Heating Value, Btu/lb.	16,840	ND

n. Elemental Analyses (Ohio No. 9 Coal Operations)

Element, PPM by Wt.	Ohio No. 9 Coal	Coal Ash	BFS Flux	Slag	Slag Quench Water	Gas Liquor from Tar Separator	Gas Liquor from Oil Separator	Main Stream Oil	Recycle Tar
Aluminum	24,000	110,000	67,000	93,000	0.3	6.6	3.4	2.9	49
Barium	130	880	560	790	0.1	< 1	< 0.04	< 0.07	0.8
Calcium	5,900	24,000	240,000	110,000	55	< 50	< 35	< 2	41
Chromium	50	230	14	130	< 0.1	< 0.2	0.2	0.5	1.0
Iron	30,000	140,000	14,000	97,000	2.6*	100	140	8.4	160
Lead*	40	200	200	400	0.02	0.02	0.06	ND	ND
Magnesium	1,570*	6,570*	53,000	35,000	4.8*	1.2*	3.7*	< 2	25
Manganese	1,100	5,100	5,900	3,800	0.4	0.2	< 0.05	0.08	2.2
Nickel*	100	500	268	600	0.04	0.08	0.03	ND	ND
Potassium	3,700	17,000	3,400	13,000	1.3	8.8	3.1	< 0.3	9.8
Silicon	53,000	240,000	100,000	170,000	< 40	260	< 150	< 50	230
Sodium	460	2,000	2,300	2,700	16	21	25	1.0	3.2
Strontium	97*	620	1,200	530	0.1*	0.02*	0.05*	< 0.1	< 0.5
Sulfur	ND	ND	ND	ND	61	656	2,345	ND	ND
Titanium	1,300	5,700	3,000	4,800	< 0.1	< 5	< 8	0.6	5.8
Vanadium	43	200	40	180	0.002	< 0.05	0.04	0.09	0.5
Zinc	55	140	88*	68*	47	0.3	0.4	< 0.5	90
Antimony	0.8	2.9	0.1	0.6	< 0.005	0.09	0.03	0.07	0.7
Arsenic	16	70	3.5	17	0.002	3.3	0.8	13	20
Beryllium*	< 12	< 12	< 12	< 12	< 0.002	< 0.002	< 0.002	ND	ND
Cadmium	< 0.5	37*	< 4	< 2	0.003*	0.005*	0.003*	< 0.1	< 0.1
Cobalt	7.0	31	3.8	54	0.02	< 0.05	0.04	0.02	0.6
Copper	< 1.6*	< 20*	103*	146*	0.01*	0.04*	0.2*	0.1	2.3
Mercury	0.2	< 0.7	< 0.5	< 0.3	< 0.02	< 0.06	< 0.06	< 0.02	0.06
Molybdenum	8.1	31	6.5	14	< 0.1	< 0.2	< 0.2	< 0.05	0.4
Selenium	4.2	2.3	3.2	7.4	< 0.05	3.4	1.5	0.8	1.0
Uranium	5.1	22	9.2	17	0.002	< 0.04	< 0.05	< 0.01	0.05

Notes:
1. All elements except sulfur were determined by either Neutron Activation Analysis or Atomic Absorption Spectrophotometry (AAS). Elements determined by AAS are marked by an arterisk.
2. Sulfur was determined by a chemical method.
3. All samples were taken from TSP Run 5 except the Slag Quench Water is from TSP Run 4, the Mainstream Oil is from TSP Run 6, and the Recycle Tar is a composite from TSP Runs 4, 5, and 6.

3. No. 1 Heat and Material Balance - Ohio No. 9 Coal & Blast Furnace Slag Flux

Material Balance, Pounds (Basis: 1,000 pounds dry coal and flux)

Input	Rate	Carbon	Hydrogen	Nitrogen	Sulfur	Oxygen	Chlorine	Ash	Heat Balance Therms/Hr.
Coal/Flux	1076	523	46	8	28	113	1	357	2611
Steam	266		30			236			105
Fuel Gas	3	2	1						22
Recycle Tar	57	46	3	1	1	4		2	245
Oxygen/ Air	457			58		399			-
	1859	571	80	67	29	752	1	359	2983
Output									
Heat Loss									52
Methane	57	43	14						404
Carbon Monoxide	911	391				520			1192
Hydrogen	38		38						699
Carbon Dioxide	146	40				106			8
Inert Gas	85			85					4
Ethylene	3	3							17
Ethane	9	7	2						60
Ammonia	3		1	2					-
Hydrogen Sulfide	24		1		23				51
Carbonyl Sulfide	5	1			3	1			-
Tar	76	64	6	1	1	4			376
Naphtha	18	16	2						88
Liquor	149	1	16			131	1		60
Slag	363	4						359	90
	1887	570	80	88	27	762	1	359	3101
Input-Output Error, %	+1.5	-0.2	0	+31.3	-6.9	+1.3	0	0	+4.0

4. Data Used in No. 1 Balances

Coal Heating Value, Btu/lb.	8,431*
Coal Proximate Analysis	**Wt. %***
Moisture	7.08
Ash	33.17
Volatile Matter	26.85
Fixed Carbon	32.90
	100.00
DAF Coal Ultimate Analysis	**Wt. %**
Carbon	81.35
Hydrogen	5.80
Nitrogen	1.21
Oxygen	7.06
Sulfur	4.42
Chlorine	0.16
	100.00
Moisture of Decomposition	134 lb/ton DAF Coal
Gas Composition	**Vol. %**
Methane	5.72
Carbon Monoxide	51.95
Hydrogen	30.15
Carbon Dioxide	5.30
Inert Gas	4.84
Ethylene	0.14
Ethane	0.50
Hydrogen Sulfide	1.13
Ammonia	0.27
	100.00
Crude Gas Offtake Temperature	466°C
Gasifier Pressure	350 psig

* Includes flux.

Byproducts

Composition Wt. %	Naphtha	Product Tar	Recycle Tar	Minor Liquor Comp.
Carbon	89.47	84.40	80.85	20.3
Hydrogen	8.96	7.30	6.30	-
Nitrogen	0.10	0.90	0.95	-
Sulfur	1.47	1.27	1.09	7.9
Chlorine	-	-	-	17.8
Oxygen	-	6.05	7.42	54.0
Ash	-	0.08	3.39	-
	100.00	100.00	100.00	100.00

Heating Value	Btu/lb.
Naphtha	16,840
Product Tar	16,270
Recycle Tar	14,818
Minor Liquor Components	0

5. Performance Data - No. 1 Balances

Steam Consumption	3.36 lb/therm gas
Steam Decomposition	90.2%
Oxygen Consumption	59.65 SCF/therm gas 14,680 SCF/ton DAF coal
Crude Gas Production*	246.2 therms/ton DAF coal
Gas Liquor Yield	1.84 lb/therm gas

Thermal Efficiencies,%	Gas Only	Gas, Tar, Oil & Naphtha
$\frac{\text{Crude Gas}}{\text{Coal}}$	87.23	95.08
$\frac{\text{Crude Gas}}{\text{Coal, Steam \& Oxygen}}$	75.22	82.00

* Includes coal lock gas.

6. No. 2 Heat and Material Balance - Ohio No. 9 Coal & Blast Furnace Slag Flux

Material Balance, Pounds (Basis 1,000 pounds dry coal and flux)

Input	Rate	Carbon	Hydrogen	Nitrogen	Sulfur	Oxygen	Chlorine	Ash	Heat Balance Therms/Hr.
Coal/Flux	1076	524	46	8	28	113	1	356	2694
Steam	277		31			246			112
Fuel Gas	4	3		1					24
Recycle Tar	34	28	2			3		1	149
Oxygen/Air	482			76		406			-
	1873	555	79	85	28	768	1	357	2979
Output									
Heat Loss									59
Methane	50	37	13						360
Carbon Monoxide	930	399				531			1257
Hydrogen	39		39						736
Carbon Dioxide	146	40				106			9
Inert Gas	87			87					6
Ethylene	3	2	1						16
Ethane	8	6	2						54
Ammonia	3		1	2					1
Hydrogen Sulfide	36		2		34				80
Carbonyl Sulfide	5	1			3	1			-
Tar	55	47	4		1	3			285
Naphtha	18	16	2						93
Liquor	152	1	17			133	1		63
Slag	361	4						357	92
	1893	553	81	89	38	774	1	357	3111
Input-Output Error, %	+1.1	-0.4	+2.5	+4.7	+35.7	+0.8	0	0	+4.4

7. Data Used in No. 2 Balances

Coal Heating Value, Btu/lb.	8,441*

Coal Proximate Analysis	Wt. %*
Moisture	7.09
Ash	33.08
Volatile Matter	26.88
Fixed Carbon	32.95
	100.00

DAF Coal Ultimate Analysis	Wt. %
Carbon	81.35
Hydrogen	5.80
Nitrogen	1.21
Oxygen	7.06
Sulfur	4.42
Chlorine	0.16
	100.00

Moisture of Decomposition	134 lb/ton DAF Coal

Gas Composition	Vol. %
Methane	4.86
Carbon Monoxide	52.20
Hydrogen	30.29
Carbon Dioxide	5.23
Inert Gas	4.90
Ethylene	0.14
Ethane	0.42
Hydrogen Sulfide	1.68
Ammonia	0.28
	100.00

Crude Gas Offtake Temperature	492°C
Gasifier Pressure	350 psig

* Includes flux.

Byproducts

Composition Wt. %	Naphtha	Product Tar	Recycle Tar	Minor Liquor Comp.
Carbon	89.47	84.40	80.69	20.26
Hydrogen	8.96	7.30	6.19	-
Nitrogen	0.10	0.90	0.95	-
Sulfur	1.47	1.27	7.32	7.88
Chlorine	-	-	-	17.84
Oxygen	-	6.05	3.76	54.02
Ash	-	0.08	1.09	-
	100.00	100.00	100.00	100.00

Heating Value	Btu/lb.
Naphtha	16,840
Product Tar	16,270
Recycle Tar	14,731
Minor Liquor Components	0

8. Performance Data - No. 2 Balances

Steam Consumption	3.54 lb/therm gas	
Steam Decomposition	89.71%	
Oxygen Consumption	60.70 SCF/therm gas 14,750 SCF/ton DAF coal	
Crude Gas Production*	242.9 therms/ton DAF coal	
Gas Liquor Yield	1.89 lb/therm gas	
Thermal Efficiencies, %	Gas Only	Gas, Tar, Oil & Naphtha
Crude Gas / Coal	86.12	94.13
Crude Gas / Coal, Steam & Oxygen	74.14	81.03

* Includes coal lock gas.

TSP Run 6

Feed Coal: Ohio No. 9 and Scottish Frances Coals
Date of Run: December 4-7, 1977

1. Run Diary

Date	Time	Event
Dec 4		Gasifier pressured to 100 psig with nitrogen and filled with petroleum coke.
	1742	Coke ignited: air being fed through tuyeres.
	2052	Steam/oxygen injected into gasifier; gasifier pressure at 350 psig; Frances coal feedstock; 100,000 SCFH oxygen rate; 1.35 steam/oxygen ratio.
Dec 5	0147	Blast furnace slag fluxing started.
	1823	Gasifier offtake temperature rises and returns to normal.
Dec 6	2100	Ohio No. 9 coal replaces Frances coal as feed to gasifier; completed 48-hour test run on Frances coal.
	2247	Offtake temperature became high and CO_2 content of the offtake gas also rose.
Dec 7	0257	Slag tapping deteriorates.
	0310	Hearth conditions deteriorate.
	0350	Frances coal replaces Ohio No. 9 coal as feed.
	0357	Steam/oxygen ratio reduced to 1.30.
	0506	Slag/tapping improved.
	0653	Steam/oxygen ratio raised.
	1211	Ohio No. 9 coal replaces Frances coal as feed.
	1700	Slag tapping deteriorating.
	1900	Oxygen rate reduced to 80,000 SCFH to alleviate hot hearth condition. Steam/oxygen ratio set at 1.30.
Dec 8	0441	Slag tap blocked; run terminated.

2. Raw Data

a. Coal

Proximate Analysis (Air Dried), Wt. %	Frances Coal Dec 5-6 1400-1300	Ohio No. 9 Coal Dec 6-7 2230-0330	Ohio No. 9 Coal Dec 7-8 1300-0400
Moisture	6.28	3.82	3.17
Ash	6.78	20.96	20.22
Volatile Matter	34.50	32.89	34.30
Fixed Carbon	52.44	42.33	42.31
Ultimate Analysis (Air Dried), Wt. %			
Carbon	74.2	63.1	63.1
Hydrogen	4.9	4.6	4.6
Nitrogen	1.2	1.0	1.0
Sulfur	0.69	3.18	4.02
Chlorine	0.16	0.09	0.07
Ash	6.78	20.96	20.22
Water	6.28	3.82	3.17

Size Analysis, Wt. %	Frances Coal Dec 5 0250	Frances Coal Dec 6 0130	Ohio No. 9 Coal Dec 7 0015	Ohio No. 9 Coal Dec 7 1330	Ohio No. 9 Coal Dec 8 0030
over 1-1/4"	-	3	0.5	8	0.5
1"-1-1/4"	-	1.5	2.5	-	4
3/4"-1"	12	20	35.5	52.5	52
1/2"-3/4"	49	49	42.5	28.5	31
3/8"-1/2"	19	15.5	14	6.5	9
1/4"-3/8"	10	8	3.5	1	2.5
1/8"-1/4"	6	3	1.5	0.5	0.5
under 1/8"	4	-	-	3	0.5

Date	Time	Coal	Bulk Density, Lbs/CF	Moisture Content, Wt. %
Dec 5	0250	Frances	46.5	10.0
	1310	Frances	47	9.5
Dec 6	0130	Frances	46	14.0
	1130	Frances	-	8.0
	2150	Ohio 9	-	8.0
Dec 7	0015	Ohio 9	46	7.5
	1330	Ohio 9	49	5.0
Dec 8	0030	Ohio 9	46	-

Raw Data (Coal) continued

Coal Ash Analysis, Wt.%	Ohio 9
SiO_2	47.5
Al_2O_3	21.2
CaO	1.0
MgO	1.0
Fe_2O_3	18.6
Silica No.	70

b. Flux - Blast Furnace Slag

Date	Time	Bulk Density, Lbs/CF	Moisture Content, Wt. %
Dec 5	0250	74.5	3.0
	1310	74	8.0
Dec 6	0130	74	5.5
	1130	-	5.5
Dec 7	0015	71	4.5
	1330	73	3.0
Dec 8	0030	71	-

c. Slag

Date:	Dec 5-6**	Dec 6-7	Dec 7-8	Dec 8
Time:	1345-0045	2330-0330	1245-0045	0130-0330
Component, St. %				
SiO_2	34.3	44.7	41.8	38.6
Al_2O_3	14.6	21.0	17.2	17.3
CaO	32.6	11.8	15.0	15.0
MgO	9.7	3.7	5.0	4.9
Fe_2O_3	2.9	14.3	10.6	10.1
Carbon	1.4	2.4	2.4	2.9
	95.5	97.9	92.0	88.8
Free Iron as Fe	0.46	1.29	1.01	1.37
FeO	2.08	10.10	7.71	5.46
Total Iron as Fe	2.03	10.10	7.42	7.07
Fe^{+2}	1.62	7.86	6.00	4.25
Fe^{+3}	Nil	0.95	0.41	1.45
Total Sulfur	0.3	1.2	1.2	1.2
Total Sulfide	0.23	0.75	0.93	1.05
Silica No.	42	57	56	54
Loss on Ignition, %*	-1.0	+1.0	+0.5	+0.1

* + is a gain

** Frances coal; others are Ohio No. 9 coal.

d. Oxygen Purity, Vol. %

Date	Time	Oxygen	Argon	Nitrogen
Dec 5	0030	96.85	1.18	1.97
	0700	98.43	0.72	0.85
	1930	94.81	1.43	3.76
Dec 6	0230	95.83	1.12	3.05
	1030	95.71	0.67	3.72
	1830	98.44	0.06	3.50
Dec 7	0145	96.18	0.67	3.15
	0730	96.64	0.24	3.12
	1340	97.1	0.12	2.78
	2130	97.1	0.45	2.46
Dec 8	0030	96	0.21	3.78

e. Recycle Tar

Ultimate Analysis	Frances Coal		Ohio No. 9 Coal	
(Air Dried), Wt. %	Tar	Tar Dust	Tar	Tar Dust
Carbon	87.0	76.7	87.1	77.5
Hydrogen	7.1	1.8	6.9	1.5
Nitrogen	1.0	1.0	1.2	0.9
Sulfur	1.28	1.25	1.09	1.42
Chlorine	0.15	0.10	0.11	0.10
Ash	0.006	15.71	0.009	16.43
Water	Nil	0.69	Nil	0.53
Heating Value,Btu/lb	16,268	12,180	16,351	12,028

Moisture Content

Date	Time	Wt. %
Dec 5	1800	5.5
Dec 7	0115	1.6
	0320	4.4
	1300	6.0
Dec 8	0130	2.6

f. Crude Synthesis Gas (Main Stream Samples)

Analysis (Dry Basis), Vol.%

Date:	Dec 5				Dec 6			Dec 7						Dec 8
Time:	0300	1350-1515	1600	2200	0400	Composite	2245	0315	0215-0315	1345	1440-1600	1700	2215	0000-0200
CH_4	6.0	6.4	7.15	5.45	5.80	4.7	7.7	6.3	6.9	6.4	6.35	5.85	5.8	6.75
CO_2	4.2	2.4	3.0	1.9	2.25	3.6	4.2	4.0	3.8	4.0	4.35	4.7	5.4	4.95
C_2H_4	0.28	0.2	0.22	0.2	0.15	0.13	0.13	0.13	0.13	0.15	0.17	0.11	0.12	0.11
C_2H_6	0.38	0.6	0.6	0.49	0.44	0.36	0.54	0.45	0.49	0.5	0.9	0.44	0.42	0.47
H_2S	0.25	0.12	0.12	0.14	0.11	0.14	1.36	1.24	1.01	1.32	1.30	1.42	1.19	1.26
H_2	28.7	28.6	28.8	29.2	31.0	29.2	28.6	29.8	28.9	30.1	29.1	29.6	29.1	28.9
Ar	0.64	0.56	0.50	0.46	0.53	0.58	0.61	0.53	0.51	0.56	0.34	0.54	0.65	0.64
N_2	4.28	3.7	4.7	4.35	5.7	4.35	4.5	4.1	4.2	3.5	4.5	3.85	5.45	5.1
CO	55.5	56.8	52.8	57.8	56.1	57.9	52.8	54.68	54.0	52.5	51.0	52.4	51.4	50.4
	100.23	99.38	97.89	99.99	102.08	100.96	100.44	101.23	99.94	99.03	98.01	98.91	99.53	98.58

Note: First six samples with Frances coal feed; remainder with Ohio No. 9 coal feed.

f. Crude Synthesis Gas continued

Minor Constituents, g/m³ Date	Time	NH_3	HCN	Naphthalenes	Condensate
Dec 5	1330-1500	0.032	0.044	0.0004	26.9
Dec 6	1230-1630	0.0621	0.013	0.0005	6.73
Dec 7	0215-0315	ND	0.063	ND	5.64
Dec 7	1415-1830	0.051	0.037	0.00037	5.53
Dec 8	0005-0305	0.007	0.019	ND	7.03

	Dec 7		Dec 8
Sulfur, PPM	1415	1630	0005
COS	1004	1140	1384
CS_2	6.6	1.75	12.8
Thiophenes	5.7	3.7	8.0

g. Side Stream Samples

Date:	Dec 5	Dec 7	Dec 7	Dec 7-8
Time Period:	1315-1915	0200-0330	1445-2115	2330-0430
Gas Volume, SCF	1220	313	1135	1138
Tar/Oil Product, grams	1485	178.5	1476	1048
Dust Product, grams	10.5	4.0	21.2	12.5
Gas Liquor Product, grams	4926	584.5	4133	3839

h. Crude Synthesis Gas Composition (Side Stream Sample)

Date:	Dec 5	Dec 7	Dec 7	Dec 8
Time Period:	1330-1515	0215-1315	1440-1600	0025-0200
Analysis, Vol.%	Frances	Ohio 9	Ohio 9	Ohio 9
CH_4	6.1	6.1	7.2	6.8
CO_2	2.65	3.4	4.6	4.95
C_2H_4	0.2	0.1	0.13	0.11
C_2H_6	0.56	0.25	0.46	0.47
H_2S	0.13	0.99	1.34	1.13
H_2	27.5	26.5	27.2	28.8
O_2	Trace*	2.1*	-	-
Ar	0.94	1.5	0.7	0.65
N_2	6.7	9.1	5.0	4.8
CO	54.6	51.2	50.8	48.4
	99.38	101.24	97.43	96.11

* Air in sample.

h. Crude Synthesis Gas Composition continued

Minor Constituents, g/m^3

Date:	Dec 5	Dec 7	Dec 7	Dec 8
Time Period:	1330-1515	0215-1315	1440-1600	0025-0200
Analysis, Vol. %	Frances	Ohio 9	Ohio 9	Ohio 9
NH_3	0.0983	ND	0.1783	0.013
HCN	0.0102	0.023	0.0153	0.031
Naphthalene	0.01	ND	0.00614	ND
Condensibles	4.19	0.72	4.34	12.1
PPM				
COS	ND	1052	1170	1424
CS_2	ND	6.4	2.9	15.1
Thiophenes	ND	3.0	3.4	8.0

i. Tar Analysis

Density at 20°C	1.157	
Toluene Insolubles	8.5 Wt. %	
Viscosity 10mm cup standard tar viscometers	7.8 sec. at 20°C	
	1.2 sec. at 40°C	
Distillation, % OH	Vol. %	Wt. %
IBP = 158°C		
IBP to 200°C	3.1	2.3
200°C - 320°C	39.4	34.5
320°C - EP	57.5	63.2
Phenols in Tar	12.2	11.0

j. Gas Liquor Analysis (Tar Separator)

	mg/l
Total phenols as Phenol	2500
Monohydric phenols as Phenol	2000
Nitrate as NO_3	10.9
Fatty acids as acetic acid	822
Cyanide as CN	338
Thiocyanates as CNS	2000

k. Combined Tar and Oil (Side Stream Samples)

Date: Time Period: Ultimate Analysis, Wt.%	Dec 5 1315-1915	Dec 7 1445-2115	Dec 7-8 2330-0430
Carbon	85.6	85.4	85.6
Hydrogen	7.5	7.5	7.7
Nitrogen	0.9	0.6	0.8
Sulfur	0.67	1.42	1.48
Chlorine	0.20	0.17	0.13
Ash	0.006	0.011	0.011
Water	Nil	Nil	Nil
Heating Value, Btu/lb.	16565	16360	16245

l. Gas Liquor Analysis (Side Stream Samples)

Date: Time Period:	Dec 5 1315-1915	Dec 7 1445-2115	Dec 7-8 2330-0430	Dec 7 1800*
Tar/Oil Content, mg/l	1500	33800	19600	-
Total Dissolved Solids, mg/l	17116	7250	5450	179
Total Sulfur	632	1819	1512	34.3
Total Sulfide as S	-	-	-	Nil
Total Ammonia	15487	17408	15776	
Free Ammonia	11220	15810	14330	
Fixed Ammonia	4267	1595	1446	
Carbonate as CO_2	17600	23584	19624	
Chloride	8333	1418	1418	30
pH	8.72	8.92	8.78	5.18
Specific Gravity	1.017	1.02	1.018	-

Biological & Chemical Oxygen Demands

	mg/l
B.O.D. (5 days)	3,000
C.O.D.	18,000

* Slag quench water.

m. Condensible Naphtha Analysis (Collected at Flare)

Analysis, Wt. %	Overall Frances	Overall Ohio 9
Carbon	91.7	90.6
Hydrogen	9.3	9.4
Nitrogen	<0.01	<0.01
Sulfur	0.14	1.15
Chlorine	<0.1	<0.1
Ash	Nil	Nil
Water	Nil	Nil
Heating Value, Btu/lb.	17,980	18,645

3. Heat and Material Balance - Frances Coal & Blast Furnace Slag Flux

Material Balance, Pounds (Basis: 1,000 pounds dry coal and flux)

Input	Rate	Carbon	Hydrogen	Nitrogen	Sulfur	Oxygen	Chlorine	Ash	Heat Balance Therms/Hr.
Coal/Flux	1089	673	54	11	6	132	1	212	2152
Steam	307		34			273			80
Fuel Gas	5	4	1						22
Recycle Tar	23	19	2			2			66
Oxygen/Air	534			90		444			-
	1958	696	91	101	6	851	1	212	2320
Output									
Heat Loss									47
Methane	73	55	18						344
Carbon Mon-oxide	1135	487				648			992
Hydrogen	41		41						505
Carbon Di-oxide	75	20				55			3
Inert Gas	85			85					3
Ethylene	4	3	1						17
Ethane	13	10	3						56
Ammonia	4		1	3					-
Hydrogen Sulfide	3				3				4
Tar	73	63	6			4			243
Naphtha	7	7							25
Liquor	201	1	22			176	2		53
Slag	215	3						212	38
	1929	649	92	88	3	883	2	212	2330
Input-Output Error, %	-1.5	-6.7	+1.1	-12.9	-50.0	+3.8	+100.0	0	+0.4

4. Data Used in Balances - Frances Coal

Coal Heating Value, Btu/lb.	9,348*

Coal Proximate Analysis	Wt. %*
Moisture	8.19
Ash	19.40
Volatile Matter	28.73
Fixed Carbon	43.68
	100.00

DAF Coal Ultimate Analysis	Wt. %
Carbon	85.35
Hydrogen	5.64
Nitrogen	1.38
Oxygen	6.66
Sulfur	0.79
Chlorine	0.18
	100.00

Gas Composition	Vol. %
Methane	6.42
Carbon Monoxide	56.97
Hydrogen	28.70
Carbon Dioxide	2.40
Inert Gas	4.27
Ethylene	0.20
Ethane	0.60
Hydrogen Sulfide	0.12
Ammonia	0.32
	100.00

Crude Gas Offtake Temperature	469^{o}C
Gasifier Pressure	350 psig
Heat Loss from Jacket & Hearth	9.24 therms/hour
Jacket Steam Production	2025 lb/hour

* Includes flux.

Byproducts

Composition Wt. %	Naphtha	Product Tar	Recycle Tar	Minor Liquor Comp.
Carbon	90.66	85.61	81.19	18.07
Hydrogen	9.20	7.50	6.80	-
Nitrogen	-	0.90	0.95	-
Sulfur	0.14	0.67	1.21	2.38
Chlorine	-	-	-	48.18
Oxygen	-	5.12	8.14	31.37
Ash	-	0.20	1.71	-
	100.00	100.00	100.00	100.00

Heating Value	Btu/lb.
Naphtha	17,980
Product Tar	16,565
Recycle Tar	14,694
Minor Liquor Components	0

5. <u>Performance Data - Frances Coal</u>

Steam Consumption	3.22 lb/therm gas
Steam Decomposition	79.64%
Oxygen Consumption	54.91 SCF/therm gas 13,316 SCF/ton DAF coal
Crude Gas Production*	242.5 therms/ton DAF coal
Gas Liquor Yield	2.02 lb/therm gas

Thermal Efficiencies, %	Gas Only	Gas, Tar, Oil & Naptha
$\frac{\text{Crude Gas}}{\text{Coal}}$	85.39	90.11
$\frac{\text{Crude Gas}}{\text{Coal, Steam \& Oxygen}}$	74.52	82.36

* Includes coal lock gas.

6. Heat and Material Balance - Ohio No. 9 Coal & Blast Furnace Slag Flux

Material Balance, Pounds (Basis: 1,000 pounds dry coal and flux)

Input	Rate	Carbon	Hydrogen	Nitrogen	Sulfur	Oxygen	Chlorine	Ash	Heat Balance Therms/Hr.
Coal/Flux	1045	552	45	9	35	73	1	330	1937
Steam	297		33			264			80
Fuel Gas	5	4	1						22
Recycle Tar	44	36	3			5			133
Oxygen/Air	519			86		433			-
	1910	592	82	95	35	775	1	330	2172
Output									
Heat Loss									42
Methane	66	50	16						322
Carbon Monoxide	930	399				531			838
Hydrogen	38		38						483
Carbon Dioxide	125	34				91			5
Inert Gas	88			86					4
Ethylene	3	2	1						13
Ethane	10	8	2						44
Ammonia	3		1	2					-
Hydrogen Sulfide	29		2		27				42
Carbonyl Sulfide	4	1			2	1			-
Tar	68	58	5		1	4			232
Naphtha	6	6							25
Liquor	158	1	17			140			43
Slag	339	9						330	71
	1867	568	82	90	30	767	0	330	2164
Input-Output Error, %	-2.3	-4.1	0	-5.3	-14.3	-1.0	-100.0	0	-0.4

7. Data Used in Balances - Ohio No. 9 Coal

Coal Heating Value, Btu/lb.	8,505*

Coal Proximate Analysis	Wt. %*
Moisture	4.27
Ash	31.61
Volatile Matter	28.71
Fixed Carbon	35.41
	100.00

DAF Coal Ultimate Analysis	Wt. %
Carbon	82.36
Hydrogen	6.00
Nitrogen	1.31
Oxygen	4.99
Sulfur	5.25
Chlorine	0.09
	100.00

Gas Composition	Vol. %
Methane	6.49
Carbon Monoxide	52.09
Hydrogen	29.71
Carbon Dioxide	4.45
Inert Gas	4.94
Ethylene	0.17
Ethane	0.51
Hydrogen Sulfide	1.33
Ammonia	0.31
	100.00

Crude Gas Offtake Temperature	456°C
Gasifier Pressure	350 psig
Heat Loss from Jacket & Hearth	9.73 therms/hour
Jacket Steam Production	1650 lb/hour

* Includes flux.

Byproducts

Composition Wt. %	Naphtha	Product Tar	Recycle Tar	Minor Liquor Comp.
Carbon	89.57	85.40	81.17	23.98
Hydrogen	9.29	7.50	6.76	-
Nitrogen	-	0.60	1.11	-
Sulfur	1.14	1.42	1.03	6.78
Chlorine	-	-	-	5.29
Oxygen	-	4.90	8.62	63.95
Ash	-	0.18	1.31	-
	100.00	100.00	100.00	100.00

Heating Value	Btu/lb.
Naphtha	18,645
Product Tar	16,360
Recycle Tar	15,053
Minor Liquor Components	0

8. Performance Data - Ohio No. 9 Coal

Steam Consumption	3.61 lb/therm gas
Steam Decomposition	78.71%
Oxygen Consumption	61.37 SCF/therm gas 15,100 SCF/ton DAF coal
Crude Gas Production*	246.0 therms/ton DAF coal
Gas Liquor Yield	1.85 lb/therm gas

Thermal Efficiencies, %	Gas Only	Gas, Tar, Oil & Naphtha
Crude Gas / Coal	84.33	90.32
Crude Gas / Coal, Steam & Oxygen	72.61	77.77

* Includes coal lock gas.

TSP Run 7

Feed Coal: Metallurgical Coke and Ohio No. 9 Coal/Coke Layered
Date of Run: December 18-21, 1977

1. Run Diary

Date	Time	Event
Dec 18	0835	Preparations were made for startup with the gasifier full of petroleum coke and pressurized with nitrogen.
	0905	The petroleum coke was ignited.
	0935	Air was admitted to the tuyeres.
	1118	Gasifier lined out on blast furnace metallurgical coke at oxygen loading of 160,000 SCFH and 350 psig; first test period started.
	2315	First test period on coke completed. Coke locking was switched to raw gas with no problems. Steam/oxygen ratio was reduced for ranging tests. (1.15 - 1.45).
Dec 19	0730	Oxygen loading reduced to 130,000 SCFH.
	1530	Steam/oxygen ratio was altered.
	2330	Steam/oxygen ratio was adjusted to 1.30 with loading unchanged in preparation for feeding Ohio No. 9 coal alternately with coke (2 locks of coke to 1 of coal).
Dec 20	0718	First full lock of Ohio No. 9 fed to gasifier.
	0738	Obvious signs of Ohio No. 9 coal in the gasifier with some irregularities in bed DP. Continued feeding Ohio No. 9 coal at a 1:2 coal to coke ratio.
	1445	Coal charging was switched to alternating locks of Ohio No. 9 coal and metallurgical coke (1:1 coal to coke ratio).
	2245	Coal charging switched to two locks of Ohio No. 9 coal followed by one lock of coke. (2:1 coal to coke ratio). No radical differences from 1:1 ratio.
Dec 21	0610	Coal charging switched to 3 locks of Ohio No. 9 coal followed by one lock of coke (3:1 coal to coke ratio). Problems with tuyeres flashing and offtake temperature fluctuations were encountered during this period.

Run Diary continued

Date	Time	Event
Dec 21	1550	It was decided not to proceed with the planned 4:1 coal to coke ratio but to revert back to the 2:1 ratio after first feeding four successive locks of coke.
	1800	Gasifier running on 2 locks of coal to one lock of coke.
	1930	Continuous locks of coke were fed to the gasifier to try and reduce slag fouling in the quench chamber.
	2025	Run was terminated using standard procedures due to slag fouling in the quench chamber.

Summary Date	Time	Fuel Fed to Gasifier
Dec 18-20	1000-0718	Randolph Colliery Coke (Metallurgical).
Dec 20	0718-1445	Layering: 1 lock Ohio No. 9 Coal to 2 locks Coke.
Dec 20	1445-2245	Layering: 1 lock Coal to 1 lock Coke.
Dec 20-21	2245-0610	Layering: 2 locks Coal to 1 lock Coke.
Dec 21	0610-1550	Layering: 3 locks Coal to 1 lock Coke.
Dec 21	1550-1800	Layering: 2 locks Coal to 1 lock Coke.
Dec 21	1800-2025	Metallurgical Coke only.

2. Raw Data

a. Ohio No. 9 Coal & Randolph Colliery Coke (Metallurgical)

Proximate Analysis (Air Dried), Wt. %		Moisture	Ash	Volatile Matter	Fixed Carbon
Randolph Colliery Coke					
Date	Time				
Dec 18-19	1300-0530	2.15	9.64	5.09	83.12
Dec 19-20	0630-0530	1.09	8.08	1.44	89.39
Ohio No. 9 Coal					
Dec 20-21	1830-0530	2.25	20.38	30.62	46.75
Dec 21	0630-2030	2.64	23.51	30.53	43.32

Ultimate Analysis (Air Dried), Wt. %	Coke Dec 18-19	Coke Dec 19-20	Ohio 9 Dec 20-21	Ohio 9 Dec 21
Carbon	82.90	87.20	61.10	57.70
Hydrogen	1.10	0.80	4.00	3.80
Nitrogen	1.00	1.00	0.90	1.06
Sulfur	1.18	1.07	3.58	3.26
Chlorine	0.03	0.02	0.04	0.04
Ash	9.64	8.08	20.38	23.51
Water	2.15	1.09	2.25	2.64
Oxygen (Diff.)	2.00	0.74	7.75	7.99
	100.00	100.00	100.00	100.00
Heating Value (Air Dried), Btu/lb.	12,158	12,367	10,865	10,329

Size Analysis, Wt. %	Dec 18	Dec 19			Dec 20		Dec 21
	1600*	0015*	1300*	2030*	1335	2230	1315
over 1-1/4"	30.0	72.5	19.0	48.0	-	0.5	4.0
1"-1/1/4"	34.0	19.0	34.5	28.0	2.0	4.0	7.5
3/4"-1"	31.0	7.5	36.0	15.5	28.0	40.0	39.0
1/2"-3/4"	4.0	-	8.0	6.5	44.0	38.0	30.5
3/8"-1/2"	0.5	1.0	0.5	1.0	16.0	11.5	13.0
1/4"-3/8"	0.5	-	0.5	0.25	3.0	0.5	1.0
1/8"-1/4"	-	-	1.5	0.25	6.5	3.0	2.0
under 1/8"	-	-	-	0.5	0.5	2.5	3.0
Bulk Density, Lbs/CF	31	32	31	34	49	49.5	48
Moisture Content	8.0	6.5	5.5	ND	7.5	6.0	7.5

* Randolph Colliery Coke; others are Ohio No. 9 coal.

b. Flux – Blast Furnace Slag

Date:	Dec 18	Dec 19			Dec 20		Dec 21	
Time:	1600	0015	1300	2300	1335	2230	1315	2100
Bulk Density, Lbs/Cf	70.0	72.0	70.0	72.0	70.5	74.0	68.0	ND
Moisture Content, Wt. %	7.0	5.5	5.5	ND	6.5	6.5	ND	6.5

c. Slag

	Coke			1:1 Layer	3:1 Layer	Coke
Date:	Dec 18-19	Dec 19	Dec 19-20	Dec 20	Dec 21	Dec 21
Time:	1830-0530	0630-1730	1830-0530	1630-2230	0700-1600	2030
Component, Wt. %						
SiO_2	33.6	34.1	34.6	40.3	42.8	42.4
Al_2O_3	15.5	15.6	16.6	18.1	18.9	18.4
CaO	34.3	32.5	32.1	26.4	22.4	23.2
MgO	10.4	11.0	11.1	8.2	6.1	6.8
Fe_2O_3	2.5	3.5	2.8	5.8	8.4	7.9
Carbon	0.17	.23	.26	.66	.50	.45
	96.5	96.9	97.5	99.5	99.1	99.2
Free Iron as Fe	0.10	0.11	0.10	0.50	0.38	0.19
FeO	2.15	2.59	2.50	4.10	7.15	6.61
Total Iron as Fe	1.75	2.45	1.96	4.06	5.88	5.53
Fe^{+2}	1.67	2.01	1.94	3.19	5.56	5.14
Fe^{+3}	Nil	.33	Nil	.37	Nil	.20
Silica No.	42	42	43	50	54	53
Loss on Ignition, % *	+0.3	+0.2	+0.3	+1.1	+1.8	+1.6

* + is a gain.

d. Oxygen Purity, Vol. %

Date	Time	Oxygen	Nitrogen	Argon
Dec 18	1115	97.9	1.7	0.4
	1500	96.6	2.3	1.1
	1930	84.5	13.7	1.8
	2015	93.3	3.0	3.7
Dec 19	0015	93.3	ND	ND
	0330	95.5	ND	ND
	0900	98.2	1.8	0.0
	1320	97.1	2.0	ND
	1750	98.0	2.0	0.0
	1935	96.1	4.0	0.0
Dec 20	0020	96.5	ND	ND
	0400	94.3	ND	ND
	0620	96.5	ND	ND
	1050	96.2	3.8	0.0
	1645	97.1	3.8	0.1
	1900	95.5	4.5	0.0
	2230	97.3	ND	ND
Dec 21	0245	98.3	ND	ND
	0645	97.4	ND	ND
	1110	97.4	2.6	0.0
	1500	98.3	1.6	0.1
	1900	97.9	2.1	0.0

e. Recycle Tar

Ultimate Analysis (Dry, Dust Free), Wt. %	Dec 18-20 1000-0900	Dec 20 0945-2030
Carbon	86.5	84.1
Hydrogen	6.8	7.0
Nitrogen	0.9	1.1
Sulfur	1.2	1.3
Chlorine	0.14	0.15
Ash	0.19	0.09
Water	Nil	Nil
Heating Value, Btu/lb.	16,007	16,216

Moisture and Dust Content, Wt. %

Date	Time	Moisture	Dust
Dec 19	1345	ND	40
Dec 20	0945	12.6	22
Dec 20	2200	0.3	ND
Dec 21	1105	29.2	16.6
Dec 21	2200	20.0	20.0

e. **Recycle Tar continued**

Dust Proximate Analysis (Air Dried)	Wt. %
Moisture	0.77
Ash	29.26
Volatile Matter	1.37
Fixed Carbon	68.6
	100.00

Dust Ultimate Analysis (Air Dried), Wt. %	Dec 18-20 1000-0900	Dec 20 0945-2030
Carbon	75.0	68.6
Hydrogen	0.8	1.0
Nitrogen	1.1	0.7
Sulfur	1.94	2.32
Chlorine	0.04	0.03
Ash	21.95	29.26
Water	0.46	0.77
Dust Heating Value, Btu/lb.	10,985	10,038

f. **Crude Synthesis Gas (Main Stream Samples)**

Analysis (Dry Basis), Vol. %

Date:	Dec 18					Dec 19								Dec 20			
Time:	1320	1515	1615	1800	1040–2120	0550	0430	0315–0515	1020–1120	1130	1850	1725–2130	2130	0215	0300	0330	0520
CH_4	0.52	0.37	0.42	0.37	0.3	0.38	0.46	0.46	0.47	0.45	0.71	0.5	.5	0.7	0.7	0.47	0.62
CO_2	1.7	1.68	1.88	3.39	2.3	3.05	3.16	3.42	3.83	3.66	1.77	3.2	3.4	2.47	2.27	3.36	3.48
C_2H_4	Nil	-	-	-	-	-	0.01	0.01	0.04	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.01
C_2H_6	Nil	-	-	-	-	-	0.03	0.02	0.06	0.04	0.03	0.04	0.04	0.03	0.03	0.02	0.03
H_2S	Trace	0.07	0.15	0.15	0.20	0.18	0.28	0.28	0.25	0.10	0.21	0.19	0.2	0.19	0.17	0.18	0.19
H_2	25.96	28.3	26.67	28.35	25.6	27.42	27.42	27.42	28.5	28.34	25.1	24.9	25.3	26.38	26.69	26.69	27.03
O_2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ar	0.67	0.86	0.90	0.91	0.9	0.80	0.85	0.82	0.43	0.36	0.31	0.5	0.4	0.52	0.42	0.46	0.40
N_2	2.46	3.66	2.75	2.49	3.9	2.72	2.31	2.5	2.4	2.86	2.43	4.4	4.0	3.29	2.58	2.49	2.97
CO	67.05	64.15	64.44	63.04	64.5	63.1	63.42	63.42	61.5	60.44	68.85	66.1	66.1	65.05	66.34	64.62	64.97
	98.36	99.09	97.21	98.7	97.7	97.73	97.94	98.35	97.48	96.27	99.42	99.85	99.96	98.64	99.21	98.3	99.7

f. **Crude Synthesis Gas continued**

Analysis (Dry Basis), Vol. %

Date:	Dec 20							Dec 21							
Time:	0900	1050	1330	1500	1745	2145	2330	0050	0330	0530	0930	1110	1315	1500	1730
CH_4	2.9	4.21	3.69	0.96	2.68	4.61	5.0	4.92	2.41	4.25	2.10	5.68	4.34	5.01	3.24
CO_2	3.94	2.28	2.35	2.15	2.12	2.12	2.73	3.09	3.10	3.35	2.78	3.19	4.24	3.34	2.23
C_2H_4	0.03	0.10	0.11	0.01	0.06	0.11	0.11	0.08	0.02	0.08	0.02	0.13	0.10	0.13	0.09
C_2H_6	0.12	0.30	0.37	0.05	0.22	0.32	0.37	0.28	0.08	0.30	0.17	0.38	0.36	0.4	0.27
H_2S	0.65	0.44	0.81	0.53	0.57	0.47	0.47	0.47	0.48	0.47	0.69	1.01	1.15	1.05	0.59
H_2	28.24	27.75	25.68	26.46	26.15	26.7	26.83	27.94	27.41	26.66	26.65	26.8	27.1	27.13	26.45
O_2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ar	0.4	0.38	0.53	0.55	0.39	0.57	0.60	0.6	0.56	0.47	0.43	0.63	0.74	0.58	0.55
N_2	3.17	2.22	3.18	2.85	2.82	2.73	2.01	2.69	3.32	2.66	2.64	3.26	2.98	2.89	3.15
CO	59.44	62.30	63.49	65.0	62.32	60.86	60.29	58.02	60.30	59.16	61.73	56.3	56.16	57.58	62.32
	98.89	99.98	100.21	98.56	97.33	98.49	98.41	98.09	97.68	97.4	97.21	97.38	97.17	98.11	98.89

f. Crude Synthesis Gas continued

Minor Constituents, g/m^3

Date	Time	Naphtha-lene	NH_3	HCN_3	Condensate
Dec 18	1750	.0018	.0023	.0216	Nil
Dec 19	0100-1450	.021	.0072	.023	Nil
	1100-1450	.0009	.015	.0096	Nil
	1805-2115	ND	.0017	.017	Nil
Dec 20	0200-0500	ND	.004	.025	Nil
	1200-1500	.0046	.006	.019	7.14
	2100-0100	ND	.012	.022	Nil
Dec 21	0300-0600	ND	.01	.018	Nil
	1500-1715	.0014	.056	.0415	4.88
	2100-0010	ND	.012	.024	Nil

Sulfur Content, PPM

Date	Time	COS	CS_2	Thiophenes
Dec 18	1830	345	5.3	3.0
Dec 19	0400	280	4.7	ND
	1300	281	1.3	Nil
	1910	358	1.3	Nil
Dec 20	0315	307	1.1	Nil
	0520	303	1.3	Nil
	1210	510	6.4	Nil
	1915	851	8.2	4.6
Dec 21	0100	585	4.0	3.0
	0600	1030	13.0	7.0
	1715	1180	25.6	7.8

g. Flash Gas From Oil Separator

Analysis, Vol. %

Date:	Dec 20
Time:	1050
CH_4	2.12
CO_2	4.06
C_2H_4	0.07
C_2H_6	0.14
H_2S	0.85
H_2	26.64
Ar	0.58
N_2	3.62
CO	60.30
	98.38

h. Flash Gas From Tar Separator

Gas Analysis, Vol. %

Date:	Dec 20
Time:	1500
CH_4	1.18
CO_2	9.39
C_2H_4	0.02
C_2H_6	0.04
H_2S	5.27
H_2	24.40
Ar	0.55
N_2	2.65
CO	53.30
NH_3	0.27
	97.07

Condensate

	Dec 20
	1500
Vol. of Gas, liter	0.17
Vol. of Cond., liter	7.0
NH_3, g/l	3.09
H_2S, g/l	2.55
CO_2, g/l	3.85

Gas

HCN, g/m^3	0.0817

i. Side Stream Samples

Sample	S/S1	S/S2	S/S3	S/S4
Date	Dec 18	Dec 19	Dec 19	Dec 19
Time Period	1640-2115	0315-0725	1010-1510	1725-2115
Gas Volume, SCF	693.8	802.9	1195.0	714.5
Tar/Oil Product, grams	33.7	38.9	464.0	494.7
Gas Liquor Product, grams	935.6	1689.4	4628.9	1849.4
Dust, grams	1.0	2.7	1.0	2.6

j. Crude Synthesis Gas Composition (Side Stream Sample)

Analysis, Vol. %	S/S1	S/S2	S/S3	S/S4
CH_4	0.30	0.31	.43	.5
CO_2	3.00	4.56	5.34	3.6
C_2H_4	Nil	.01	.02	.02
C_2H_6	Nil	.01	.06	.02
H_2S	0.08	.26	.23	.22
H_2	25.3	27.87	28.82	25.3
Ar	0.9	.89	.57	.5
N_2	4.2	2.64	2.04	2.4
CO	63.6	61.43	62.57	64.7
O_2	1.8	0	0	0
	99.18	97.98	100.08	97.26
Minor Constituents, g/m^3				
NH_3, g/m^3	Nil	0.0086	0.018	0.003
HCN, g/m^3	0.033	0.018	0.028	ND
Naphthalene g/m^3	ND	0.019	0.0117	ND
Condensibles	Nil	Nil	Nil	Nil
COS, PPM	350	310	291	419
CS_2, PPM	5.8	5.6	1.1	1.68
Thiophenes, PPM	3.0	Trace	Nil	Nil

k. Combined Tar and Oil (Side Stream Sample)

Ultimate Analysis, Wt. %	Composite S/S 3 & 4
Carbon	87.0
Hydrogen	7.2
Nitrogen	1.0
Ash	Nil
Water	Nil
Sulfur	1.18
Chlorine	0.17
Oxygen (Diff.)	3.45
	100.00

Heating Value, Btu/lb.	16,272

l. Gas Liquor Analysis (Side Stream Samples)

PPM	S/S1	S/S2	S/S3	S/S4
Total Dissolved Solids	3045	1891	2248	2704
Total Sulfur	54.8	28.4	27.9	36.9
Total Ammonia	2057	1496	1496	1428
Free Ammonia	1360	1429	952	1105
Fixed Ammonia	697	67	544	323
Carbonate as CO_2	3850	3300	3080	2420
Chloride	1418	1241	886	709
pH	8.62	8.44	7.3	8.21
Specific Gravity	1.00	1.00	1.0002	1.00

m. Naphtha (Main Stream Sample)

Ultimate Analysis, Wt. %		
Carbon	89.0	89.0
Hydrogen	9.3	9.3
Nitrogen	0.1	< 0.1
Sulfur	1.15	1.15
Chlorine	< 0.1	< 0.1
Ash	Nil	Nil
Water	Nil	Nil

Heating Value, Btu/lb.	18,420

n. Slag Found In Hearth At End Of Run

Component	Wt. %
SiO_2	95.9
Al_2O_3	Nil
Fe_2O_3	6.4
CaO	3.4
MgO	Nil

3. Heat and Material Balance - Randolph Colliery Metallurgical Coke - Blast Furnace Slag Flux

Material Balance, Pounds (Basis: 1,000 pounds per hour of dry fuel and flux)

Input	Rate	Carbon	Hydrogen	Nitrogen	Sulfur	Oxygen	Chlorine	Ash	Heat Balance Therms/Hr.
Coal/Flux	1054	676	15	8	10	66	<1	279	2032
Steam	496		56			440			137
Fuel Gas	4	3	1						22
Recycle Tar	20	14	1			3		2	48
Oxygen/Air	754			104		650			-1
	2328	693	73	112	10	1159	<1	281	2238
Output									
Heat Loss									48
Methane	6	4	2						33
Carbon Monoxide	1518	651				867			1507
Hydrogen	47		47						636
Carbon Dioxide	129	35				94			14
Inert Gas	79			79					8
Ethylene	<1								1
Ethane	1	1							2
Ammonia	<1								0
Hydrogen Sulfide	8		1		7				13
Carbonyl Sulfide	1				1				-
Tar	3	3							12
Liquor	173		19			154	<1		71
Slag	282	1						281	44
	2247	695	69	79	8	1115	<1	281	2389
Input-Output Error, %	-3.5	+0.3	-5.4	-29.5	-20.0	-3.8	-	0	+6.7

4. Data Used in Balances - Coke

Coal Heating Value, Btu/lb.	9410*

Coal Proximate Analysis	Wt. %*
Moisture	5.26
Ash	26.47
Volatile Matter	3.94
Fixed Carbon	64.33
	100.00

DAF Coal Ultimate Analysis	Wt. %
Carbon	93.87
Hydrogen	1.25
Nitrogen	1.13
Oxygen	2.38
Sulfur	1.34
Chlorine	0.03
	100.00

Gas Composition	Vol. %
Methane	0.48
Carbon Monoxide	64.47
Hydrogen	27.87
Carbon Dioxide	3.48
Inert Gas	3.37
Ethylene	0.01
Ethane	0.02
Hydrogen Sulfide	0.28
Ammonia	0.02
	100.00

Crude Gas Offtake Temperature	574°C
Gasifier Pressure	350 psig
Heat Loss from Jacket & Hearth	13.51 therms/hour
Jacket Steam Production	1800 lb/hour

* Includes flux.

Byproducts

Composition Wt. %	Product Tar	Recycle Tar	Minor Liquor Components
Carbon	87.00	70.95	19.70
Hydrogen	7.20	5.11	-
Nitrogen	1.00	0.86	-
Sulfur	1.18	1.32	0.62
Chlorine	0.17	-	27.16
Oxygen	3.45	13.49	52.52
Ash	-	8.27	-
	100.00	100.00	100.00

Heating Value	Btu/lb.
Product Tar	16,272
Recycle Tar	12,115
Minor Liquor Comp.	0

5. Performance Data - Coke

Steam Consumption	5.14 lb/therm gas
Steam Decomposition	76.35%
Oxygen Consumption	80.02 SCF/therm gas 21,407 SCF/ton DAF coal
Crude Gas Production*	267.5 therms/ton DAF coal

Thermal Efficiencies, %	Gas Only	Gas, Tar, Oil & Naphtha
Crude Gas / Coal	97.05	96.02
Crude Gas / Coal, Steam & Oxygen	77.88	77.05

* Includes coal lock gas.

TSP Run 8

Feed Coal: Ohio No. 9 and Randolph Metallurgical Coke
Date of Run: February 26 - March 1, 1978

1. Run Diary

Date	Time	Event
Feb 26	0550	Gasifier full of petroleum coke; coke ignited.
	0937	Commenced gasification of Randolph metallurgical coke at 350 psig and steam/oxygen ratio of 1.15; blast furnace slag flux; 160,000 SCFH oxygen rate.
	1137	Faulty vent control valve on oxygen supply caused full pressure standby. Clinkering problems on the moving fluidized grate of the boiler impeded steam supply.
	1547	Gasifier on line at 275 psig and steam/oxygen ratio of 1.15; Randolph coke at full gasification rates and 350 psig.
	1730	Oxygen preheated to 200°F but preheater turned off because of irregular offtake temperatures and uneven slag tapping.
	2235	Preheater turned back on. Tuyeres became brighter. At full gasification rates and steady performance.
Feb 27	0033	Oxygen loading reduced.
	0125	Oxygen loading at 130,000 SCFH.
	0225	Distributor revolution rate increased.
	0300	Started charging alternating locks of Ohio No. 9 coal and Randolph coke.
	0326	Ohio No. 9 coal enters hearth.
	0334	Tuyeres dim and flash.
	0350	Number 3 Stream Wash Cooler Pump problem. All flow down Number 4 Stream.
	1525	Began coke only feeding to gasifier.
	1811	Began feeding 50/50 blend of Ohio No. 9 coal and Randolph coke to gasifier.
	1855	Tuyeres began to flash.
	2037	Coal Lock hydraulics failed. Gasifier on standby.
	2107	Gasifier back to full load on coke feed.
	2242	50/50 blended feed restarted.
	2335	Tuyeres began to flash.
Feb 28	0250	Distributor revolution rate close to zero, and offtake temperature rose. Rates were dropped.

Run Diary continued

Date	Time	Event
Feb 28	0305	Distributor reset. Coke only fed to gasifier.
	0435	Blended feed restarted. Distributor at lower speed.
	1121	Distributor revolution rate increased.
	1535	Slag runs interfered with by slag growths beneath the slag tap.
	1900	Coke only fed to gasifier.
	2243	Layering of coal to coke at two to one ratio started.
Mar 1	0045	Coke only fed to gasifier.
	0840	Ohio No. 9 coal only fed to gasifier.
	0908	Shutdown of gasifier.

Summary

Date	Time	Fuel Fed To Gasifier
Feb 26-27	0937-0300	Metallurgical coke only.
Feb 27	0300-1525	Alternate locks of Ohio No. 9 coal and coke.
Feb 27	1525-1811	Metallurgical coke only.
Feb 27	1811-2107	50/50 blend Ohio No. 9 coal and coke.
Feb 27	2107-2242	Metallurgical coke only.
Feb 27-28	2242-0305	50/50 blend Ohio No. 9 coal and coke.
Feb 28	0305-0435	Metallurgical coke only.
Feb 28	0435-1900	50/50 blend Ohio No. 9 coal and coke.
Feb 28	1900-2243	Metallurgical coke only.
Feb 28-Mar 1	2243-0045	2:1 layering of coal and coke.
Mar 1	0045-0840	Metallurgical coke only.
Mar 1	0840-0908	Ohio No. 9 coal only.

2. Raw Data

a. Ohio No. 9 Coal and Metallurgical Coke*

Proximate Analysis (Air Dried), Wt. %	Coke Feb 27 0125-0310	Ohio 9 Feb 27 0410-1710	1:1 Blend Feb 27-28 2010-1910	Ohio 9 Feb 28-Mar 1 0210-0110
Moisture	2.88	2.68	2.84	2.70
Ash	9.80	18.14	22.14	22.20
Volatile Matter	9.33	31.74	24.00	29.13
Fixed Carbon	77.99	47.44	51.02	45.97
Ultimate Analysis (Air Dried), Wt. %				
Carbon	82.3	62.3	59.8	59.7
Hydrogen	1.6	4.3	3.8	4.0
Nitrogen	1.1	0.9	0.8	0.8
Sulfur	0.90	3.57	3.46	4.23
Chlorine	0.07	0.05	0.04	0.04
Heating Value (Air Dried), Btu/lb.	12,054	11,211	10,771	10,541

Size Analysis, Wt. %	Feb 27		Feb 28		Mar 1
	0430	1200	0030	1430	0030
over 1-1/4"	Nil	Nil	9.0	26.0	2.0
1-1/4"-1"	2.5	6.0	17.0	21.0	5.0
1"-3/4"	28.0	43.0	28.0	25.0	26.0
3/4"-1/2"	53.0	24.0	18.0	11.5	48.5
1/2"-3/8"	9.0	14.0	14.0	6.5	12.5
3/8"-1/4"	4.5	5.0	8.0	3.0	4.0
1/4"-1/8"	1.5	2.0	4.0	2.0	1.5
under 1/8"	1.5	6.0	2.0	5.0	0.5
Bulk Density, Lbs/CF	55	54	55.5	46	53.5

Moisture Content

Date	Time	Wt. %
Feb 27	0410	8.0
	1200	6.0
	1800	6.5
Feb 28	0030	11.0
	1430	11.0
Mar 1	0030	7.5

* TSP Run 8 included operating periods of 1:1 layering of coal and coke (alternate locks), 1:1 blend of coal and coke, and 2:1 layering of coal and coke (2 locks coal: 1 lock coke).

Coal and Coke continued

Ash Analysis, Wt. %	Metallurgical Coke	Ohio No. 9 Coal
SiO_2	44.6	52.3
Al_2O_3	26.7	25.5
CaO	5.6	4.2
MgO	1.7	Nil
Fe_2O_3	19.0	17.7
	97.6	99.7
Silica Number	63	70

b. Flux - Blast Furnace Slag

Component, Wt. %	Composite
SiO_2	35.7
Al_2O_3	12.0
CaO	34.0
MgO	11.4
Fe_2O_3	1.4
	94.5
Silica Number	43
Loss on Ignition, %	-1.2

Date	Time	Bulk Density, Lbs/CF	Moisture, Wt.%
Feb 27	0430	76	8.0
	1200	77	7.0
	1800	ND	8.0
Feb 28	0030	75	7.5
	1430	76	8.0
Mar 1	0030	78	7.0

c. Slag

Feed:	Coke	1:1 Layer	1:1 Blend	1:1 Blend	2:1 Layer	Coke
Date:	Feb 27	Feb 27	Feb 27-28	Feb 28	Mar 1	Mar 1
Time:	0125-1310	0410-1510	2010-1040	1140-1910	0010	0910
Component, Wt. %						
SiO_2	40.6	44.6	44.6	46.7	42.4	40.2
Al_2O_3	17.6	18.6	18.5	18.7	19.1	20.5
CaO	27.2	19.9	22.2	21.1	19.9	28.1
MgO	8.6	6.5	6.5	5.6	4.6	8.0
Fe_2O_3	2.4	8.4	6.3	7.0	11.8	2.1
Carbon	0.5	0.8	0.5	0.5	0.7	0.5
	96.9	98.8	98.6	99.6	98.5	99.4
Free Iron as Fe	0.6	0.6	0.8	0.6	1.5	1.2
FeO	1.3	5.9	0.2	0.8	8.1	0.4
Total Iron as Fe	1.7	5.9	4.4	4.9	8.3	1.5
Fe^{+2}	1.0	4.6	Nil	0.7	6.3	0.3
Fe^{+3}	0.1	0.7	3.6	3.6	0.5	Nil
Total Sulfur	0.32	0.36	0.45	0.50	1.29	0.52
Sulfide,S	0.14	0.27	0.38	0.46	0.50	0.27
Silica No.	52	56	56	58	53	51
Loss on Ignition,%*	+0.7	+2.0	+0.8	+1.8	+2.8	+0.5

* + is a gain.

d. Oxygen Purity, Vol. %

Date	Time	Oxygen	Nitrogen	Argon
Feb 26	1700	96.1	ND	ND
	2130	95.21	4.7	0.005
Feb 27	0015	94.0	5.9	0.1
	0530	96.3	3.6	0.2
	1430	95.7	3.8	0.5
	2130	94.1	5.6	0.3
Feb 28	0350	96.1	2.5	1.4
	1300	96.2	3.3	0.5
	1900	96.1	3.5	0.4
	2300	97.0	2.6	0.4
Mar 1	0500	98.5	1.3	0.2

e. Recycle Tar

Ultimate Analysis (Dry, Dust Free), Wt. %	Feb 28 0020	Mar 1 0220	Tar Solids Overall Run
Carbon	86.3	86.9	61.8
Hydrogen	6.9	6.8	1.0
Nitrogen	1.0	0.9	0.6
Sulfur	1.34	1.42	2.56
Chlorine	0.03	0.04	0.035
Ash	Nil	Nil	33.28
Water	Nil	Nil	0.38
	95.57	96.06	99.655
Heating Value, Btu/lb.	16,207	16,335	9,178

Moisture Content

Date	Time	Wt. %
Feb 27	0200	10.4
	1645	16.0
Feb 28	0020	13.6
Mar 1	0230	10.8

f. <u>Crude Synthesis Gas (Main Stream Samples)</u>

<u>Analysis (Dry Basis), Vol. %</u>

Date:	Feb 26	Feb 27													
Time:	2100	0010	0350	0430	0550	0640	0720	0915	1100	1200	1214	1835	2130	]]24	2400
CH_4	0.47	0.48	1.65	1.18	1.42	2.36	2.77	4.2	2.44	4.43	4.2	3.4	0.63	0.63	3.87
CO_2	1.00	1.99	1.87	1.83	2.21	2.71	2.03	3.2	1.33	3.01	2.2	1.77	2.48	1.87	2.36
C_2H_4	-	-	0.16	-	-	0.06	0.07	0.07	-	0.13	0.11	0.08	-	-	0.09
C_2H_6	-	-	-	-	-	0.18	0.27	0.25	0.15	0.34	0.33	0.21	-	-	0.29
H_2S	Trace	Trace	0.45	0.49	0.45	0.73	0.45	0.75	0.75	0.89	0.84	0.95	0.34	0.22	0.77
H_2	24.41	25.14	25.99	26.39	27.23	27.66	25.6	27.46	27.11	26.87	28.2	24.56	26.03	25.6	25.86
Ar	0.62	0.87	1.01	0.99	0.86	0.88	0.85	0.78	0.82	0.80	0.76	0.89	1.02	0.78	0.82
N_2	4.93	3.8	3.31	3.84	3.74	2.55	3.18	3.95	3.26	3.10	3.84	3.56	3.92	3.95	2.72
CO	64.62	63.28	60.78	60.28	57.51	59.53	61.72	55.43	61.13	57.36	58.18	64.56	64.65	55.43	62.45
	96.05	95.56	95.22	95.00	93.42	96.66	94.94	96.09	96.99	96.93	98.66	99.98	99.07	88.48	99.23

f. <u>Crude Synthesis Gas (Main Stream Samples) continued</u>

<u>Analysis (Dry Basis), Vol. %</u>

Date:	Feb 28													Mar 1		
Time:	0050	0235	0500	0615	0655	0930	Incre-mental	1300	1410	1515	1650	1900	2300	2400	0500	Incre-mental
CH_4	4.43	4.24	2.61	3.83	4.78	3.38	3.56	3.93	4.43	4.5	4.45	4.11	2.63	2.00	0.72	0.74
CO_2	3.10	3.01	2.08	2.86	3.23	2.37	2.79	3.09	[illegible].84	3.21	2.83	3.11	0.96	1.4	1.58	1.9
C_2H_4	0.11	0.08	0.07	0.07	0.07	0.08	0.06	0.16	0.08	0.09	0.09	0.10	-	-	-	-
C_2H_6	0.26	0.29	0.18	0.20	0.22	0.25	0.23	0.29	0.26	0.24	0.30	0.27	0.24	0.4	-	-
H_2S	0.77	0.79	0.43	0.79	0.75	0.68	0.67	0.82	0.80	0.92	0.88	0.84	0.49	0.75	0.23	0.26
H_2	26.05	25.73	25.99	26.52	26.26	25.3	24.8	26.37	25.6	25.6	27.77	25.7	25.34	25.8	24.81	24.68
Ar	0.87	0.88	0.90	0.80	0.91	0.67	0.88	0.71	0.82	0.79	0.67	0.68	0.71	0.73	0.75	0.98
N_2	2.83	3.45	3.87	3.36	3.03	3.27	4.06	3.02	4.10	4.5	2.7	3.31	4.17	4.46	4.93	5.76
CO	60.88	60.78	63.93	60.87	61.11	62.59	60.5	60.45	60.0	58.95	61.01	61.35	64.74	62.63	66.16	65.41
	99.30	99.25	100.06	99.30	100.36	98.59	97.55	98.84	98.93	98.8	99.70	99.47	99.28	98.17	99.18	99.73

f. Crude Synthesis Gas continued

Minor Constituents

Date	Time	NH_3 g/m^3	Naphthalene g/m^3	Condensate g/m^3
Feb 28	0930-1315	0.153	3.243	0.0282

Sulfur Constituents, PPM

Date	Time	COS	CS_2	Thiophenes
Feb 27	0630	777	18.6	6.9
	1030	656	20.3	7.6
	1315	623	20.0	6.8
Feb 28	0620	974	27.0	8.5
	1315	710	31.0	5.4

g. Flash Gas From Oil Separator

Analysis, Vol. %

Date:	Feb 28	Mar 1
Time:	0630	0030
CH_4	3.43	3.26
CO_2	4.33	2.29
C_2H_4	0.10	Nil
C_2H_6	0.23	0.36
H_2S	3.90	3.26
H_2	23.09	22.72
Ar	0.92	1.28
N_2	3.66	6.48
CO	58.92	55.08
	98.58	94.73

h. Side Stream Samples

Date:	Feb 28
Time Period:	0020-0230, 1000-1400
Gas Volume, SCF	962.72
Tar Product, grams	561.8
Gas Liquor Product, grams	4295.7
Dust, grams	14.0

i. Crude Synthesis Gas Composition (Side Stream Sample)

Analysis, Vol. %	Feb 28, 0235
CH_4	4.08
CO_2	3.13
C_2H_4	0.06
C_2H_6	0.26
H_2S	0.59
H_2	24.56
Ar	2.08
N_2	8.17
CO	54.87
	97.80

Minor Constituents, g/m^3	Feb 28, 1030-1345
NH_3	0.032
Naphthalene	Nil
Condensibles	Nil

Sulfur, PPM	Feb 28, 1100
COS	680
CS_2	33.0
Thiophenes	4.3

j. Combined Tar and Oil (Side Stream Samples)

Ultimate Analysis, Wt. %	Feb 28 0220-0230, 1000-1400
Nitrogen	0.8
Carbon	86.3
Hydrogen	7.4
Ash	Nil
Water	Nil
Sulphur	1.65
Chlorine	0.05
Heating Value, Btu/lbs.	16,400

k. Condensible Naphthas

Ultimate Analysis, Wt. %	Overall Run
Carbon	85.8
Hydrogen	8.7
Nitrogen	0.1
Chlorine	0.02
Ash	Nil
Water	Nil
	94.62

l. Gas Liquor Analysis (Side Stream Samples)

Analysis, mg/l	Feb 28, 1000-1400	Slag Quench Water
Total Dissolved Solids	1210	171
Total Sulfur	2324	286
Total Ammonia	4471	Nil
Free Ammonia	4063	-
Fixed Ammonia	408	-
Carbonate as CO_2	5016	-
Chloride	443	13
Tar/Oil Content	4945	-
pH	8.5	6.7
Specific Gravity	1.0003	-

3. Heat and Material Balance - 1:1 Blend of Randolph Coke and Ohio No. 9 Coal - Blast Furnace Slag Flux

Material Balance, Pounds (Basis: 1,000 pounds dry blend and flux)

Input	Rate	Carbon	Hydrogen	Nitrogen	Sulfur	Oxygen	Chlorine	Ash	Heat Balance Therms/Hr.
Coal /Flux	1104	519	45	7	30	154		349	2094
Steam	312		35			277			97
Fuel Gas	4	3	1						22
Recycle Tar	26	19	2			4		1	81
Oxygen/Air	566			82		484			-
	2012	541	83	89	30	919	0	350	2294
Output									
Heat Loss									65
Methane	38	29	9						215
Carbon Monoxide	1136	487				649			1185
Hydrogen	34		34						490
Carbon Dioxide	82	22				60			3
Inert Gas	92			92					4
Ethylene	1	1							6
Ethane	5	4	1						25
Ammonia	1			1					-
Hydrogen Sulfide	15		1		14				26
Carbonyl Sulfide	2				1	1			-
Tar	31	28	2			1			124
Liquor	241		27		1	213			76
Slag	352	2						350	64
	2030	573	74	93	16	924	0	350	2283
Input-Output Error, %	0.9	5.9	-10.8	4.5	-46.7	0.5	0	0	-0.5

4. Data Used in Balances - 1:1 Blend Coke and Coal

Coal Heating Value, Btu/lb.	8,222*

Coal Proximate Analysis	Wt. %*
Moisture	9.43
Ash	31.63
Volatile Matter	18.86
Fixed Carbon	40.08
	100.00

DAF Coal Ultimate Analysis	Wt. %
Carbon	79.71
Hydrogen	5.07
Nitrogen	1.07
Oxygen	9.49
Sulfur	4.61
Chlorine	0.05
	100.00

Gas Composition	Vol. %
Methane	3.64
Carbon Monoxide	61.90
Hydrogen	25.37
Carbon Dioxide	2.85
Inert Gas	5.05
Ethylene	0.06
Ethane	0.24
Hydrogen Sulfide	0.69
Ammonia	0.10
Carbonyl Sulfide	0.10
	100.00

Crude Gas Offtake Temperature	416^0C
Gasifier Pressure	350 psig
Heat Loss	0.00851 therms/therm of gas

* Includes flux.

Byproducts

Composition Wt. %	Product Tar	Recycle Tar	Minor Liquor Components
Carbon	86.30	74.01	17.58
Hydrogen	6.90	6.99	-
Nitrogen	1.00	0.85	-
Sulfur	1.34	1.26	29.86
Chlorine	0.03	-	5.69
Oxygen	4.43	14.46	46.87
Ash	-	2.43	-
	100.00	100.00	100.00

Heating Value	Btu/lb.
Product Tar	16,207
Recycle Tar	13,722
Minor Liquor Components	0

5. Performance Data - 1:1 Blend Coke and Coal

Steam Consumption	3.88 lb/therm gas
Steam Decomposition	63.53%
Oxygen Consumption	71.55 SCF/therm gas 17,652 SCF/ton DAF coal
Crude Gas Production*	246.5 therms/ton DAF coal
Gas Liquor Yield	2.99 lb/therm gas

Thermal Efficiencies, %	Gas Only	Gas, Tar, Oil & Naphtha
Crude Gas / Coal	88.37	90.28
Crude Gas / Coal, Steam & Oxygen	74.18	75.78

* Includes coal lock gas.

TSP Run 9

Feed Coal: Blast Furnace Metallurgical Coke
Date of Run: March 15, 1978

1. Run Diary

Date	Time	Event
Mar 15	0345	Standard start-up procedures began.
	0517	Steam/oxygen was introduced to the gasifier. Conditions for gasifying blast furnace metallurgical coke were gradually established - oxygen load at 160,000 SCFH and steam/oxygen ratio at 1.35.
	0940	Oxygen loading reduced to 130,000 SCFH.
	1105	Fluxing rate was reduced.
	1800	The hearth condition deteriorated sharply. Steam/oxygen ratio was cut to 1.15 and fluxing rate was increased.
	1920	Run terminated.

2. Raw Data

a. Metallurgical Coke

Proximate Analysis (Air Dried), Wt. % Date	Time	Moisture	Ash	Volatile Matter	Fixed Carbon
Mar 15	1810	4.05	8.10	0.72	87.13

Size Analysis, Wt. %	Mar 15
over 1-1/4"	29
1"-1-1/4"	29.5
3/4"-1"	26
1/2"-3/4"	12
3/8"-1/2"	1
1/8"-3/8"	1.5
under 1/8"	1

Bulk Density, Lbs/CF 38.0

Moisture Content, Wt. %

Date	Time	Moisture
Mar 15	0730	8.0
Mar 15	1130	13.0

b. Flux - Blast Furnace Slag

Date:	Mar 15	
Time:	0730	1330
Bulk Density, Lbs/CF	77.0	76.0
Moisture Content, Wt.%	6.0	6.5

c. Slag

Date:	Mar 15	Mar 15	Hearth Deposit	Fuel in Hearth	Coke Ash
Time:	0810-1830	Last Lock	Matrix	Matrix	0710-1830
Component, Wt. %					
SiO_2	45.6	46.7	44.5	43.0	47.1
Al_2O_3	19.4	23.0	26.1	28.5	29.1
CaO	20.9	16.8	16.0	3.5	2.8
MgO	7.4	5.8	5.6	1.5	1.5
Fe_2O_3	3.8	4.1	2.5	13.2	13.8
Carbon	.27	0.18	-	-	-
	97.37	96.58	94.7	89.7	94.3

c. Slag continued

Date:	Mar 15	Mar 15	Hearth Deposit	Fuel in Hearth	Coke Ash
Time:	0810-1830	Last Lock	Matrix	Matrix	0710-1830
Component, Wt. Wt. %					
Free Iron as Fe	.4	.5			
FeO	2.7	3.1			
Total Iron as Fe	2.7	2.9			
Fe^{+2}	2.1	2.4			
Fe^{+3}	0.2	0			
Total Sulfur	1.20	0.59			
Sulfide	0.34	0.26			
Silica No.	59	64	65	70	72
Loss on Ignition, %*	+0.4	+0.4			

d. Oxygen Purity, Vol. %

Date	Time	Oxygen	Nitrogen	Argon
Mar 15	1045	93.11	5.90	1.02
	1430	94.1	5.2	0.7
	1850	96.3	4.7	Nil

e. Recycle Tar

Dust Content	Wt. %
Mar 15	20.0

f. Crude Synthesis Gas (Main Stream Samples)

Analysis (Dry Basis), Vol. %

Date:	Mar 15			
Time:	0700	1000	1345	1651
CH_4	0.69	0.72	0.70	0.50
CO_2	1.55	2.79	1.48	2.40
C_2H_4	Nil	0.06	Nil	Nil
C_2H_6	Nil	Nil	Nil	0.08
H_2S	0.06	0.22	0.24	0.26
H_2	27.37	26.56	26.56	27.00
O_2	Nil	Nil	Nil	Nil
Ar	0.96	1.03	0.90	0.53
N_2	3.73	3.98	4.50	3.23
CO	65.36	63.1	63.27	64.94
	99.72	98.46	97.65	98.94

*+ is a gain.

f. Crude Synthesis Gas continued

Minor Constituents, g/ml	Mar 15 1445-1700
NH_3	0.0038
Naphthalene	Nil
Condensate	Nil

Sulfur Content, PPM	
COS	302
CS_2	3.4
Thiophenes	Nil

g. Side Stream Samples

Sample:	S/S1	S/S2
Date:	Mar 15	Mar 15
Time Period:	1415-1700	1715
Gas Volume, SCF	1171.5	ND
Tar/Oil Product, grams	234	ND
Gas Liquor Product, grams	3318	ND

h. Crude Synthesis Gas Composition (Side Stream Sample)

Analysis, Vol. %	S/S1	S/S2
CH_4	0.62	0.62
CO_2	2.24	2.70
C_2H_4	Nil	0.05
C_2H_6	Nil	Nil
H_2S	0.20	0.20
H_2	25.60	27.13
Ar	1.04	0.66
N_2	5.25	3.57
CO	63.66	64.33
	98.61	99.26

Minor Constituents	
NH_3, g/ml	Nil
HCN, g/ml	Nil
Naphthalene, g/ml	Nil
Condensibles, g/ml	Nil
COS, PPM	438
CS_2, PPM	4.6
Thiophenes, PPM	Nil

3. Heat and Material Balance

The run was too short and the data insufficient to permit making a heat and material balance.

TSP Run 10

Feed Coal: Blast Furnace Metallurgical Coke
Date of Run: March 21-22, 1978

1. Run Diary

Date	Time	Event
Mar 20	0759	Standard startup was used and steam/oxygen admitted for gasifying blast furnace metallurgical coke; 130,000 SCFH oxygen load and 1.15 steam/oxygen ratio.
	1445	Steam/oxygen ratio raised to 1.35.
	1845	Steam/oxygen ratio was adjusted to 1.25 because of a cool hearth.
Mar 21	0745	Feedstock was changed from narrow range (20 mm x 10 mm) to a wide range (2" x 0) coke.
	1207	Problems were encountered; so feed was switched back to narrow range coke. Feed was later returned to wide range coke.
Mar 22	0945	Main burner air failed due to compressor problems. Gasifier was put on standby.
	1120	Gasifier restart was attempted, but the tuyeres were blocked with frozen slag; so the run was terminated.

2. Raw Data

a. Metallurgical Coke

Proximate Analysis (Air Dried), Wt. % Date	Time	Moisture	Ash	Volatile Matter	Fixed Carbon
Mar 21	0710	1.54	10.66	1.14	86.66
Mar 21	2010	1.15	9.60	1.14	88.11

Size Analysis, Wt. %	Mar 20 1630	Mar 21 0030	Mar 21 1130	Mar 22 1000
over 1-1/4"	20	30	29	49
1"-1-1/4"	30	25	18	18
3/4"-1"	29	25	18	19
1/2"-3/4"	14	7	10	8.5
3/8"-1/2"	2	9	6	3
1/4"-3/8"	1	0.5	3.5	1
1/8"-1/4"	2	1	4	0.5
under 1/8"	2	2.5	8	1
Bulk Density, Lbs/CF	37.0	37.0	37.5	35.0
Moisture Content, Wt.%	8.5	11.5	10.0	12.0

Coal Ash Analysis, Wt.%		
Date:	Mar 20-21	Mar 21
Time:	0910-0710	0810-2010
SiO_2	44.7	44.5
Al_2O_3	26.1	26.3
CaO	9.1	9.1
MgO	2.5	2.3
Fe_2O_3	11.7	11.9
	94.1	94.1
Silica Number	66	66

b. Flux - Blast Furnace Slag

Component, Wt. %	Mar 20-21 0240-0710	Mar 21 0810-2010
SiO_2	35.9	34.9
Al_2O_3	12.8	13.2
CaO	35.4	36.8
MgO	11.0	10.8
Fe_2O_3	1.4	1.2
Carbon	0.0	0.0
	96.5	96.9
Loss on Ignition, Wt.%	-2.2	-2.0
Silica Number	43	42

b. Flux continued

Date	Time	Moisture Content, Wt. %	Bulk Density Lbs/CF
Mar 20	1630	7.0	75
Mar 21	0030	6.5	78
	1330	7.0	75

c. Slag

Date:	Mar 20-21	Mar 21	Mar 21-22
Time:	1040-0740	1040-1240	1340-0940
Component, Wt. %			
SiO_2	41.3	40.6	40.9
Al_2O_3	19.0	17.9	18.8
CaO	26.7	26.1	25.5
MgO	7.9	8.3	8.1
Fe_2O_3	3.5	3.7	3.5
Carbon	0.2	1.2	0.16
	98.6	97.8	96.96
Free Iron as Fe	0.2	0.4	0.3
FeO	2.7	2.7	2.3
Total Iron as Fe	2.45	2.45	2.6
Fe^{+2}	2.1	2.1	1.8
Fe^{+3}	0.15	0	0.5
Total Sulfur	0.98	0.62	0.54
Sulfide	0.39	0.32	0.32
Silica No.	52	52	52
Loss on Ignition, %*	-0.8	-1.7	+0.1

* + is a gain.

d. Oxygen Purity, Vol. %

Date	Time	Oxygen	Nitrogen	Argon
Mar 20	1330	94.4	4.0	1.6
	2115	96.6	2.7	0.6
Mar 21	0100	95.5	4.5	Nil
	0445	97.0	3.0	Nil
	0950	95.7	4.3	Nil
	1425	95.5	4.5	Nil
	1830	95.0	3.9	1.1
	2200	96.0	ND	ND
Mar 22	0130	96.0	ND	ND
	0600	94.2	5.3	0.5

e. Recycle Tar

Dust Content	Wt. %
Mar 20	20.0
Mar 21	30.0

Moisture	
Mar 21	15.2

f. Crude Synthesis Gas (Main Stream Samples)

Analysis (Dry Basis), Vol. %

Date:	Mar 20			Mar 21						Mar 22
Time:	1040	1700	2115	0015	0315	0615	1115	1415	1715	0230
CH_4	0.62	0.78	0.44	0.65	0.7	0.59	1.19	0.78	0.62	0.5
CO_2	1.12	3.02	1.59	2.83	1.75	1.61	1.96	1.24	1.95	2.23
C_2H_4	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
C_2H_6	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
H_2S	0.28	0.36	0.24	0.2	0.2	0.24	0.28	0.04	0.18	0.24
H_2	27.0	26.56	25.49	25.04	25.82	25.6	25.54	25.86	25.66	25.86
O_2	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Ar	0.38	0.86	0.68	0.61	0.62	0.66	0.97	0.88	1.08	0.94
N_2	3.90	3.54	4.28	3.50	3.8	3.87	4.57	3.48	3.19	4.02
CO	66.1	63.73	66.47	65.79	66.87	66.86	65.31	66.84	66.31	65.5
	99.4	98.85	99.19	98.62	99.76	99.43	99.82	99.12	98.99	99.29

f. Crude Synthesis Gas continued

Sulfur Content, PPM

Date	Time	COS	CS_2	Thiophenes
Mar 20	1845	431	6.4	Nil
Mar 21	0330	367	0	Nil
	1150	349	1.8	Nil
	1730	348	1.0	Nil
	2230	414	0.7	Nil
Mar 22	0615	444	0.8	Nil

g. Flash Gas From Oil Separator

Analysis, Vol. %

Date:	Mar 20
Time:	1415
CH_4	0.79
CO_2	8.20
C_2H_4	Nil
C_2H_6	Nil
H_2S	2.37
H_2	24.10
Ar	1.05
N_2	4.39
CO	57.58
	98.48

h. Flash Gas From Tar Separator

Analysis, Vol. %

Date:	Mar 20
Time:	1415
CH_4	0.61
CO_2	14.20
C_2H_4	Nil
C_2H_6	Nil
H_2S	0.07
H_2	23.22
Ar	1.20
N_2	4.23
CO	50.42
	95.08

3. Heat and Material Balance

The run was too short and the data insufficient to permit making a heat and material balance.

TSP Run 11

Feed Coal: Pittsburgh No. 8 Coal and Metallurgical Coke Layered 1:1 Ratio
Date of Run: March 25-31, 1978

1. Run Diary

Date	Time	Event
Mar 25	2130	Standard start up procedures were used. Steam and oxygen were admitted to the gasifier. Rates were adjusted to 130,000 SCFH on Randolph Colliery coke with the steam/oxygen ratio at 1.25 and gasifier pressure at 350 psig. Flux was blast furnace slag.
Mar 26	0340	Stirrer revolutions were increased. Commenced feeding Pittsburgh No. 8 coal/coke 1:1 volumetric layering (alternate coal locks). Oxygen loading at 130,000 SCFH and steam/oxygen ratio at 1.25.
	0440	Steam/oxygen ratio adjusted to 1.35.
	1350	Steam/oxygen ratio reduced to 1.25.
	1500	Good slag tapping was apparent; so the steam/oxygen ratio was increased to 1.35.
	1700	Slight uncertainties about slag tapping were apparent; so the ratio was again reduced to 1.25 and remained there for the remainder of the run. Gasifier exhibited cyclic behavior, but there was no deterioration in performance for the next 112 hours.
Mar 31	0924	With coke stocks almost depleted the gasifier was shutdown in an orderly fashion.

2. Raw Data

a. Pittsburgh No. 8 Coal & Metallurgical Coke

Pgh No. 8 Coal Proximate & Ultimate Analyses

Date:	Mar 26-28	Mar 28-30	Mar 30-31
Time:	0345-0345	0345-0245	0445-0345
Proximate Analysis (Air Dried), Wt. %			
Moisture	2.51	2.14	2.79
Ash	8.38	8.40	7.86
Volatile Matter	31.62	33.16	32.65
Fixed Carbon	57.49	56.30	56.70
Ultimate Analysis (Air Dried), Wt. %			
Carbon	76.00	75.67	77.00
Hydrogen	4.90	5.02	5.18
Nitrogen	1.48	1.62	1.50
Sulfur	2.18	1.92	1.71
Chlorine	0.15	0.14	0.12
Oxygen (Diff)	4.40	5.09	3.84
Ash	8.38	8.40	7.86
Water	2.51	2.14	2.79

Randolph Coke Proximate & Ultimate Analysis

Date:	Mar 25-27	Mar 27-29	Mar 29-31
Time:	0445-0345	0445-0445	0445-0345
Proximate Analysis (Air Dried), Wt. %			
Moisture	1.82	1.76	2.42
Ash	9.52	10.12	9.73
Volatile Matter	1.54	1.57	1.65
Fixed Carbon	87.12	86.55	86.20
Ultimate Analysis (Air Dried), Wt. %			
Carbon	84.80	84.80	83.90
Hydrogen	1.05	0.88	1.00
Nitrogen	1.17	1.15	1.16
Sulfur	1.15	0.96	1.10
Chlorine	0.10	0.09	0.09
Oxygen (Diff)	0.39	0.24	0.60
Ash	9.52	10.12	9.73
Water	1.82	1.76	2.42

Pgh No. 8 Coal Size Analysis, Wt. %

Date:	Mar 26		Mar 27		Mar 28		Mar 29		Mar 30	
Time:	1730	2310	1000	2200	1100	2230	1130	2130	1100	2115
Size Range:										
over 1-1/4"	0.5	4	6	2	4.5	5	4	4	4.5	2.5
1"-1-1/4"	8	11.5	9.5	8	16	14	17.5	12	3	10
3/4"-1"	13	24	26	28.5	39	30	35.5	30	19	24
1/2"-3/4"	29.5	26.5	26.5	29	24.5	28	22.5	33	33	29
3/8"-1/2"	24	16	17.5	20	10.5	15	13.5	13	23	21.5
1/4"-3/8"	14	7	7	8	3.5	6	5	5	11.5	9
1/8"-1/4"	8	3.5	3.5	2	1.5	1	1	2	3	3
under 1/8"	3	7.5	4	2.5	0.5	1	1	1	3	1
Moisture Wt. %	5.5	6.0	4.5	6.0	5.0	4.5	4.5	5.0	5.0	5.5
Bulk Density, Lbs/CF	47	51.5	47	46	48	47	47.5	47	48	46

Randolph Coke Size Analysis, Wt. %

Date:	Mar 26			Mar 27		Mar 28		Mar 29		Mar 30	
Time:	0115	1730	2310	1000	2200	1100	2230	1130	2130	1100	2215
Size Range:											
over 1-1/4"	24	39.5	25.5	18	38.5	39	44.5	35.5	39	38.5	44
1"-1-1/4"	23	28	25	17.5	21	22	20	24	21	22	24
3/4"-1"	30.5	24	29	43.5	29	27.5	27	23.5	26	21.5	21
1/2"-3/4"	10.5	6.5	10.5	9.5	8.5	6.5	5.5	8.5	7	8.5	6
3/8"-1/2"	4	0.5	2	2	1	1.5	1.5	2.5	1.5	2	1
1/4"-3/8"	2	0.5	1.5	2	0.5	1	0.5	1.5	1.5	1	1
1/8"-1/4"	1.5	0.5	1.5	2	0.5	1	0.5	2	1.5	3	1
under 1/4"	4.5	0.5	5	5.5	1	1.5	0.5	2.5	2.5	3.5	2
Moisture Wt. %	11.5	10.0	11.0	10.5	12.0	13.0	10.0	10.0	12.0	11.5	11.0
Bulk Density, Lbs/CF	35	35	36	35	35	35	36	35	35	35	35

Coal & Coke Ash Analysis, Wt. %	Pittsburgh No. 8 Coal	Randolph Coke
SiO_2	45.1	47.2
Al_2O_3	24.1	25.9
CaO	4.0	4.3
MgO	1.9	2.5
Fe_2O_3	20.9	14.9
Na_2O	0.2	1.1
K_2O	1.8	2.2
TiO_2	0.9	0.8
Silica Number	63	68

Other Properties of Pgh No. 8 Coal

Forms of Sulfur in Coal	Wt. %
Organic Sulfur	0.28
Inorganic Sulfur	1.14
Pyritic Sulfur	0.76
Total Sulfur	2.18

Free Swelling Index	7 to 7-1/2
Gray-King Coke	G8

b. Flux - Blast Furnace Slag

Date	Time	Moisture Content, Wt.%	Bulk Density, Lbs/CF
Mar 26	0115	7.0	74
	2310	7.0	76.5
Mar 27	1000	8.0	75.5
	2200	7.0	75
Mar 28	1100	2.0	76
	2200	7.5	75
Mar 29	1130	8.0	75
	2130	8.0	75.5
Mar 30	1100	ND	76
	2115	7.5	75

c. Slag

Date:	Mar 26	Mar 27-28	Mar 28-29	Mar 29-31
Time:	0340	0540-0440	0540-2140	2240-0840
Component, Wt. %				
SiO_2	36.9	40.1	40.5	39.9
Al_2O_3	17.2	18.5	18.6	18.1
CaO	25.3	27.6	27.2	28.5
MgO	8.1	8.2	8.1	8.3
Fe_2O_3	4.9	3.3	3.5	3.3
Na_2O	ND	ND	0.2	0.2
K_2O	ND	ND	1.5	1.4
TiO_2	ND	ND	0.6	0.7
Carbon	0.4	0.4	1.9	0.8
Free Iron as Fe	0.7	0.5	0.4	0.7
FeO	3.6	2.2	2.8	2.9
Total Iron as Fe	3.4	2.3	2.5	2.9
Fe^{+2}	2.8	1.7	2.2	2.2
Fe^{+3}	Nil	0.1	Nil	Nil
Total Sulfur	0.55	0.80	0.77	0.78
Sulfide	0.52	0.33	0.38	0.39
Silica No.	49	51	51	50

d. Oxygen Purity, Vol. %

Date	Time	Oxygen	Nitrogen	Argon
Mar 25	2340	93.5	4.8	1.7
Mar 26	0420	94.4	4.1	1.5
	1155	91.7	ND	ND
	1240	92.7	4.2	3.0
	1630	94.4	5.4	0.2
	2400	94.7	4.7	0.6
Mar 27	0630	95.5	4.1	0.4
	1315	94.8	ND	ND
	2115	94.8	4.9	0.3
Mar 28	0550	94.2	5.1	0.7
	1350	94.8	4.8	0.4
	2115	94.8	4.8	0.4
Mar 29	0500	94.7	4.7	0.6
	1050	95.3	4.4	0.4
	1835	95.2	4.8	Nil
Mar 30	0200	93.8	5.4	0.8
	0955	94.5	5.5	Nil
	1815	94.0	4.8	1.2
Mar 31	0100	95.5	4.0	0.5
	0900	95.8	4.2	Nil

e. Recycle Tar

Ultimate Analysis (Dry, Dust Free), Wt. %	Tar Mar 26-28	Tar Mar 29-31
Carbon	84.6	87.8
Hydrogen	6.7	6.69
Nitrogen	1.04	1.20
Sulfur	0.89	0.87
Chlorine	0.05	0.04
Ash	Nil	Nil
Water	Nil	Nil
Heating Value, Btu/lb.	15,126	15,993

Moisture & Dust Content, Wt. %

Date	Time	Moisture	Dust
Mar 26	1330	12.2	25.0
Mar 26	2115	13.8	19.0
Mar 27	1300	13.2	20.0
Mar 28	1320	2.6	8.0
Mar 29	1030	2.2	20.0
Mar 29	1430	ND	13.0
Mar 29	1915	ND	5.0
Mar 30	1630	2.6	8.0
Mar 31	0530	1.8	ND

Ultimate Analysis Tar Solids (Dust), Wt.%	Mar 26-28	Mar 29-31
Carbon	78.80	78.90
Hydrogen	1.82	1.32
Nitrogen	1.07	0.99
Sulfur	1.69	1.52
Chlorine	0.05	0.04
Ash	18.82	17.04
Water	0.76	0.62
Tar Solids Heating Value, Btu/lb.	12,192	12,157

f. Crude Synthesis Gas (Main Stream Samples)

Analysis (Dry Basis), Vol. %

Date:	Mar 25	Mar 26					Mar 27			Mar 28			
Time:	1140	0300	0515	1130-1325	1915	1725-2330	0445	1740	2015-2115	0110	0326	0336	0945
CH_4	0.3	0.67	5.68	4.10	1.68	4.09	4.64	2.22	2.98	4.44	3.21	5.36	2.0
CO_2	1.8	2.58	2.01	3.01	2.08	1.93	0.94	1.94	1.19	1.30	1.23	1.47	1.39
C_2H_4	Nil	Nil	0.15	0.11	0.06	0.08	Nil	Nil	0.25	Nil	0.06	0.16	Nil
C_2H_6	Nil	Nil	0.5	0.29	0.06	0.30	0.47	0.15	Nil	0.59	0.37	0.35	Nil
H_2S	0.24	0.25	0.33	0.18	0.2	0.36	0.34	0.16	0.43	0.36	0.38	0.30	0.32
H_2	26.9	26.53	26.39	27.33	26.47	26.87	26.80	27.11	26.07	25.8	26.62	26.28	17.04
Ar	0.9	0.68	0.69	1.18	0.86	1.07	0.74	0.92	0.92	0.97	1.09	0.94	1.06
N_2	4.1	4.65	4.3	5.33	3.25	3.78	3.12	4.07	3.92	2.62	3.48	3.89	4.10
CO	65.0	62.73	58.84	56.97	63.58	60.74	58.74	61.56	63.41	62.39	63.55	61.04	64.3
	99.24	98.09	98.89	98.50	98.24	99.22	95.79	98.13	99.17	98.47	99.99	99.79	90.21

f. Crude Synthesis Gas continued

Analysis (Dry Basis), Vol. %

Date:	Mar 28		Mar 29					Mar 30				Mar 31
Time:	1135-1305	2115	0130	0330-0710	1040	1500	2215	0400	0950	1620	2215	0515
CH_4	4.74	5.15	2.46	3.97	5.75	3.8	2.71	4.78	2.79	5.0	4.54	2.51
CO_2	1.23	0.99	1.20	1.28	2.0	4.33	2.91	2.83	2.95	2.03	1.87	1.86
C_2H_4	0.11	0.14	0.07	0.12	0.21	0.11	0.08	Nil	0.09	0.15	0.13	Nil
C_2H_6	0.31	0.41	0.17	0.37	0.57	0.46	0.42	0.45	0.29	0.42	0.50	0.08
H_2S	0.40	0.37	0.35	0.39	0.43	0.42	0.31	0.48	0.39	0.45	0.35	0.22
H_2	26.42	25.74	25.00	25.87	27.11	26.57	27.11	26.67	26.64	27.22	27.27	27.13
Ar	1.09	0.91	1.01	2.12	0.84	0.97	0.96	1.09	1.0	0.53	0.81	0.74
N_2	3.84	3.63	3.13	7.05	3.19	2.95	3.86	3.11	3.26	3.44	3.5	3.36
CO	61.17	60.8	66.01	58.28	60.14	61.26	60.57	59.29	60.93	60.0	59.9	63.81
	99.31	98.14	99.4	99.45	100.24	100.87	98.93	98.7	98.34	99.24	98.87	99.71

f. Crude Synthesis Gas (continued)

Minor Constituents, g/m^3

Date	Time	NH_3	HCN	Conden-sate	Naphtha-lene
Mar 26	0500-0800	0.0122	0.0106	2.014	ND
Mar 26	1130-2430	0.0115	0.008	3.53	ND
Mar 26	1730-2100	0.0121	0.0077	1.895	ND
Mar 27	2330-0230*	0.233	ND	ND	ND
Mar 27	1645-1900	0.029	0.0083	2.35	ND
Mar 28	1130-1435	0.0105	0.0119	4.24	ND
Mar 29	0500-0700*	0.205	0.0086	1.608	0.00167
Mar 29	0930-1545	ND	ND	ND	0.00122
Mar 30	0400-0700	0.046	0.006	2.94	0.00248

*H_2S removed from sample by zinc oxide prior to analysis.

Sulphur Content, PPM

Date	Time	COS	CS_2	Thiophenes
Mar 26	1315	743	6.1	Nil
Mar 26	1815	509	8.0	Nil
Mar 27	0445	495	3.0	Nil
Mar 27	1800	432	5.1	Nil
Mar 28	0321	454	2.8	Nil
Mar 28	0333	501	4.6	Nil
Mar 28	1240	393	4.8	Nil
Mar 29	0450	461	3.2	Nil
Mar 29	1730	598	2.9	Nil
Mar 30	1720	1022	3.5	Nil
Mar 31	0400	700	6.5	Nil

g. Flash Gas from Oil Separator

Analysis, Vol. %

Date:	Mar 28	Mar 29	Mar 30
Time:	0100	1835	1820
CH_4	5.28	3.86	2.98
CO_2	4.19	3.79	3.86
C_2H_4	0.31	0.15	0.12
C_2H_6	0.88	0.52	0.39
H_2S	1.98	1.90	1.82
H_2	22.78	25.53	24.67
Ar	0.88	1.15	1.07
N_2	2.92	4.66	4.37
CO	56.90	58.00	56.81
	96.12	99.56	96.09

h. Flash Gas From Tar Separator

Analysis, Vol. %

Date:	Mar 28	Mar 30
Time	0055	1430
CH_4	2.48	5.57
CO_2	1.64	5.5
C_2H_4	0.07	0.24
C_2H_6	0.21	0.60
H_2S	3.16	1.23
H_2	26.94	29.44
Ar	1.28	0.87
N_2	3.16	2.56
CO	59.21	50.48
	98.15	96.49

i. Side Stream Samples

Sample:	S/S1	S/S2	S/S3	S/S4	S/S5	S/S6
Date:	Mar 26	Mar 26	Mar 27	Mar 27	Mar 28	Mar 29
Time Period:	1115-1520	1705-2330	0130-0630	1640-2330	1110-1455	0315-0815
Gas Volume, SCF	1,034	1,518	1,049	1,367	882	1,263
Tar/Oil Product, grams	625.2	1,228.4	879.3	1,244.1	596.1	962.8
Gas Liquor Product, grams	3,154.8	4,276.9	2,311.5	3,078.7	1,751.4	2,376.4
Dust, grams	8.0	11.8	6.0	6.0	4.0	5.0

j. Combined Tar and Oil (Side Stream Samples)

Ultimate Analysis, Wt. %	S/S1	S/S2	S/S3	S/S4	S/S5	S/S6
Carbon	87.00	88.00	87.20	86.50	82.70	83.80
Hydrogen	7.30	7.10	7.12	7.39	6.80	7.04
Nitrogen	0.97	1.14	1.30	1.06	1.01	1.08
Sulfur	0.91	1.00	0.65	0.69	0.87	0.85
Chlorine	0.04	0.05	0.05	0.04	0.04	0.04
Oxygen	3.78	2.71	3.68	4.32	8.58	7.19
Ash	Nil	Nil	Nil	Nil	Nil	Nil
Water	Nil	Nil	Nil	Nil	Nil	Nil
Heating Value, Btu/lb.	16,380	16,339	16,341	16,298	16,427	16,436

k. Gas Liquor Analysis (Side Stream Samples)

Sample: mg/l	S/S1	S/S2	S/S3	S/S4	S/S5	S/S6
Tar/Oil Content	3,700	6,060	9,000	6,700	6,060	5,620
Total Dissolved Solids	4,677	4,230	2,297	3,031	6,569	4,994
Total Sulphur	2,948	2,609	5,032	6,987	6,229	7,815
Total Ammonia	13,549	14,909	17,170	15,861	16,269	16,490
Free Ammonia	11,526	12,648	13,651	12,070	13,600	14,450
Fixed Ammonia	2,023	2,261	3,519	3,791	2,669	2,040
Carbonate as CO_2	14,740	15,400	14,520	12,760	12,980	15,840
Chloride	2,305	2,482	3,014	2,128	2,482	2,305
pH	8.86	8.64	8.68	8.82	8.81	8.76
Specific Gravity	1.014	1.015	1.016	1.014	1.015	1.016

mg/l	S/S1 - S/S6 Combined
Total Phenols	3,333
Monohydric Phenols	2,800
Nitrate as NO_3	Nil
Fatty Acids as Acetic Acid	1,488
Cyanide as CN	146
Thiocyanates as CNS	1,820

1. Crude Synthesis Gas Composition (Side Stream Sample)

Date:	Mar 26		Mar 27		Mar 28	Mar 29
Time:	1115-1520	1705-2330	0445	1650-2115	1440	0330-0710
Analysis, Vol. %						
CH_4	3.97	3.94	3.45	3.98	3.46	5.55
CO_2	2.42	2.01	1.01	1.19	1.13	1.79
C_2H_4	0.10	0.07	0.05	0.28	0.08	0.15
C_2H_6	0.31	0.27	0.31	0.54	0.23	0.52
H_2S	0.20	0.32	0.39	0.42	0.36	0.39
H_2	26.95	27.01	26.4	24.46	25.6	24.85
Ar	1.11	1.13	0.78	0.87	1.15	1.19
N_2	4.72	4.35	3.59	8.89	4.10	5.28
CO	58.86	59.91	59.92	58.34	63.16	59.94
	98.64	99.01	95.9	98.97	99.27	99.66
Minor Constituents, g/m^3						
NH_3	0.3579	0.0462	-	0.100	0.0313	ND
HCN	0.0379	0.0136	-	0.0478	ND	0.0704
Naphthalene	ND	ND	-	ND	ND	0.00446
Condensibles	Nil	1.75	-	3.46	4.2	0.34
Sulphur Constituents, PPM						
COS	997	1165	477	461	475	394
CS_2	10.6	9.0	4.0	5.9	5.5	3.0
Thiophenes	Nil	5.0	Nil	Nil	Nil	Nil

m. Naphtha Analysis (Main Stream Sample)

Mar 26-31	Wt. %
Carbon	91.0
Hydrogen	9.4
Nitrogen	0.3
Sulfur	0.06
Chlorine	0.03
Ash	Nil
Water	Nil

Heating Value, Btu/lb. 17,855

n. Gas Liquor Analysis (Main Stream Samples)

mg/l	Oil Separator	Tar Separator
Total Dissolved Solids	5,323	4,588
Total Sulfur	2,437	412
Total Ammonia	16,600	850
Free Ammonia	15,589	69
Fixed Ammonia	1,071	781
Carbonate as CO_2	28,600	3,520
Chloride as Cl	1,241	887
Total Phenols	3,000	1,833
Monohydric Phenols	600	1,600
Nitrate as NO_3	Nil	Nil
Fatty Acids as Acetic Acid	360	720
Cyanide as CN	146	42
Thiocyanates as CNS	1,140	360
pH	8.80	8.54
Specific Gravity	1.023	1.00

o. Tar and Oil Analysis (Main Stream Samples)

	Oil	Tar
Density at 20°C, g/ml	0.970	1.16
Toluene Insolubles, Wt. %	0.25	3.8
Viscosity, Redwood No. 1		
20°C, sec	31.6	ND
40°C, sec	29.0	ND
Standard Tar Viscometer		
20°C, sec	ND	65.6
40°C, sec	ND	50.0

p. Oil Distillation (Main Stream Sample)

Volume, ml	Temperature, °C
IBP	84
5	134
10	152
20	178
30	194
40	207
50	215
60	225
70	232
80	247
90	272
95	292

Temperature, °C	Vol. %	Wt. %
IBP-200	36.9	34.3
200-310	60.2	60.8
310-EP	2.9	4.9
Phenols (Wet)	12.3	13.2

q. Tar Distillation (Main Stream Sample)

Temperature, °C	Vol. %	Wt. %
IBP-200	Nil	Nil
200-320	24.4	22.4
320-EP	75.6	77.6
Phenols (Wet)	4.1	3.6

r. Slag Quench Water Analysis

mg/l	Mar 26 1630	Mar 27 1630
Total Dissolved Solids	270	250
Total Sulphur	329	393
Chloride as Cl	19	16
pH	7.16	6.74

s. Elemental Analyses

Element, PPM by Wt.	Pgh. No. 8 Coal	Pgh. No. 8 Coal Ash	Randolph Coke	Randolph Coke Ash	BFS Flux	Slag	Slag Quench Water	Gas Liquor from Tar Separator	Gas Liquor from Oil Separator	Main Stream Oil	Main Stream Tar
Aluminum	9,800	120,000	12,000	120,000	58,000	83,000	0.2	4.6	0.4	0.9	9.0
Barium	42	580	100	1,200	480	620	< 0.1	< 0.3	< 0.07	< 0.05	< 0.6
Calcium	2,000	26,000	1,900	30,000	230,000	160,000	17	< 15	9.7	1.2	< 5
Chromium	24	330	89	1,100	11	79	< 0.1	< 0.1	0.5	0.2	0.3
Iron	12,000	160,000	9,200	110,000	6,200	25,000	3.1*	45	820	7.0	51
Lead*	40	200	40	200	200	200	0.04	0.04	0.08	ND	ND
Magnesium	546*	3,100	622*	8,700	64,000	41,000	5.6*	0.3*	0.4*	< 2	< 10
Manganese	65	670	72	1,000	5,400	4,200	0.03	1.3	0.8	0.05	2.8
Nickel*	100	400	1,000	4,000	200	200	0.01	0.1	0.2	ND	ND
Potassium	1,100	12,000	1,500	16,000	4,300	6,500	1.2	51	1.2	< 0.2	2.4
Silicon	20,000	220,000	16,000	190,000	150,000	180,000	< 50	<150	< 50	< 40	110
Sodium	270	3,100	920	9,100	2,700	3,200	56	23	4.2	0.5	1.6
Strontium	51	630	48	324*	465*	550*	0.09*	0.03*	0.05*	< 0.05	< 1
Sulfur	ND	ND	ND	ND	ND	ND	41	446	3,550	ND	ND
Titanium	520	5,900	510	5,600	3,200	4,300	< 0.1	< 1	< 0.2	< 0.1	5.5
Vanadium	28	380	71	770	69	210	0.002	0.1	< 0.01	0.04	1.2
Zinc	24	280	63	490	241*	87*	1.8	0.3	0.15*	< 0.2	11
Antimony	0.8	7.6	2.1	22	0.08	0.4	< 0.001	0.1	0.04	0.03	2.5
Arsenic	8.6	92	8.9	83	< 1	5.1	0.007	2.5	0.7	3.2	8.5
Beryllium*	< 1	< 12	< 1	< 12	< 12	< 12	< 0.002	< 0.002	< 0.002	ND	ND
Cadmium	< 0.5	< 0.5	< 1	25*	< 2	< 2	0.03*	0.003*	0.006*	< 0.05	< 0.05
Cobalt	4.7	58	14	110	8.4	21	< 0.01	< 0.1	0.08	< 0.01	0.2
Copper	< 1.6*	< 20*	< 1.6*	255*	< 20*	20*	0.03*	0.06*	0.77*	< 0.1	8.2
Mercury	0.08	< 0.2	< 0.1	< 0.7	< 0.4	< 0.3	< 0.01	< 0.03	0.4	0.02	< 0.02
Molybdenum	2.3	26	3.8	43	12	7.2	< 0.05	< 0.1	0.4	< 0.02	0.1
Selenium	2.0	3.5	2.0	3.2	4.3	3.5	< 0.05	2.0	1.6	0.3	0.3
Uranium	0.8	8.7	1.7	19	13	11	0.005	< 0.03	< 0.005	< 0.005	0.02

Notes: 1. All elements except sulfur were determined by either Neutron Activation Analyses or Atomic Absorption Spectrophotometry (AAS). Elements determined by AAS are marked by an asterisk.
2. Sulfur was determined by a chemical method.

3. **Heat and Material Balance - Layered 1:1 Pittsburgh 8 and Randolph Coke with Blast Furnace Slag Flux**

Material Balance, Pounds (Basis: 1,000 pounds dry fuel and flux)									Heat Balance
Input	Rate	Carbon	Hydrogen	Nitrogen	Sulfur	Oxygen	Chlorine	Ash	Therms/Hr.
Coal/Flux	1090	683	38	12	14	105	1	237	2351
Steam	359		40			319			102
Fuel Gas	4	3	1						22
Recycle									
Tar	31	24	2			4		1	90
Oxygen/Air	629			96		533			3
	2113	710	81	108	14	961	1	238	2568
Output									
Heat Loss									76
Methane	41	31	10						212
Carbon									
Monoxide	1317	539				778			1306
Hydrogen	40		40						542
Carbon									
Dioxide	40	11				29			2
Inert Gas	104			104					4
Ethylene	2	2							11
Ethane	8	6	2						36
Ammonia	2			2					-
Hydrogen									
Sulfide	11		1		10				17
Carbonyl									
Sulfide	3	1			1	1			-
Tar	56	48	4	1		3			205
Naphtha	6	5	1						27
Liquor	142		16		1	125			41
Slag	239	1						238	39
	2011	644	74	107	12	936	0	238	2518
Input-Output									
Error, %	-4.8	-9.3	-8.6	-.9	-14.3	-2.6	0	-0.2	-1.9

4. Data Used in Balances - Layered 1:1 Coal: Coke

Coal Heating Value, Btu/lb.	10,184*
Coal Proximate Analysis	**Wt. %***
Moisture	8.25
Ash	21.77
Volatile Matter	15.31
Fixed Carbon	54.67
	100.00
DAF Coal Ultimate Analysis	**Wt. %**
Carbon	89.53
Hydrogen	3.68
Nitrogen	1.52
Oxygen	3.23
Sulfur	1.9
Chlorine	0.14
	100.00
Gas Composition	**Vol. %**
Methane	3.342
Carbon Monoxide	63.446
Hydrogen	26.077
Carbon Dioxide	1.187
Inert Gas	4.838
Ethylene	0.110
Ethane	0.329
Hydrogen Sulfide	0.429
Ammonia	0.184
Carbonyl Sulfide	0.058
	100.00
Crude Gas Offtake Temperature	428°C
Gasifier Pressure	350 psig
Heat Loss from Jacket & Hearth	12.48 therms/hour
Jacket Steam Production	3951 lb/hour

* Includes flux.

Byproducts

Composition Wt. %	Product Tar	Recycle Tar	Minor Liquor Components
Carbon	86.50	77.24	15.91
Hydrogen	7.39	6.65	-
Nitrogen	1.06	0.96	-
Sulfur	0.69	0.89	31.94
Chlorine	0.04	0.04	42.42
Oxygen	4.32	12.70	9.73
Ash	-	1.52	-
	100.00	100.00	100.00

Heating Value	Btu/lb.
Product Tar	16,298
Recycle Tar	13,687
Minor Liquor Comp.	0

5. Performance Data - Layered 1:1 Coal: Coke

Steam Consumption	3.75 lb/therm gas
Steam Decomposition	96.46%
Oxygen Consumption	65.98 SCF/therm gas 16,629 SCF/ton DAF coal
Crude Gas Production	251.8 therms/ton DAF coal
Gas Liquor Yield	1.46 lb/therm gas

Thermal Efficiencies, %	Gas Only	Gas, Tar, Oil & Naphtha
$\frac{\text{Crude Gas}}{\text{Coal}}$	86.23	90.82
$\frac{\text{Crude Gas}}{\text{Coal, Steam \& Oxygen}}$	73.42	77.34

TSP Run 12

Feed Coal: Ohio No. 9 Coal and Metallurgical Coke Layered 1:1 Ratio
Date of Run: May 29-June 1, 1978

1. Run Diary

Date	Time	Event
May 29	0739	Start-up began with gasifier full of petroleum coke and pressured to 100 psig.
	0955	Steam/oxygen injected into the gasifier. Metallurgical coke charging commenced.
	1025	Steam/oxygen ratio at 1.15 and gasifier pressure at 350 psig.
	1425	Oxygen load adjusted to 130,000 SCFH and steam/oxygen ratio at 1.25.
	2006	Started alternating locks of Ohio No. 9 coal and metallurgical coke to achieve 1:1 volumetric layering of coal and coke.
May 30	1520	Bottom coal lockhopper cone did not seat. Flare valve shut in slightly. Pressure surged with cone reseated. The relief valve on the Number 3 Waste Heat Boiler lifted. Valve reseated with minimum upset to gasifier.
May 31	1700	Cyclic conditions due to layering could be causing wear at hearth bottom
June 1	0206	Controlled shutdown completed.

2. Raw Data

a. Ohio No. 9 Coal and Randolph Coke

Proximate Analysis (Air Dried), Wt. %	Coke May 29-30 2015-1915	Coke May 30-31 2015-1915	Coke May 31-Jun 1 2015-0110	Coal May 29-30 2015-1915	Coal May 30-31 2015-1915	Coal May 31-Jun 1 2015-0110
Moisture	1.14	0.98	1.37	2.3	2.45	1.93
Ash	10.22	10.30	10.40	11.22	19.67	17.03
Volatile Matter	1.44	3.08	2.53	35.26	32.55	35.33
Fixed Carbon	87.20	85.64	85.70	51.22	45.33	45.71
Ultimate Analysis (Air Dried), Wt. %						
Carbon	87.6	88.5	87.9	70.9	62.8	67.0
Hydrogen	0.7	1.1	1.0	5.0	4.1	4.7
Nitrogen	1.0	1.0	1.0	0.8	0.8	0.7
Sulfur	1.19	1.33	1.35	3.73	4.02	4.46
Chlorine	0.09	0.09	0.11	0.19	0.18	0.24
Ash	10.22	10.3	10.4	11.22	19.67	17.03
Water	1.14	0.98	1.37	2.3	2.45	1.93
Swelling Index	-	-	-	4.5	5.0	4.5
Gray King Coke	-	-	-	G3	G3	G3

a. Ohio No. 9 Coal and Randolph Coke continued

Size Analysis, Wt. % - Coke	May 29 1330	May 30 0100	May 30 1330	May 31 0130	May 31 1330	June 1 0030
over 1-1/4"	29.5	26.0	27.5	26.0	26.0	32.5
1-1/4"-1"	22.0	26.0	34.0	22.0	21.5	20.5
1"-3/4"	27.5	25.5	25.5	30.0	25.5	25.5
3/4"-1/2"	10.0	8.5	7.0	13.0	15.0	12.5
1/2"-3/8"	3.0	4.0	2.0	5.0	6.0	1.0
3/8"-1/4"	2.5	2.0	1.0	1.5	2.0	2.0
1/4"-1/8"	1.5	4.0	1.0	0.5	2.0	1.0
under 1/8"	4.0	4.0	2.0	2.0	3.0	5.0
Coke Bulk Density, Lbs/CF	35	34	34	34	35	35
Coke Moisture Content, Wt. %	6.0	7.0	6.0	9.0	9.0	9.5
Size Analysis, Wt. % - Coal						
over 1-1/4"		2.0	2.0	2.5	3.0	3.0
1-1/4"-1"		11.0	17.5	14.5	6.0	14.5
1"-3/4"		30.5	42.0	31.0	31.0	31.5
3/4"-1/2"		35.0	21.5	30.5	25.0	25.0
1/2"-3/8"		13.5	9.0	12.5	15.0	10.0
3/8"-1/4"		4.5	3.0	4.0	7.0	8.0
1/4"-1/8"		1.0	1.0	1.0	5.0	3.5
under 1/8"		2.5	4.0	4.0	8.0	4.5
Coal Bulk Density, Lbs/CF		49.0	48.0	49.0	48.5	49.0
Coal Moisture Content, Wt. %		3.0	3.0	3.5	4.0	3.5

a. Ohio No. 9 Coal and Randolph Coke continued

Ash Composition

Component, Wt. %	Randolph Coke Overall Run	Ohio 9 Coal Overall Run
SiO_2	41.6	43.5
Al_2O_3	19.6	23.8
CaO	3.1	5.6
MgO	1.2	2.1
Fe_2O_3	24.2	15.0
	89.7	90.0
Silica Number	64	69

b. Flux-Blast Furnace Slag

Date	Time	Bulk Density, Lbs/CF	Moisture Wt. %
May 29	1330	74.0	1.0
May 30	0100	75.0	0.5
May 30	1330	74.0	1.0
May 31	0130	75.0	1.5
May 31	1330	75.0	3.5
Jun 1	0030	75.0	1.0

Component, Wt. %	Overall Run
SiO_2	34.7
Al_2O_3	12.2
CaO	40.8
MgO	10.6
Fe_2O_3	0.9
	99.2
Sulfide	0.2
Total Sulfur	1.04
Silica Number	40
Loss on Ignition, Wt. %	-0.9

c. Slag

Date: Time:	May 29-30 2015-0815	May 30 0900-2100	May 30-31 2115-0815	May 31 0815-2115	May 31-Jun 1 2115-0115
Component, Wt. %					
SiO_2	39.2	38.7	39.7	39.7	36.2
Al_2O_3	17.2	16.2	17.2	17.0	16.7
CaO	25.7	24.7	25.9	26.1	26.0
MgO	6.7	6.6	6.8	7.2	7.0
Fe_2O_3	8.6	9.2	8.0	7.7	8.7
Carbon	0.9	0.97	1.32	1.11	0.93
	98.3	96.37	98.92	98.81	95.53
Free Iron as Fe	0.6	1.0	0.9	0.6	0.5
FeO	6.9	7.1	6.2	6.1	7.2
Total Iron as Fe	6.0	6.4	5.6	5.4	6.1
Fe^{+2}	5.4	5.5	4.8	4.7	5.6
Fe^{+3}	Nil	Nil	Nil	0.1	Nil
Sulfide	0.83	0.97	0.86	0.83	0.91
Total Sulfur	0.66	1.39	1.09	0.96	1.40
Silica No.	50	50	50	50	48
Loss on Ignition *	+1.6	+2.3	+2.3	+1.7	+1.9

d. Oxygen Purity, Vol. %

Date	Time	Oxygen	Nitrogen	Argon
May 29	1010	92.1	4.6	2.3
	1800	95.3	4.4	0.3
May 30	0230	96.2	ND	ND
	0700	94.0	ND	ND
	2100	96.1	ND	ND
	2400	95.1	4.0	0.9
May 31	0410	95.7	3.7	0.7
	1110	95.6	3.4	1.0
	1915	95.3	3.8	0.9
	2240	96.1	3.5	0.3
June 1	0400	98.4	1.6	Nil
	0540	98.0	2.0	Nil

* is a gain.

e. Recycle Tar

Ultimate Analysis (Dry), Wt. %	Dust Free Tar	Tar Solids
Carbon	88.8	77.0
Hydrogen	7.5	1.1
Nitrogen	0.4	0.7
Sulfur	1.19	2.12
Chlorine	0.02	0.04
Ash	Nil	17.41
Water	Nil	0.84
Heating Value, Btu/lb	16,233	11,855

Moisture Content

Date	Time	Wt. %
May 29	2145	4.0
May 30	1830	1.5
	2230	2.5
May 31	1730	1.2
	2215	1.0

Dust Content

Date	Time	Wt. %
May 29	2145	16.0
May 30	2230	12.0
May 31	2215	20.0

Tar Distillation

Volume, ml	Temperature, °C
IBP	93
2	204
5	228
7	230
10	240
12	246
15	250
17	258
20	262
23	265
25	270
28	278
30	280
30 + Residue	Pitch

f. Crude Synthesis Gas (Main Stream Samples)

Analysis (Dry Basis), Vol. %

Date:	May 29					May 30									
Time:	1130	1530	1800	2145	2230	0345	0530	1030	Composite	1330	1333	1336	1339	1342	1345
CH_4	0.19	0.60	0.44	2.24	1.50	6.13	6.32	2.33	3.88	6.47	4.46	3.48	2.86	2.13	2.38
CO_2	3.15	3.56	3.85	3.84	2.58	3.37	3.82	3.07	2.91	3.47	2.49	3.02	2.93	3.67	3.33
C_2H_4	Nil	Nil	Nil	Nil	Nil	0.11	0.14	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
C_2H_6	Nil	Nil	Nil	0.15	Nil	0.36	0.35	Nil	0.13	0.25	0.14	0.12	0.09	Nil	0.11
H_2S	0.18	0.18	0.22	0.79	0.55	1.09	1.77	0.81	0.97	1.01	0.80	0.97	Nil	0.42	0.47
H_2	27.01	27.1	27.03	27.69	27.46	26.48	26.61	28.66	25.70	27.32	27.68	28.10	27.68	27.25	26.26
O_2	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0.95	Nil	Nil	Nil	Nil	Nil	Nil
Ar	0.86	0.83	0.82	0.80	0.75	0.78	0.94	0.85	0.85	0.70	0.69	0.73	0.74	0.78	0.70
N_2	4.64	4.10	3.89	3.23	3.97	3.49	2.93	4.11	6.98	2.45	2.56	2.79	3.94	3.52	4.18
CO	61.84	63.04	61.28	59.79	58.73	57.00	56.39	57.92	54.47	56.67	59.84	59.28	60.51	59.39	60.64
	99.87	99.41	97.53	98.53	95.54	98.81	99.27	97.75	96.84	98.34	98.66	98.49	98.75	97.16	98.07

f. Crude Synthesis Gas (Main Stream Samples) continued

Analysis (Dry Basis), Vol. %

Date:	May 30					May 31								June 1
Time:	1348	1351	1354	1357	2240	0135	0330	0630	0930	1320	Composite	1930	2230	0030
CH_4	3.25	5.42	5.89	6.54	5.42	5.41	3.09	6.86	5.44	6.29	4.30	3.91	4.19	5.01
CO_2	3.16	2.98	2.88	3.19	3.48	3.63	3.58	3.18	3.32	4.09	3.30	3.27	2.94	4.35
C_2H_4	Nil	Nil	Nil	Nil	Nil	0.06	Nil	0.07	0.11	0.09	0.06	0.09	0.29	0.13
C_2H_6	0.22	0.24	0.24	0.26	0.23	0.31	Nil	0.42	0.45	0.44	0.27	Nil	0.06	0.41
H_2S	0.79	0.91	0.55	1.03	0.96	1.07	0.83	0.83	1.23	1.34	0.55	1.14	0.83	0.79
H_2	26.69	26.54	26.83	27.11	26.62	27.53	28.68	26.36	25.4	25.78	26.56	26.13	27.59	26.83
O_2	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Ar	0.80	0.81	0.78	0.73	0.67	0.66	0.69	0.61	0.62	0.67	0.78	0.83	0.69	0.71
N_2	4.24	3.84	3.61	3.67	2.61	2.16	3.58	3.63	3.46	2.88	3.53	3.24	3.37	2.47
CO	59.57	58.66	58.69	57.19	56.96	56.29	55.60	56.77	58.63	57.19	60.56	58.95	59.21	57.17
	98.72	99.40	99.47	99.72	96.95	97.12	96.05	98.73	98.66	98.77	99.91	97.56	99.17	97.87

f. Crude Synthesis Gas continued

Minor Constituents, g/m³		NH_3	HCN	Naph-thalene	Con-densate
Date	Time				
May 29-30	2230-0130	0.077	0.022	0.006	4.11
May 30	1045-1430	0.072	0.052	0.041	5.21
May 30-31	2245-0145	0.018	0.004	0.008	4.80
May 31	1100-1345	0.041	0.023	0.003	5.48
May 31-June 1	2230-0130	0.061	0.012	0.018	7.53

Sulfur Content, PPM		COS	CS_2	Thiophenes
Date	Time			
May 29	2315	782	12.4	56.8
May 30	0630	753	8.7	3.0
	1325	847	14.2	4.7
	1336	746	11.1	4.8
	1350	830	10.7	3.8
	1405	836	14.5	5.1
	2355	805	12.6	4.6
May 31	0630	914	9.9	6.6
	1325	842	12.8	7.5
	2240	847	12.1	3.8

g. Flash Gas

Analysis, Vol. %

Date:	May 30	May 30	May 30
Time:	0515	0225	1400
Separator:	Oil	Oil	Tar
CH_4	4.4	6.8	2.9
CO_2	5.29	5.99	13.7
C_2H_4	Nil	Nil	0.14
C_2H_6	0.21	0.22	0.26
H_2S	2.77	3.04	5.30
H_2	25.44	24.79	21.21
O_2	Nil	Nil	2.19
Ar	1.05	1.08	1.0
N_2	4.04	4.09	12.6
CO	54.22	55.85	31.23
	97.42	101.85	90.53

h. Side Stream Samples

Date:	May 30	May 31
Time Period:	1000-1600	1000-1600
Gas Volume, SCF	1485.3	1726.7
Tar Product, grams	799.8	832.4
Oil Product, grams	20.4	16.1
Gas Liquor Product, grams	4387	4311

i. Combined Tar and Oil (Side Stream Analysis)

Ultimate Analysis, Wt. %

Date:	May 30	May 30
Time:	1000-1600	1000-1600
Carbon	88.3	86.7
Hydrogen	8.5	7.7
Nitrogen	0.1	0.1
Sulfur	2.18	2.10
Chlorine	0.08	0.10
Ash	Nil	Nil
Water	Nil	Nil
Heating Value, Btu/lb.	16,113	16,070

j. Crude Synthesis Gas Composition (Side Stream Sample)

Analysis, Vol. %

Date:	May 30
Time:	1030-1300*
CH_4	4.05
CO_2	2.42
C_2H_4	-
C_2H_6	0.21
H_2S	0.70
H_2	25.01
O_2	1.61
Ar	0.85
N_2	6.72
CO	55.98
	97.55

Minor Constituents, g/m^3

Date:	May 30	May 31
Time:	1030-1130	1100-1330
NH_3	0.117	0.168
HCN	0.0293	0.109
Naphthalene	0.0056	0.0098
Condensibles	1.75	2.38

*Air in sample.

Sulfur Content, PPM

Date:	May 30	May 31	May 31	May 31	May 31
Time:	1135	1330	1345	1400	1415
COS	853	874	866	853	614
CS_2	11.2	12.8	12.5	11.6	5.1
Thiophenes	3.4	4.5	4.1	4.1	1.3

k. Naphtha (Side Stream Analysis)

Ultimate Analysis	Wt. %
Carbon	83.9
Hydrogen	8.1
Nitrogen	<0.1
Sulfur	1.52
Chlorine	0.01
Ash	-
Water	-

Heating Value, Btu/lb. 18,304

l. Gas Liquor

Side Stream Analysis, mg/l

Date:	May 30	May 31
Time:	1000-1600	1000-1600
Tar/Oil Content	10,200	8,820
Total Dissolved Solids	8,270	4,614
Total Sulfur	4,517	2,524
Total Ammonia	10,064	11,611
Free Ammonia	7,956	9,792
Fixed Ammonia	2,018	1,819
Carbonate as CO_2	14,080	16,280
Chloride	2,836	3,546
pH	8.56	8.68
Specific Gravity	1.012	1.012

1. Gas Liquor continued

Oil Water Analysis, mg/l*

Date:	May 31	June 1
Time:	1930	0900
Tar/Oil Content	1,760	1,900
Total Dissolved Solids	3,672	3,400
Total Sulfur	3,542	3,789
Total Ammonia	21,369	21,080
Free Ammonia	20,893	19,975
Fixed Ammonia	476	1,105
Carbonate as CO_2	40,480	42,680
Chloride	1,773	2,128
pH	8.62	8.54
Specific Gravity	1.032	1.03

Tar Water Analysis, mg/l *

Date:	May 31	June 1
Time	1930	0900
Tar/Oil Content	4,666	3,500
Total Dissolved Solids	9,330	8,168
Total Sulfur	330	467
Total Ammonia	2,244	2,516
Free Ammonia	1,020	714
Fixed Ammonia	1,224	1,802
Carbonate as CO_2	176	176
Chloride	2,836	3,191
pH	8.78	8.76
Specific Gravity	1.002	1.002

Slag Quench Water Analysis, mg/l

Date:	May 30	May 31	June 1
Time:	0445	0230	0115
Total Dissolved Solids	275	260	240
Total Sulfur	43	49	47
Chloride	16	15	14
pH	6.04	5.46	5.42

* Sampled at plant separators.

3. Heat and Material Balance - Layered 1:1 Ohio 9 Coal and Randolph Coke with Blast Furnace Slag Flux

Material Balance, Pounds (Basis: 1,000 pounds dry fuel and flux)

Input	Rate	Carbon	Hydrogen	Nitrogen	Sulfur	Oxygen	Chlorine	Ash	Heat Balance Therms/Hr.
Coal/Flux	1060	602	31	7	25	84	1	310	2276
Steam	314		35			279			99
Fuel Gas	4	3	1						22
Recycle Tar	0								0
Oxygen/Air	558			82		476			3
	1936	605	67	89	25	839	1	310	2403
Output									
Heat Loss									56
Methane	48	36	12						269
Carbon Monoxide	1171	502				669			1230
Hydrogen	37		37						545
Carbon Dioxide	100	27				73			4
Inert Gas	83			83					4
Ethylene	1	1							6
Ethane	5	4	1						28
Ammonia	1			1					-
Hydrogen Sulfide	13		1		12				22
Carbonyl Sulfide	3	1			2				-
Tar	27	24	2		1				109
Naphtha	3	3							16
Liquor	147	1	16			129	1		46
Slag	312	3						309	64
	1951	602	69	84	15	871	1	309	2399
Input-Output Error, %	0.8	-0.5	3.0	-5.6	-40.0	3.8	0	-0.3	-0.2

4. Data Used In Balances - Layered 1:1 Coal: Coke

Coal Heating Value, Btu/lb.	9263*
Coal Proximate Analysis	Wt. %*
Moisture	5.65
Ash	29.12
Volatile Matter	16.41
Fixed Carbon	48.82
	100.00
DAF Coal Ultimate Analysis	Wt. %
Carbon	87.14
Hydrogen	3.56
Nitrogen	1.06
Oxygen	4.46
Sulfur	3.60
Chlorine	0.18
	100.00
Gas Composition	Vol. %
Methane	4.29
Carbon Monoxide	60.48
Hydrogen	26.53
Carbon Dioxide	3.30
Inert Gas	4.31
Ethylene	0.06
Ethane	0.26
Hydrogen Sulfide	0.55
Ammonia	0.14
Carbonyl Sulfide	0.08
	100.00
Crude Gas Offtake Temperature	430°C
Gasifier Pressure	350 psig
Heat Loss from Jacket & Hearth	11.87 therms/hour

* Includes flux.

Byproducts

Composition Wt. %	Naphtha	Product Tar	Minor Liquor Components
Carbon	83.90	86.7	19.87
Hydrogen	8.10	7.7	-
Nitrogen	0.10	0.1	-
Sulfur	1.52	2.1	11.29
Chlorine	0.01	0.1	52.97
Oxygen	6.37	3.3	15.87
	100.00	100.00	100.00

Heating Value	Btu/lb.
Naphtha	18,304
Product Tar	16,070
Minor Liquor Components	0

5. Performance Data - Layered 1:1 Coal: Coke

Steam Consumption	3.64 lb/therm gas
Steam Decomposition	85.2%
Oxygen Consumption	65.26 SCF/therm gas 16,279 SCF/ton DAF coal
Crude Gas Production*	249.5 therms/ton DAF coal
Gas Liquor Yield	1.66 lb/therm gas

Thermal Efficiencies, %	Gas Only	Gas, Tar, Oil & Naphtha
Crude Gas / Coal	87.83	92.49
Crude Gas / Coal, Steam & Oxygen	74.70	78.66

* Includes coal lock gas.

TSP Run 13

Feed Coal: Pittsburgh No. 8 Coal
Date of Run: June 19-23, 1978

1. Run Diary

Date	Time	Event
June 19	0615	Air introduced into gasifier for standard start-up, pressure at 100 psig, and the gasifier filled with petroleum coke. Start-up was delayed to investigate a potential problem with one tuyere. The problem was found to be nonexistent.
	1135	Steam and oxygen were introduced into the gasifier and Randolph Colliery coke fluxed with blast furnace slag was fed into the top through the coal lock. Operating conditions were adjusted to 130,000 SCFH oxygen rate, 1.30 steam/oxygen ratio, and 350 psig pressure.
	2002	Started feeding Pittsburgh No. 8 coal fluxed with blast furnace slag into the gasifier through the coal lock.
	2030	Bed DP, gas offtake temperatures, and stirrer/distributor torque increased. Stirrer/distributor revolution rate was decreased, and oxygen rate was momentarily reduced.
	2130	Gasifier operating well on Pittsburgh No. 8 coal at 130,000 SCFH oxygen loading and 1.30 steam/oxygen ratio.
June 20	0930	Started tar recycle tests by discontinuing the tar recycle to the top of the gasifier.
	1657	Tar recycle restarted.
	2000	Bottom of the bed DP unsteady.
	2125	Tar recycle discontinued.
June 21	0140	Tar recycle restarted.
	1058	Tar recycle discontinued to obtain a side stream sample without tar recycle.
	1715	Tar recycle restarted.
	2000	Oxygen loading increased to 135,000 SCFH as part of run program to raise loading to rate proposed for Demonstration Plant design.

1. Run Diary continued

Date	Time	Event
June 22	0230	Oxygen loading increased.
	0325	High torque on stirrer/distributor and bed behavior unsteady. Stirrer/distributor revolution rate was decreased, and tar recycle was discontinued. Continued planned increases in oxygen loading.
	1216	Gasifier bed unsteady; reverted to a lower oxygen loading.
	1630	Began increasing oxygen loading to reach 170,000 SCFH.
	2000	Oxygen rate reduced to 160,000 SCFH as a precautionary measure after the stirrer/distributor tripped out because of a high torque.
	2330	Gasifier operating well on Pittsburgh No. 8 coal at 160,000 SCFH oxygen loading and 1.30 steam/oxygen ratio.
June 23	1135	Gasifier shutdown in a controlled fashion as scheduled.

2. Raw Data

.. Pittsburgh No. 8 Coal

Proximate Analysis (Air Dried), Wt. %	June 19-20 2215-2115	June 20-21 2215-2115	June 21-22 2215-2115
Moisture	2.20	2.07	2.00
Ash	6.80	7.66	7.46
Volatile Matter	37.18	35.20	35.86
Fixed Carbon	53.82	55.15	54.68

Ultimate Analysis (Air Dried), Wt. %			
Carbon	75.0	75.4	74.5
Hydrogen	4.8	5.2	5.3
Nitrogen	1.4	1.5	1.5
Sulfur	1.48	1.39	2.28
Chlorine	0.09	0.08	0.10
Ash	6.8	7.66	7.46
Water	2.2	2.07	2.0
Heating Value, Btu/lb.	13,634	13,440	13,533
Swelling Index	7	7	7.5
Gray King Coke	G7	G8	G8

	June 20		June 21		June 22		
Size Analysis, Wt. %	0005	1330	0005	1330	0005	1400	2215
over 1-1/4"	5.0	1.0	3.5	4.0	4.0	6.0	2.0
1-1/4"-1"	7.5	6.5	8.5	10.5	13.5	14.5	4.5
1"-3/4"	20.0	30.0	24.0	24.5	30.0	24.0	15.5
3/4"-1/2"	28.5	34.0	30.0	28.5	28.5	26.0	28.5
1/2"-3/8"	21.5	18.0	18.0	17.5	14.5	16.5	23.5
3/8"-1/4"	9.5	5.0	13.0	9.5	6.5	9.0	14.5
1/4"-1/8"	4.0	2.0	2.0	3.5	2.0	3.0	7.5
under 1/8"	4.0	3.5	1.0	2.0	1.0	1.0	4.0
Bulk Density, Lbs/CF	49	47	49	49	50	50	49
Moisture Content, Wt.%	4.0	4.0	3.0	2.0	2.5	3.0	3.0

Forms of Sulfur, Wt.%	June 19-20	June 20-21	June 21-22
Organic Sulfur	0.22	0.24	0.29
Pyritic Sulfur	1.30	1.35	1.16
Sulfate Sulfur	0.24	0.21	0.15
Total Sulfur	1.76	1.80	1.60

a. Pittsburgh No. 8 Coal continued

Ash Analysis	Wt. %
SiO_2	48.4
Al_2O_3	24.8
CaO	2.2
MgO	1.0
Fe_2O_3	18.6
	95.0
Silica Number	69

b. Flux - Blast Furnace Slag

Flux Analysis, Wt. %	June 19-22 2215-2115
SiO_2	33.4
Al_2O_3	13.4
CaO	36.9
MgO	11.3
Fe_2O_3	0.7
	95.7
Silica Number	41

Date	Time	Moisture Content, Wt. %	Bulk Density, Lbs/CF
June 20	0005	1.0	67
	1330	5.0	71
June 21	0005	3.0	70
	1330	2.5	69
June 22	0005	3.0	70
	1400	4.0	66
	2215	3.0	69

c. Slag

Analysis, Wt. %	June 20-21 0930-0830	June 21-22 0930-0830	June 22-23 0930-0830
SiO_2	40.1	40.7	40.0
Al_2O_3	18.0	18.0	17.8
CaO	26.5	26.2	26.7
MgO	7.8	7.8	7.8
Fe_2O_3	5.7	5.7	5.9
Carbon	0.6	0.5	0.5
	98.7	98.9	98.7
Free Iron as Fe	0.69	0.66	1.00
FeO	3.9	3.99	3.93
Total Iron as Fe	3.99	3.99	4.13
Fe^{+2}	3.03	3.1	3.05
Fe^{+3}	0.27	0.23	0.08
Total Sulfide	0.33	0.26	0.10
Total Sulfur	0.58	0.52	0.55
Silica Number	50	51	50
Loss on Ignition, Wt.%*	+1.4	+1.6	+1.4

d. Oxygen Purity, Vol. %

Date	Time	Oxygen	Argon	Nitrogen
Jun 19	0805	93.75	2.58	3.67
	1500	92.15	3.0	4.8
	1900	93.2	2.4	4.4
Jun 20	0145	95.2	0.2	4.6
	0630	94.7	1.1	4.2
	1205	94.4	1.1	4.6
	1630	94.4	0.6	5.1
	1910	94.7	0.7	4.6
	2340	94.6	1.0	4.4
Jun 21	0350	94.6	0.7	4.4
	0730	94.1	0.3	5.6
	0900	94.7	1.3	4.1
	1345	94.1	0.3	5.6
	1720	94.0	0.8	5.2
	2300	95.7	0.3	4.1

* + is a gain.

d. Oxygen Purity continued

Date	Time	Oxygen	Argon	Nitrogen
June 22	0315	94.6	1.0	4.4
	0720	94.6	1.2	4.2
	1200	92.5	1.7	5.7
	1425	93.3	2.0	4.7
	1855	94.0	0.7	5.3
	2315	94.6	0.6	4.8
	0330	95.1	0.9	3.9
	0850	95.0	0.3	4.8
	1205	98.0	2.0	-

e. Recycle Tar

Ultimate Analysis (Dry, Dust Free)	Wt. %
Carbon	86.4
Hydrogen	7.6
Nitrogen	1.1
Sulfur	1.05
Chlorine	0.03
Ash	Nil
Water	Nil

Heating Value, Btu/lb. 16,285

Date	Time	Moisture Content, Wt. %	Dust Content, Wt. %
Jun 19	2345	5.8	20.0
Jun 20	1745	4.1	16.0
Jun 21	0003	3.0	16.0
	0930	2.0	14.0
Jun 22	0230	2.9	15.0
	1000	2.0	22.0
Jun 23	0330	2.5	20.0

Dust Ultimate Analysis (Air Dried)	Wt. %
Carbon	78.3
Hydrogen	5.3
Nitrogen	1.5
Sulfur	1.32
Chlorine	0.03
Ash	13.47
Water	1.2

Heating Value, Btu/lb. 12,452

e. Recycle Tar continued

Dry, Dust Free Tar

Density at 20°C	1.156 g/ml
Phenols (Wet)	4.95 Vol.%

Standard Tar Viscometer

20 °C	96 sec.
40 °C	5 sec.

Dry, Dust Free Tar Distillation

Volume, ml	Temperature, °C
IBP	91
2	194
5	211
7	218
10	224
12	234
15	236
17	242
20	246
22	252
25	256
27	271
30	275
32	277
35	281
35 + Residue	Pitch

Temperature, °C	Wt.%
IBP - 200	1.3
200 - 320	29.6
320 +	69.1

f. Crude Synthesis Gas (Main Stream Samples)

Analysis (Dry Basis), Vol. %

Date:	June 19				June 20							
Time:	1200	1415	1900	2240	0030	0445	0640	0900	1310	1634	Composite	2240
CH_4	6.18	1.00	0.89	7.85	6.8	6.57	7.4	7.54	7.04	6.82	6.95	7.72
CO_2	2.19	4.13	3.76	3.11	3.19	3.08	3.50	3.55	3.64	3.71	3.30	3.89
C_2H_4	0.25	Nil	Nil	0.10	0.15	0.19	0.19	0.19	0.33	0.13	0.32	0.20
C_2H_6	0.07	Nil	Nil	0.85	0.47	0.50	0.45	0.46	0.58	0.53	1.09	0.53
H_2S	0.51	0.26	0.28	0.47	0.43	0.53	0.51	0.51	0.53	0.50	0.49	0.51
H_2	33.04	27.16	28.12	27.95	28.76	28.33	28.46	29.54	26.76	29.45	28.38	28.34
Ar	0.65	0.98	0.99	0.71	0.68	0.99	0.93	0.92	0.9	0.9	1.18	0.83
N_2	3.03	4.12	3.48	3.39	2.7	3.43	3.70	3.49	3.0	2.56	4.25	3.18
CO	47.76	59.29	61.87	52.92	53.74	54.13	53.33	52.4	54.5	53.38	53.90	52.25
	93.68	96.94	99.39	97.35	96.92	97.75	98.47	98.60	97.28	97.98	98.86	97.45

f. Crude Synthesis Gas (Main Stream Samples) continued

Analysis (Dry Basis), Vol. %

Date	June 21							June 22				June 23	
Time:	0040	0440	0730	1030	1510	Composite	2140	0030	0540	1435	1900	0430	1730
CH_4	7.27	7.05	7.74	6.74	7.04	6.73	6.46	7.22	6.73	6.75	7.01	8.03	8.27
CO_2	3.52	3.65	3.76	4.32	3.70	3.78	3.32	3.12	3.2	3.51	3.47	4.23	4.16
C_2H_4	0.19	0.27	0.20	0.2	0.29	0.14	0.16	0.1	0.12	0.13	0.17	0.16	0.19
C_2H_6	0.46	0.77	0.47	0.49	1.25	0.46	0.46	0.51	0.54	0.46	0.44	0.49	0.59
H_2S	0.67	0.55	0.59	0.53	0.57	0.53	0.53	0.67	0.6	0.52	0.45	0.59	0.59
H_2	28.88	28.32	28.55	28.82	27.54	28.85	28.19	27.82	28.08	28.05	28.57	28.32	28.28
Ar	0.93	0.84	0.83	0.92	0.88	0.82	1.24	0.81	0.82	0.89	0.79	0.78	0.76
N_2	2.83	3.66	3.68	3.29	2.73	3.77	4.44	3.36	3.02	4.0	2.83	3.66	3.04
CO	53.79	52.47	52.52	52.67	54.48	52.76	52.99	55.81	54.51	54.16	53.39	52.61	52.14
	98.54	97.58	98.34	97.98	98.48	97.85	97.79	99.42	97.62	98.47	97.12	98.87	98.02

f. Crude Synthesis Gas continued

Minor Constituents, g/m^3		NH_3	HCN	Naphthalene	Cond.
Date	Time				
June 20	0145-0445	0.06	0.0169	0.056	7.35
	0950-1315	0.011	ND	0.025	4.27
June 21	0130-0445	0.034	0.019	0.021	8.19
	1130-1445	0.0118	0.0005	0.031	8.76
June 21-22	2300-0230	0.0176	0.0187	0.0255	7.26
June 22	1325-1530	0.029	0.005	0.036	6.5
June 23	0130-0415	0.032	0.078	0.0156	6.41

Sulfur Content, PPM		COS	CS_2	Thiophenes
Date	Time			
June 20	0030	444	3.2	2.9
	0630	446	4.6	4.5
	1855	420	2.0	2.3
June 21	0645	610	8.2	4.9
	1010	644	5.0	6.4
	1525	581	3.65	3.0
June 22	0230	610	7.0	3.7
	0600	587	6.3	2.5
	1540	558	3.4	4.0
June 23	0345	650	6.4	3.1
	0730	613	5.2	2.4

g. Flash Gas

	Tar Separator		Oil Separator
Analysis, Vol. %	Gas Phase	Combined	Gas Phase
CH_4	7.87	5.98	8.91
CO_2	3.72	5.97	12.76
C_2H_4	0.34	0.26	0.31
C_2H_6	0.62	0.47	1.26
H_2S	1.26	4.39	3.83
NH_3	Trace	21.59	-
H_2	27.29	20.73	22.62
Ar	2.11	1.6	1.46
N_2	0.67	5.14	3.74
CO	44.00	33.51	44.64
	87.88	99.64	99.53

Condensate, g/l	
NH_3	7.70
H_2S	2.40
CO_2	2.9
Gaseous NH_3	1.4 (0.002 vol. %)

h. Side Stream Samples

Date:	June 20	June 21	June 22
Time Period:	0930-1650	1100-1710	1315-1615
Gas Volume, SCF	1924	1449.5	826.4
Tar/Oil Product, grams	2315.6	1221.8	586.7
Dust, grams	23.3	4.0	15.3
Gas Liquor Product, grams	2634.9	2997.5	2394.9

i. Crude Synthesis Gas Composition (Side Stream Sample)

Minor Constituents

Date:	June 20	June 21	June 22
Time:	1000-1315	1130-1445	1325-1530
NH_3, g/m^3	0.025	0.0476	0.016
HCN, g/m^3	0.002	0.0025	0.006
Naphthalene, g/m^3	0.0092	0.081	0.172
Condensibles, g/m^3	1.98	1.28	0.90
COS, PPM	438	611	591
CS_2, PPM	1.4	5.5	4.8
Thiophenes, PPM	Nil	1.5	1.1

j. Combined Tar and Oil (Side Stream Samples)

Ultimate Analysis, Wt. %

Date:	June 20	June 21	June 22
Time:	0930-1650	1100-1710	1315-1615
Carbon	86.1	86.9	86.9
Hydrogen	7.5	7.5	7.2
Nitrogen	0.9	1.2	1.1
Sulfur	1.17	0.7	0.69
Chlorine	0.11	0.06	0.08
Ash	Nil	Nil	Nil
Water	Nil	Nil	Nil
Heating Value, Btu/lb.	16,374	16,348	16,404

Composite Sample

Density at 20 °C 1.099 g/ml
Phenols (Wet) 7.35 Vol.%

Viscosity, Redwood No. 1

20 °C 1380 sec.
40 °C 337 sec.

j. Combined Tar and Oil continued

Composite Distillation

Volume, ml	Temperature, °C
IBP	101
5	182
10	230
20	256
30	278
40	304
50	328
60	338
Pitch Residue	340 +

Temperature, °C	Wt.%
IBP - 200	0.18
200 - 320	57.14
320 +	42.68

k. Condensible Naphtha from Crude Synthesis Gas

Ultimate Analysis	Wt.%
Carbon	90.0
Hydrogen	8.8
Nitrogen	0.3
Sulfur	0.33
Chlorine	0.01

Heating Value, Btu/lb. 17,945

1. Gas Liquor

Side Stream Analysis, mg/l

Date:	June 20	June 21	June 22
Time:	0930-1650	1100-1710	1315-1615
Tar/Oil Content	2,026	6,103	5,616
Total Dissolved Solids	11,922	10,402	9,389
Total Sulfur	6,857	7,490	4,789
Total Ammonia	32,623	31,620	21,132
Free Ammonia	28,526	30,600	17,408
Fixed Ammonia	4,097	1,020	3,774
Carbonate as CO_2	37,400	36,300	20,680
Chloride	1,773	1,418	2,128
pH	9.06	8.84	8.58
Specific Gravity	1.036	1.035	1.025

Analysis, mg/l

Date:	June 22	June 22
Time:	0600	0600
Separator:	Oil	Tar
Tar/Oil Content	1,200	1,520
Total Dissolved Solids	4,696	8,071
Total Sulfur	5,123	730
Total Ammonia	33,286	3,026
Free Ammonia	32,504	1,190
Fixed Ammonia	782	1,836
Carbonate as CO_2	50,600	2,860
Chloride	2,128	1,418
pH	8.5	8.54
Specific Gravity	1.044	1.002

Slag Quench Water Analysis, mg/l

Date:	June 20	June 21	June 22
Time:	1530	1530	1800
Total Dissolved Solids	400	335	340
Total Sulfur	70	67	61
Chloride	10	13	8
pH	7.14	7.04	7.41

3. Heat and Material Balance - Pittsburgh No. 8 Coal & Blast Furnace Slag Flux

Material Balance, Pounds (Basis: 1,000 pounds dry Coal & flux)

Input	Rate	Carbon	Hydrogen	Nitrogen	Sulfur	Oxygen	Chlorine	Ash	Heat Balance Therms/Hr.
Coal/Flux	1044	648	46	12	13	110	1	214	2811
Steam	320		36			284			104
Fuel Gas	4	3	1						22
Oxygen/Air	544			89		455			3
	1912	651	83	101	13	849	1	214	2940
Output									
Heat Loss									62
Methane	83	62	21						484
Carbon Monoxide	1120	480				640			1220
Hydrogen	42		42						649
Carbon Dioxide	108	30				78			6
Inert Gas	89			89					5
Ethylene	5	4	1						25
Ethane	13	10	3						68
Ammonia	4		1	3					1
Hydrogen Sulfide	13		1		12				22
Carbonyl Sulfide	1				1				-
Tar	72	62	5	1	1	3			298
Naphtha	3	3							14
Liquor	129	1	14		1	113			43
Slag	215	1						214	42
	1897	653	88	93	15	834	0	214	2939
Input-Output Error, %	-0.8	0.3	6.0	-7.9	15.4	-1.8	-100.0	0	-0.03

4. Data Used in Balances - Pittsburgh No. 8 Coal

Coal Heating Value, Btu/lb.	11,285*

Coal Proximate Analysis	Wt. %*
Moisture	4.16
Ash	20.52
Volatile Matter	30.78
Fixed Carbon	44.54
	100.00

DAF Coal Ultimate Analysis	Wt. %
Carbon	82.41
Hydrogen	5.27
Nitrogen	1.54
Oxygen	9.05
Sulfur	1.63
Chlorine	0.10
	100.00

Gas Composition	Vol. %
Methane	7.06
Carbon Monoxide	54.73
Hydrogen	28.82
Carbon Dioxide	3.35
Inert Gas	4.37
Ethylene	0.23
Ethane	0.57
Hydrogen Sulfide	0.50
Ammonia	0.33
Carbonyl Sulfide	0.04
	100.00

Crude Gas Offtake Temperature	507°C
Gasifier Pressure	350 psig
Heat Loss from Jacket & Hearth	11.7 therms/hour
Jacket Steam Production	3000 lb/hour

* Includes flux.

Byproducts

Composition Wt. %	Naphtha	Product Tar	Minor Liquor Components
Carbon	90.00	86.10	22.16
Hydrogen	8.80	7.50	-
Nitrogen	0.30	0.90	-
Sulfur	0.33	1.17	14.90
Chlorine	0.01	0.11	3.85
Oxygen	0.56	4.22	59.09
	100.00	100.00	100.00

Heating Value	Btu/lb.
Naphtha	17,945
Product Tar	16,374
Minor Liquor Components	0

5. <u>Performance Data - Pittsburgh No. 8 Coal</u>

Steam Consumption	3.27 lb/therm gas
Steam Decomposition	88.02%
Oxygen Consumption	54.86 SCF/therm gas 13,696 SCF/ton DAF coal
Crude Gas Production*	249.7 therms/ton DAF coal
Gas Liquor Yield	1.26 lb/therm gas

Thermal Efficiencies, %	Gas Only	Gas, Tar, Oil & Naphtha
Crude Gas / Coal	83.31	94.04
Crude Gas / Coal, Steam & Oxygen	72.90	82.29

* Includes coal lock gas.

TSP Run 14

Feed Coal: Ohio No. 9 Coal
Date of Run: June 27-29, 1978

1. Run Diary

Date	Time	Event
June 27	1645	Steam/oxygen introduced into gasifier through the tuyeres. Frances coal and blast furnace slag flux fed into the top through the coal lock. Steam/oxygen ratio set at 1.3 and gasifier pressure at 350 psig. Adjusted oxygen rate to 130,000 SCFH.
	2252	Ohio No. 9 coal fluxed with blast furnace slag was fed to gasifier through the coal lock.
June 28	0050	Frances coal reintroduced into gasifier because clay materials in the Ohio No. 9 coal were binding the coal lumps together and plugging the bunker feed to the coal lock.
	0330	Ohio No. 9 coal reintroduced into gasifier
	0745	Frances coal reintroduced into gasifier because of reoccurrance of plugging problem.
	1522	Ohio No. 9 coal fed once again to gasifier; oxygen loading at 130,000 SCFH and steam/oxygen ratio at 1.30.
	1710	Fluxing rate decreased.
	2010	Tuyeres flashing and going black. Steam/oxygen ratio trimmed to 1.25 and fluxing rate increased.
June 29	0026	Gasifier back to normal conditions.
	1026	Tuyeres flashing and going black. Fluxing rate increased.
	1126	Gasifier conditions restored to normal.
	1632	Gasifier shutdown in controlled fashion as scheduled. This run had to be shortened because most operating personnel were scheduled for annual vacation period in July.

2. Raw Data

a. Ohio No. 9 Coal

Proximate Analysis (Air Dried), Wt. %		
Date:	June 28	June 28-29
Time:	0440-0800	1910-1410
Moisture	3.08	4.01
Ash	17.12	21.60
Volatile Matter	35.48	33.55
Fixed Carbon	44.32	40.84

Ultimate Analysis (Air Dried), Wt. %		
Carbon	63.30	59.30
Hydrogen	4.80	4.50
Nitrogen	0.90	0.90
Sulfur	4.29	4.17
Chlorine	0.05	0.04
Ash	17.12	21.60
Water	3.08	4.01
Swelling Index	4.5	4.5
Gray King Coke	G	G

Size Analysis, Wt. %				
Date:	June 28	June 28	June 29	June 29
Time:	0115	1730	0530	1045
over 1-1/4"	3.0	3.0	1.0	-
1-1/4"-1"	4.5	6.5	1.0	2.0
1"-3/4"	21.5	30.5	16.5	21.0
3/4"-1/2"	34.5	31.0	43.5	57.5
1/2"-3/8"	20.0	17.0	22.0	12.5
3/8"-1/4"	7.5	3.5	7.0	3.0
1/4"-1/8"	1.5	2.5	4.0	2.0
under 1/8"	7.5	6.0	5.0	2.0
Bulk Density, Lb/CF	ND	51	50	50
Moisture Content Wt. %	5.0	6.0	5.0	6.5

Forms of Sulfur, Wt. %	June 28	June 29
Organic Sulfur	1.24	1.16
Pyritic Sulfur	2.45	2.39
Sulfate Sulfur	0.60	0.62
Total Sulfur	4.29	4.17

a. Ohio No. 9 Coal continued

Ash Analysis	Wt. %
SiO_2	45.4
Al_2O_3	21.1
CaO	2.2
MgO	1.2
Fe_2O_3	21.3
	91.2

Silica Number	65

b. Flux

Size Analysis, Wt. %		
Date:	June 28	June 29
Time:	1500	1045
over 1/2"	6.0	11.0
1/2"-3/8"	69.0	69.5
3/8"-1/4"	23.0	19.0
1/4"-1/8"	1.5	0.5
under 1/8"	0.5	0.5
Bulk Density, Lb/CF	69.0	70.5
Moisture Content, Wt. %	5.0	3.0

Analysis	Wt. %
SiO_2	33.4
Al_2O_3	13.4
CaO	37.5
MgO	10.6
Fe_2O_3	0.8
	95.7

Silica Number	41

c. Slag

Analysis, Wt. %			
Date:	June 28	June 28	June 29
Time:	0440-0800	1630-1830	0915-1530
SiO_2	39.9	43.1	43.0
Al_2O_3	17.4	19.0	19.0
CaO	21.5	18.0	20.4
MgO	6.4	5.1	5.6
Fe_2O_3	12.2	12.2	9.7
Carbon	1.0	1.1	0.8
	98.4	98.5	98.5

c. Slag continued

Analysis, Wt. %

Date:	June 28	June 28	June 29
Time:	0440-0800	1630-0830	0915-1530
Free Iron as Fe	1.06	0.62	1.08
FeO	9.00	9.04	6.99
Total Iron as Fe	8.53	8.53	6.78
Fe^{+2}	7.00	7.00	5.27
Fe^{+3}	0.47	0.91	0.43
Total Sulfides	0.37	0.65	0.78
Total Sulfur	1.44	1.94	1.23
Silica Number	50	55	55
Loss on Ignition, Wt.%*	+3.0	+2.3	+2.3

d. Oxygen Purity, Vol. %

Date	Time	Oxygen	Argon	Nitrogen
June 27	2245	94.0	1.5	4.5
June 28	1405	95.1	0.6	4.2
	0700	95.1	0.9	4.0
	1120	96.1	0.9	3.0
	1500	96.3	1.2	2.5
	1905	96.2	1.3	2.4
	2230	95.1	1.5	2.6
June 29	0100	96.2	1.1	2.7
	0500	95.7	0.9	3.4
	0655	95.7	1.3	3.0
	1055	95.9	1.4	2.7
	1400	95.9	1.2	2.9

* + is a gain.

e. Crude Synthesis Gas (Main Stream Samples)

Analysis (Dry Basis), Wt. %

Date:	June 27	June 28						June 29				
Time:	2335	0400	0705	1115	1540	1915	2210	0200	0400	0700	1030	1430
CH_4	7.06	7.41	7.11	7.70	6.87	8.72	8.10	6.95	7.13	8.17	6.26	6.19
CO_2	4.05	4.01	4.94	3.34	3.98	4.98	5.17	4.87	5.73	5.07	5.70	6.29
C_2H_4	0.14	0.14	0.14	0.19	0.16	0.14	0.14	0.17	0.13	0.26	0.07	0.21
C_2H_6	0.46	0.49	0.45	0.61	0.50	0.57	0.83	0.54	0.58	0.66	0.36	0.72
H_2S	0.79	0.99	1.28	1.00	0.95	1.48	1.28	1.25	1.21	1.34	1.20	1.40
H_2	28.13	28.00	28.07	28.24	27.90	28.47	27.93	27.93	28.19	27.93	27.59	29.68
Ar	0.74	0.67	0.69	0.66	0.70	0.67	0.70	0.61	0.59	0.73	0.70	0.65
N_2	4.11	3.00	2.77	2.70	2.55	2.88	3.02	2.56	4.56	2.95	3.16	2.27
CO	53.95	53.21	52.45	54.84	56.50	51.88	52.73	54.47	51.59	52.81	51.27	48.92
	99.43	97.92	97.90	99.28	100.11	99.79	99.90	99.35	99.71	99.92	96.31	96.33

e. Crude Synthesis Gas continued

Minor Constituents, g/m^3

Date:	June 28	June 28
Time:	0630-0750	1945-2300
NH_3	0.136	0.095
HCN	0.024	-
Naphthalene	0.014	-
Condensate	12.6	6.57

Sulfur Content, PPM

Date:	June 28	June 28	June 29
Time:	0515	1900	0510
COS	1270	1385	1347
CS_2	10.3	10.0	10.7
Thiophenes	5.7	6.5	5.3

f. Side Stream Samples

Date:	June 25	June 28	June 29
Time:	0630-0830	1730-2305	1000-1430
Gas Volume, SCF	419.8	448.5	725.1
Tar/Oil Product, grams	332.0	332.4	727.8
Dust, grams	12.3	11.8	20.7
Gas Liquor Product, grams	1417.6	1043.2	2287.0

g. Crude Synthesis Gas Composition (Side Stream Sample)

Analysis, Vol. %

Date:	June 29
Time:	1000-1430
CH_4	6.73
CO_2	5.31
C_2H_4	0.18
C_2H_6	0.32
H_2S	1.15
H_2	27.94
O_2	Nil
Ar	0.74
N_2	3.15
CO	51.78
	97.30

g. Crude Synthesis Gas continued

Minor Constituents, g/m^3

Date:	June 28	June 28
Time:	0630-0830	1730-2305
NH_3	0.336	0.012
HCN	0.038	0.005
Naphthalene	ND	0.022
Condensibles	6.8	Trace

Sulfur Content, PPM

COS	1238	1403
CS_2	10.0	8.7
Thiophenes	2.5	3.9

h. Combined Tar and Oil (Side Stream Sample)

Analysis, Wt. %

Date:	June 25	June 28	June 28
Time:	0630-0830	1730-2305	1000-1430
Carbon	85.80	84.90	85.20
Hydrogen	7.30	7.50	9.30
Nitrogen	0.90	1.20	0.40
Sulfur	1.41	1.82	1.89
Chlorine	0.03	0.04	0.03
	95.44	95.46	96.82
Heating Value, Btu/lb.	17,086	16,356	16,860

i. Gas Liquor

Side Stream Analysis, mg/l

Date:	June 28	June 28	June 29
Time:	0630-0830	1730-2305	1000-1430
Tar/Oil Content	29,680	19,320	23,400
Total Dissolved Solids	4,753	8,031	5,474
Total Sulfur	6,718	7,995	4,057
Total Ammonia	15,470	18,768	18,530
Free Ammonia	12,988	16,660	16,116
Fixed Ammonia	2,482	2,108	2,414
Carbonate as CO_2	18,920	20,240	22,000
Chloride	1,773	1,773	1,773
pH	8.56	8.64	8.59
Specific Gravity	1.019	1.022	1.022

Gas Liquor from Plant Separators, mg/l

Date:	June 29	June 29
Time:	1500	1500
Separator:	Oil	Tar
Tar/Oil Content	400	4840
Total Dissolved Solids	5553	10395
Total Sulfur	3351	656
Total Ammonia	42160	3587
Free Ammonia	38148	1411
Fixed Ammonia	4012	2176
Carbonate as CO_2	63800	2200
Chloride	1773	2837
pH	8.38	8.69
Specific Gravity	1.052	1.002

3. **Heat and Material Balance - Ohio No. 9 Coal & Blast Furnace Slag Flux**

Material Balance, Pounds (Basis: 1,000 pounds dry coal & flux)									Heat Balance
Input	Rate	Carbon	Hydrogen	Nitrogen	Sulfur	Oxygen	Chlorine	Ash	Therms/Hr.
Coal/Flux	1065	535	48	8	38	107		329	2731
Steam	262		29			233			100
Fuel Gas	4	3	1						23
Oxygen/Air	465			68		397			3
	1796	538	78	76	38	737	0	329	2857
Output									
Heat Loss									62
Methane	68	51	17						461
Carbon Monoxide	907	389				518			1150
Hydrogen	35		35						626
Carbon Dioxide	146	40				106			7
Inert Gas	68			68					3
Ethylene	3	3							19
Ethane	6	5	1						38
Ammonia	3		1	2					-
Hydrogen Sulfide	24		1		23				50
Carbonyl Sulfide	5	1			3	1			-
Tar	51	43	5		1	2			242
Naphtha	9	8	1						48
Liquor	144	1	16		1	126			54
Slag	332	3						329	78
	1801	544	77	70	28	753	0	329	2838
Input-Output Error, %	0.3	1.1	-1.3	-7.9	-26.3	2.2	0	0	-0.7

4. Data Used in Balance - Ohio No. 9 Coal

Coal Heating Value, Btu/lb.	9139*

Coal Proximate Analysis	Wt. %*
Moisture	6.05
Ash	30.88
Volatile Matter	28.45
Fixed Carbon	34.62
	100.00

DAF Coal Ultimate Analysis	Wt. %
Carbon	79.71
Hydrogen	6.05
Nitrogen	1.21
Oxygen	7.37
Sulfur	5.61
Chlorine	0.05
	100.00

Gas Composition	Vol. %
Methane	6.888
Carbon Monoxide	52.992
Hydrogen	28.594
Carbon Dioxide	5.434
Inert Gas	3.981
Ethylene	0.184
Ethane	0.328
Hydrogen Sulfide	1.177
Ammonia	0.287
Carbonyl Sulfide	0.135
	100.00

Crude Gas Offtake Temperature	410°C
Gasifier Pressure	350 psig
Heat Loss	11.59 therms/hour
Jacket Steam Production	3000 lb/hour**

* Includes flux.
** Estimated.

Byproducts

Composition Wt. %	Naphtha	Product Tar	Minor Liquor Components
Carbon	89.19	85.20	21.56
Hydrogen	9.24	9.30	-
Nitrogen	0.40	0.40	-
Sulfur	1.16	1.89	14.58
Chlorine	0.01	0.03	6.37
Oxygen	-	3.18	57.49
	100.00	100.00	100.00

Heating Value	Btu/lb.
Naphtha	17,945
Product Tar	16,860
Minor Liquor Components	0

5. Performance Data - Ohio No. 9 Coal

Steam Consumption	3.32 lb/therm gas	
Steam Decomposition	85.08%	
Oxygen Consumption	59.51 SCF/therm 13,998 SCF/ton DAF coal	
Crude Gas Production *	235.2 therms/ton DAF coal	
Gas Liquor Yield	1.77 lb/therm	

Thermal Efficiencies, %	Gas Only	Gas, Tar, Oil & Naphtha
Crude Gas / Coal	85.21	94.84
Crude Gas / Coal, Steam & Oxygen	74.61	83.03

* Includes coal lock gas.

TSP Run 15

Feed Coal: Pittsburgh No. 8 Coal
Date of Run: August 11-15, 1978

1. Run Diary

Date	Time	Event
Aug 11	0321	After a standard startup, steam and oxygen were introduced through the tuyeres and Frances coal was fed to the top of the gasifier. Operating conditions were adjusted to 160,000 SCFH oxygen rate, 1.35 steam/oxygen ratio, gasifier pressure of 350 psig, and blast furnace slag flux.
	0630	Oxygen load was reduced to 130,000 SCFH in preparation for introduction of Pittsburgh No. 8 coal. Stirrer/distributor tripped out twice at the higher load on Frances coal because of high torque. Cause of high torque was not determined.
	0956	Sized (1-1/4" x 1/4") Pittsburgh No. 8 coal was fed to top of gasifier; oxygen load at 130,000 SCFH; steam/oxygen ratio at 1.30; pressure at 350 psig; blast furnace slag flux.
	1400	Started increasing oxygen load.
	1609	Oxygen load reached 160,000 SCFH, but stirrer/distributor tripped out because of high torque.
Aug 12	0255	After two more attempts to increase oxygen load to 160,000 SCFH, operations were adjusted to 135,000 SCFH oxygen load and 1.32 steam/oxygen ratio. Gasification was steady under these conditions.
	2007	Started feeding recycle tar to the top of the gasifier and subsequently varied the rate of tar feed in a planned experiment.
Aug 13	0800	Completed tar recycle experimental studies as planned; no problems with tar recycle occurred.
	1000	Began to systematically add coal fines (1/4" x 0) at an increasing rate to the Pittsburgh No. 8 coal feed to the gasifier; started with six percent fines in feed.
Aug 14	2152	Fines content of feed coal now about 23 percent. No operating problems occurring because of feeding Pittsburgh No. 8 coal with a high content of 1/4" x 0 coal fines.

1. Run Diary continued

Date	Time	Event
Aug 15	2208	Gasifier shut down as planned after over 24 hours on feed containing 23 percent fines. Run was terminated because the subcontract with British Gas terminates on August 15.

Summary

Date	Time	Coal Feed	Comment
Aug 11	0321-0956	Frances	Startup
Aug 11	0956-1400	Pgh No. 8[1]	130,000 SCFH O_2
Aug 11-12	1400-0830	Pgh No. 8[1]	Varying O_2 Rate
Aug 12	0830-2007	Pgh No. 8[1]	135,000 SCFH O_2
Aug 12	2007-2040	Pgh No. 8[1]	Started Tar Recycle
Aug 12-13	2040-0340	Pgh No. 8[1]	135,000 SCFH O_2 Tar Recycle at 50%
Aug 13	0340-0800	Pgh No. 8[1]	135,000 SCFH O_2 Tar Recycle at 70%
Aug 13	0800-1000	Pgh No. 8[1]	No Tar Recycle
Aug 13	1000-1700	Pgh No. 8[2]	135,000 SCFH O_2 No Tar Recycle
Aug 13	1700-2207	Pgh No. 8[2]	135,000 SCFH O_2 Tar Recycle at 50%
Aug 13-14	2207-1000	Pgh No. 8[3]	135,000 SCFH O_2 Tar Recycle at 50%
Aug 14	1000-1750	Pgh No. 8[4]	135,000 SCFH O_2 Tar Recycle at 60%
Aug 14	1750-2152	Pgh No. 8[4]	135,000 SCFH O_2 No Tar Recycle
Aug 14-15	2152-2209	Pgh No. 8[5]	135,000 SCFH O_2 Tar Recycle at 50%

Notes: 1. Pgh No. 8 contains 6% 1/4" x 0 fines.
2. Pgh No. 8 contains 10% 1/4" x 0 fines.
3. Pgh No. 8 contains 13% 1/4" x 0 fines.
4. Pgh No. 8 contains 16% 1/4" x 0 fines.
5. Pgh No. 8 contains 23% 1/4" x 0 fines.

2. Raw Data

a. Pittsburgh No. 8 Coal

Proximate Analysis (Air Dried), Wt. %

Date:	Aug 11-12	Aug 12-13	Aug 13	Aug 13-14	Aug 14	Aug 15
Time:	1100-1000	1100-0900	1000-2300	2300-1100	1100-2300	2300-2200
Moisture	1.42	1.37	1.56	1.55	1.09	1.11
Ash	9.26	8.18	8.80	8.35	8.05	7.69
Volatile Matter	36.80	36.96	36.34	35.94	37.24	36.72
Fixed Carbon	52.52	53.49	53.30	54.16	53.62	54.48
Swelling Index	7	7-1/2	7	7-1/2	7-1/2	7
Gray King Coke	G8	G8	G8	G8	G8	G7

Ultimate Analysis (Air Dried), Wt. %

Date:	Aug 11-12	Aug 13	Aug 13-14	Aug 14	Aug 14-15
Time:	1100-1000	1100-2200	2300-1000	1100-2100	2300-2200
Carbon	73.70	74.20	74.30	74.70	75.20
Hydrogen	5.10	5.30	5.10	5.20	5.30
Nitrogen	1.50	1.40	1.40	1.30	1.20
Sulfur	1.78	2.37	1.86	1.77	1.88
Chlorine	0.08	0.10	0.09	0.08	0.08
Ash	8.72	8.80	8.35	8.05	7.69
Water	1.40	1.56	1.55	1.09	1.11

Forms of Sulfur, Wt.%	Screened*
Organic Sulfur	0.26
Pyritic Sulfur	1.25
Sulfate Sulfur	0.23
Total Sulfur	1.74

*Contains 6% fines (1/4" x 0)

a. Pittsburgh No. 8 Coal continued

Size Analysis, Wt. %

Date: Time:	Aug 11 1300	Aug 12 0100	Aug 12 1030	Aug 13 0430	Aug 13 1130
over 1-1/4"	0.5	2	3	3	1
1"-1-1/4"	3.5	12	11.5	14	3
3/4"-1"	13	31	25.5	28	22
1/2"-3/4"	38	29	29	29.5	23.5
3/8"-1/2"	26	12	18	15	19.5
1/4"-3/8"	12	8	8	7.5	8.5
1/8"-1/4"	3.5	2	2	2	10.5
under 1/8"	3.5	4	3	1	12
Bulk Density, Lb/CF	46	45	46.5	46	49
Moisture, Wt. %	4.0	6.0	4.0	4.5	6.5

Date: Time:	Aug 14 0100	Aug 14 0300	Aug 14 1330	Aug 15 0300	Aug 15 1300
over 1-1/4"	1	5	9	6	3
1"-1-1/4"	6	9	14	8	6
3/4"-1"	19	29.5	35	28	12.5
1/2"-3/4"	24	25.5	16.5	23	19
3/8"-1/2"	20	15	9	12	16
1/4"-3/8"	16	8	5.5	9	16.5
1/8"-1/4"	11	4	4	7.5	16
under 1/8"	3	4	7	6.5	11
Bulk Density, Lb/CF	ND	48.5	49	48.5	48
Moisture, Wt. %	4.5	4.5	ND	3.0	ND

Fines (1/4" x 0) Content, Wt.%

Sample No.	Screened	As Received
1	7	24
2	6	27
3	9	14
4	5	21.5
5	7	20
6	3	24.5
7	3	27
8	6	18.5
9	-	23.5
10	-	29

a. Pittsburgh No. 8 Coal continued

Ash Analysis, Wt. %

Date:	Aug 11-12	Aug 13	Aug 13-14	Aug 14	Aug 14-15	Other Components	
Time:	1100-1000	1100-2200	2300-1000	1100-2100	2300-2200		
SiO_2	49.97	49.09	49.55	48.32	48.05	TiO_2	1.21
Al_2O_3	25.02	24.38	24.67	24.21	24.28	Mn_3O_4	0.12
CaO	2.04	3.30	1.58	1.88	2.38	K_2O	1.80
MgO	0.99	1.34	1.16	1.00	0.76	Na_2O	0.31
Fe_2O_3	17.39	16.15	17.91	18.03	17.37		
	95.41	94.26	94.87	93.44	92.84		
Silica No.	75	74	74	74	73		

b. Flux - Blast Furnace Slag

Flux Analysis	Wt. %		Wt. %
SiO_2	33.74	TiO_2	0.70
Al_2O_3	12.85	Mn_3O_4	0.81
CaO	36.90	K_2O	0.49
MgO	10.00	Na_2O	0.37
Fe_2O_3	0.78	Total	96.64

Loss of Ignition, Wt.% -0.60

Silica Number 42

Date	Time	Moisture Content Wt. %	Bulk Density, Lb/CF
Aug 11	1330	4.0	69
Aug 12	1100	2.5	67.5
Aug 13	ND	4.5	69
Aug 14	1130	3.5	69
Aug 15	1400	ND	71

c. **Slag**

Analysis, Wt. % Date: Time:	Aug 11-12 1100-1000	Aug 13 1100-2200	Aug 13-14 2300-1000	Aug 14 1100-2100	Aug 14-15 2300-2200
SiO_2	41.40	40.68	41.19	38.86	40.44
Al_2O_3	17.41	17.82	17.66	17.49	17.54
CaO	24.73	26.47	26.93	26.29	26.66
MgO	7.15	7.24	7.29	7.18	7.32
Fe_2O_3	5.34	5.39	5.42	5.36	5.29
Carbon	0.29	0.27	0.25	0.39	0.33
	96.32	97.87	98.74	95.57	97.58
Free Iron as Fe	0.28	0.32	0.30	0.28	0.27
FeO	4.06	3.91	4.36	3.87	4.25
Total Iron as Fe	3.73	3.77	3.79	3.75	3.70
Fe^{+2}	3.15	3.03	3.38	3.00	3.29
Fe^{+3}	0.30	0.42	0.11	0.47	0.14
Sulfide	0.34	0.13	0.16	0.26	0.27
Total Sulfur	0.46	0.45	0.44	0.46	0.45
Loss on Ignition, Wt. %*	+0.81	+0.98	+0.86	+0.70	+0.71
Silica No.	53	52	52	51	51

Other Components	
TiO_2	0.73
Mn_3O_4	0.58
K_2O	0.92
Na_2O	0.43

* + is a gain.

d. Oxygen Purity, Vol. %

Date	Time	Oxygen	Nitrogen	Argon
Aug 11	0430	93.2	4.1	2.7
	1030	93.4	4.2	2.4
	1830	95.3	3.4	1.3
Aug 12	0210	94.5	4.3	1.1
	1100	96.5	2.5	0.1
	1900	96.2	3.1	0.7
	2330	95.5	3.6	0.9
Aug 13	0645	95.6	3.6	0.8
	1500	95.6	4.7	0.7
	2245	95.5	4.4	0.1
Aug 14	0630	95.5	3.9	0.6
	1300	97.5	1.7	0.8
	2305	95.5	3.7	0.8
Aug 15	0640	96.4	2.9	0.6
	1300	96.5	3.0	0.5
	1600	96.5	2.7	0.8

e. Recycle Tar

Tar Dust Ultimate Analysis (Air Dried)	Composite, Wt. %
Carbon	78.3
Hydrogen	5.3
Nitrogen	1.5
Sulfur	1.5
Chlorine	0.1
Ash	13.2
Water	1.1
Heating Value, Btu/lb.	12,178

Tar Properties
(Dry, Dust Free)

Density at 20°C, g/ml	1.134
Toluene Insoluables, Wt.%	4.46
Phenols (Wet), Wt.%	6.1
Phenols (Wet), Vol.%	6.7
Viscosity, seconds	
Tar (10 mm cup) at 20°C	24.2
Tar (10 mm cup) at 40°C	2.0
Redwood No. 1 at 75°C	156.8
Redwood No. 1 at 85°C	95.0
Redwood No. 1 at 95°C	68.8

e. Recycle Tar continued

Tar Ultimate Analysis (Dry, Dust Free), Wt. %

Date:	Aug 12-13	Aug 13	Aug 14	Aug 14	Aug 15
Time:	0120-0530	1330-2130	0050-0530	1130-2130	0045-2130
Carbon	85.2	85.9	82.6	86.1	86.1
Hydrogen	7.0	6.8	6.5	6.6	6.8
Nitrogen	1.1	1.1	1.2	1.4	1.1
Sulfur	1.1	1.16	2.42	0.82	0.9
Chlorine	0.05	ND	0.05	ND	0.02
Ash	Nil	Nil	Nil	Nil	Nil
Water	Nil	Nil	Nil	Nil	Nil
Heating Value, Btu/lb.	16,029	16,039	15,988	15,986	16,057

Date	Time	Moisture, Wt. %	Dust, Wt. %
Aug 11	2100	ND	9.0
Aug 12	0120	4.5	5.0
	1730	2.55	33.0
	2240	ND	22.0
Aug 13	0130	2.2	6.2
	1330	ND	7.0
	2130	ND	24.2
Aug 14	0050	6.8	22.0
	0530	ND	18.2
	1530	ND	20.8
Aug 15	0045	3.0	24.0
	0930	ND	13.9
	2130	ND	19.2

e. Recycle Tar Continued

Tar Distillation (Dry, Dust Free)

Volume, ml	Temperature, °C
IBP	203
5	224
10	232
20	278
30	306
40	320

Temperature, °C	Vol.%	Wt.%
IBP - 200	Nil	Nil
200 - 320	40.0	37.4
320 +	60.0	62.6

f. Crude Synthesis Gas (Main Stream Samples)

Analysis (Dry Basis), Vol. %

Date	Aug 11		Aug 12					Aug 13		
Time	1320	1745	0220	1005	0940-1430	1905	2335	0330	1000	1600
CH_4	7.46	7.35	6.94	7.12	8.04	7.82	7.45	6.18	6.75	6.51
CO_2	4.38	4.06	3.76	3.50	3.71	3.87	4.60	4.10	4.15	3.51
C_2H_4	0.14	0.05	0.12	0.21	0.10	0.10	0.09	0.21	0.09	0.10
C_2H_6	0.54	0.44	0.37	0.61	0.44	0.43	0.46	Nil	0.37	0.44
H_2S	0.39	0.33	0.40	0.77	0.53	0.59	0.65	0.63	0.59	0.60
H_2	27.72	29.04	29.46	29.98	28.78	28.72	29.60	31.12	29.22	29.10
Ar	0.82	0.80	0.66	0.41	0.94	0.67	0.59	0.44	0.65	0.60
N_2	2.88	3.61	3.37	3.47	4.02	3.54	2.78	3.10	3.39	3.25
CO	54.54	53.78	53.27	52.61	53.13	53.43	51.59	50.73	52.73	55.22
	98.87	99.46	98.35	98.68	99.69	99.17	97.81	96.51	97.94	99.33

f. Crude Synthesis Gas (Main Stream Samples) continued

Analysis (Dry Basis), Vol. %

Date	Aug 13			Aug 14			Aug 15			
Time	1115-1600	2245	0330	0930	1300	0145-0915	0230	0645	0930	0915-1445
CH_4	7.61	6.91	6.26	7.50	7.70	6.58	7.27	6.33	6.28	7.20
CO_2	4.35	3.97	3.62	3.70	5.02	4.91	5.25	5.32	3.79	3.88
C_2H_4	0.12	0.09	0.12	0.09	0.08	0.16	0.13	0.71	0.12	0.11
C_2H_6	0.49	0.48	0.45	0.53	0.45	0.35	0.41	Nil	0.36	0.46
H_2S	0.61	0.65	0.53	0.57	0.57	0.34	0.71	0.40	0.45	0.38
H_2	28.98	29.08	28.84	29.77	30.28	29.77	31.35	29.26	29.26	27.88
Ar	1.12	0.69	0.67	0.65	0.63	0.80	0.66	0.70	0.53	1.44
N_2	3.98	3.14	3.29	3.34	3.48	3.67	3.55	2.13	2.75	4.41
CO	52.56	52.47	53.89	52.70	50.08	49.92	50.35	53.16	54.09	52.92
	99.82	97.48	97.67	98.85	98.29	96.50	99.68	98.01	97.63	98.68

f. Crude Synthesis Gas continued

Minor Constituents, g/m^3

Date	Time	NH_3	HCN	Naph-thalene	Conden-sate
Aug 11	1730-1930	0.118	0.010	0.0247	0.88
Aug 12	0215-0515	0.018	0.004	0.0287	10.64
	1145-1400	ND	0.010	0.0271	15.00
Aug 12-13	2130-0100	0.027	0.020	0.0180	15.28
Aug 13	1140-1500	0.019	0.003	0.0378	4.80
Aug 14	0145-0420	0.006	0.004	0.0340	9.46
	1420-1900	0.014	0.005	0.0334	5.07
Aug 14-15	2310-0225	0.002	0.005	0.0310	8.45
Aug 15	1130-1530	0.012	0.004	0.0260	9.10

Sulfur Content, PPM

Date	Time	COS	CS_2	Thiophenes
Aug 11	1430	401	3.2	Nil
Aug 12	0220	401	4.0	3.3
	1115	371	3.8	2.2
	1420	411	5.6	2.6
Aug 13	0040	473	4.1	4.0
	0630	404	4.6	2.3
	1310	445	4.4	2.8
Aug 14	0115	417	5.3	5.7
	0550	440	6.7	ND
Aug 15	0235	390	6.1	9.1
	0610	400	4.6	8.0
	1400	440	5.6	Nil

g. Condensible Naphtha from Crude Synthesis Gas

Ultimate Analysis	Wt. %
Carbon	90.6
Hydrogen	8.9
Nitrogen	0.1
Sulfur	0.22
Chlorine	0.06
Ash	Nil
Water	Nil

Heating Value, Btu/lb. 18,170

h. Side Stream Samples

Sample:	S/S1	S/S2	S/S3	S/S4	S/S5	S/S6
Date:	Aug 12	Aug 12-13	Aug 13	Aug 14	Aug 14	Aug 15
Time Period:	0940-1430	2130-0330	1115-1600	0145-0915	1315-1810	0915-1445
Gas Volume, SCF	1016.4	973.8	1008.5	1717.9	1243.7	1232.2
Tar/Oil Product, grams	723	778	622	1623	981	964
Dust, grams	18.1	31.7	19.7	27.3	6.7	16.0
Gas Liquor Product, grams	2760	2803	2985	5444	3491	4967

i. Combined Tar and Oil (Side Stream Samples)

Ultimate Analysis, Wt. %	S/S1	S/S2	S/S3	S/S4	S/S5	S/S6
Carbon	88.0	86.7	87.0	87.2	87.1	86.9
Hydrogen	7.2	7.4	7.8	7.4	7.9	7.6
Nitrogen	0.9	1.0	0.9	0.9	1.1	1.5
Sulfur	1.24	0.71	0.92	0.76	1.48	0.86
Chlorine	0.01	0.02	0.02	0.02	0.02	0.04
Ash	Nil	Nil	Nil	Nil	Nil	Nil
Water	Nil	Nil	Nil	Nil	Nil	Nil
Heating Value, Btu/lb.	16,229	16,261	16,257	15,778	16,309	16,125

j. Gas Liquor (Side Stream Samples)

Analysis, mg/l	S/S1	S/S2	S/S3	S/S4	S/S5	S/S6
Tar/Oil Content	ND	ND	ND	ND	ND	ND
Total Dissolved Solids	12,952	10,888	7,038	7,762	7,217	5,715
Total Sulfur	5,798	6,386	5,723	4,837	5,372	5,276
Total Ammonia	20,961	21,658	23,851	21,097	20,910	20,604
Free Ammonia	19,108	18,921	18,904	18,003	19,193	18,598
Fixed Ammonia	1,853	2,727	4,947	3,094	1,717	2,006
Carbonate as CO_2	11,000	10,920	12,180	8,720	9,600	11,180
Chloride	2,304	2,127	2,175	1,862	1,958	2,304
pH	8.92	8.8	8.75	8.8	8.85	8.71
Specific Gravity	1.024	1.026	1.025	1.021	1.022	1.021

Minor Constituents						
Date	Aug 12	Aug 12-13	Aug 13	Aug 14	Aug 14	Aug 15
Time Period	0955-1400	2140-0100	1130-1605	0155-0425	1315-1810	1100-1430
NH_3, g/m^3	ND	0.200	0.096	0.038	ND	0.028
HCN, g/m^3	0.001	0.009	0.001	0.007	ND	0.043
Naphthalene, g/m^3	0.016	ND	0.028	0.035	ND	ND
Condensibles, g/m^3	3.46	4.87	7.79	2.94	ND	3.25
COS, PPM	529	297	557	472	445	440
CS_2, PPM	6.6	4.8	5.1	7.7	10.0	5.6
Thiophenes, PPM	4.2	3.1	2.8	ND	ND	Nil

k. Gas Liquor (Tar/Oil Separator Samples)

Analysis, mg/l	Oil Separator	Tar Separator
Tar/Oil Content	330	600
Total Dissolved Solids	3,342	10,192
Total Sulfur	5,141	664
Total Ammonia	11,611	3,570
Free Ammonia	10,540	2,550
Fixed Ammonia	1,071	1,020
Carbonate as CO_2	10,340	30,800
Chloride	2,970	1,418
Sulfide as S	80	48
Sulfate as SO_4	140	305
Total Phenols	2,400	1,800
Monohydric Phenols	425	1,450
Nitrates as NO_3	2	3
Fatty acids as acetic	396	720
Cyanides as CN	23	49
Thiocyanates as CNS	925	1,155
Fluoride	13	Nil
B.O.D. (5 days)	870	600
C.O.D.	20,700	16,300
pH	9.7	9.03
Specific Gravity	1.01	1.002

. Slag Quench Water

Total Dissolved Solids, mg/l	168
Total Sulfur, mg/l	86
Chloride, mg/l	18
Sulfide as S, mg/l	Nil
Sulfate as SO_4, mg/l	68.4
Fatty acids as acetic	Nil
pH	6.79

m. Oil Analysis (Main Stream Sample)

Density at 20°C, g/ml	0.980
Toluene Insoluables, Wt.%	0.19
Phenols (Wet), Wt.%	14.3
Phenols (Wet), Vol.%	13.5

Viscosity (Redwood No. 1)

At 25°C, sec.	32.0
At 50°C, sec.	28.6
At 75°C, sec.	26.4

Distillation

Volume, ml	Temperature, °C
IBP	96
5	140
10	153
20	170
30	196
40	201
50	210
60	217
70	227
80	242
90	268
95	297

Temperature, °C	Vol.%	Wt.%
IBP - 200	37	34.5
200 - 297	58	58.0
297 +	5	7.5

PNA Analysis on IBP-200°C Fraction

Component	Wt.%	Component	Wt.%
P3 - P7	Nil	A6 + Pyridine	5.02
P8	0.52	A7	8.18
P9	0.69	Methyl Pyridine	0.87
P10	0.52	A8	16.57
P11	0.26	A9	6.52
P12	Nil	Indene	2.50
	1.99	A10	10.28
		Indane	19.90
N5 - N7	Nil	A11	3.01
N8	0.17	Methyl Indene	4.55
N9	0.25	Naphthalene	18.78
N10	0.17	Unknown	1.07
N11	0.17		97.25
	0.76		

n. Gasifier Char (Post Shutdown Sample)

Upper Shaft Char Size Analysis

Range	Wt.%
Over 2"	0.87
1.75" - 2"	0.87
1.5" - 1.75"	0.70
1.25" - 1.5"	1.57
1" - 1.25"	4.19
3/4" - 1"	10.31
1/2" - 3/4"	21.33
3/8" - 1/2"	23.09
1/4" - 3/8"	17.66
1/8" - 1/4"	8.22
Under 1/8"	11.19
	100.00

Char at Tuyere Level Size Analysis

Range	Wt.%
1.75" - 2"	16.26
1.5" - 1.75"	9.76
1.25" - 1.5"	9.76
1" - 1.25"	6.50
3/4" - 1"	11.37
1/2" - 3/4"	11.38
3/8" - 1/2"	13.01
1/4" - 3/8"	7.32
1/8" - 1/4"	4.88
Under 1/8"	9.76
	100.00

*All pieces larger than 2" were removed from sample prior to screen analysis

o. Elemental Analyses (Pittsburgh No. 8 Coal Operations)

Elements, PPM by Wt.	Pgh. No. 8 Coal	Coal Ash	BFS Flux	Slag	Slag Quench Water	Gas Liquor	Recycle Tar	Main Stream Oil
Aluminum	11,000	118,000	64,000	88,000	0.1	4.1	14	0.4
Barium	38	480	640	290	0.04	< 6	< 0.1	< 0.2
Calcium	1,900	15,000	230,000	190,000	20	28.9*	6.8	< 2
Chromium	29	310	10	75	< 0.07	< 0.08	0.8	0.4
Iron	11,000	140,000	4,800	40,000	0.9*	110	42	20
Lead*	ND	300	< 200	< 200	0.03	0.03	ND	ND
Magnesium	600	6,000	61,000	43,000	3.6*	1.0*	1	1
Manganese	130	800	6,200	3,900	< 0.07	0.1	0.3	0.02
Nickel*	ND	300	200	300	< 0.1	0.2	< 0.7	< 0.4
Potassium	1,200	12,000	3,700	6,400	1.2	7.7	1.1	0.07
Silicon	19,000	200,000	130,000	150,000	< 50	< 200	< 50	< 50
Sodium	220	2,400	3,100	2,800	23	8.8	1.1	0.2
Strontium	ND	660*	440*	530*	0.1*	0.03*	< 0.2	< 0.2
Sulfur	1,590	4,700	9,100	5,300	33.5	950	5,200	1,200
Titanium	310	7,000	3,300	5,400	< 0.1	< 5	4.1	< 0.2
Vanadium	27	300	45	140	0.001	< 0.04	0.3	0.002
Zinc	ND	250*	50*	60*	4*	0.14*	8.3	0.7
Antimony	0.6	6.0	0.03	0.2	< 0.001	0.09	1.1	0.06
Arsenic	7.7	84	4.6	7.2	0.005	2.9	23	6.8
Beryllium*	ND	10*	10*	14*	< 0.001*	0.0035*	ND	ND
Cadmium	ND	30*	< 30*	< 30*	0.006*	0.004*	< 0.1	< 0.05
Cobalt	3.5	42	2.4	19	< 0.003	0.09	0.2	< 0.01
Copper	ND	150*	< 100*	< 100*	0.02*	0.07*	4.1	< 0.1
Mercury	14	< 0.8	< 0.6	< 0.05	< 0.01	< 0.07	< 0.03	< 0.02
Molybdenum	1.7	16	2.6	7.3	< 0.02	< 0.1	0.1	< 0.05
Selenium	1.8	3.3	2.3	3.2	< 0.08	3.7	0.6	0.2
Uranium	0.9	8	10	9	< 0.002	< 0.01	0.02	< 0.007

Notes: 1. All elements except sulfur were determined by either Neutron Activation Analysis or Atomic Absorption Spectrophotometry (AAS). Elements determined by AAS are marked by an asterisk.

2. Sulfur was determined by a chemical method.

3. Heat and Material Balance - Pittsburgh No. 8 Coal Screened (1¼" x ¼")* & Blast Furnace Slag Flux

Material Balance, Pounds (Basis: 1000 pounds dry coal & flux)

Input	Rate	Carbon	Hydrogen	Nitrogen	Sulfur	Oxygen	Chlorine	Ash	Heat Balance Therms/Hr.
Coal/Flux	1039	630	48	13	15	105	1	227	2849
Steam	324		36			288			112
Fuel Gas	4	3	1						22
Oxygen/Air	525			72		453			3
	1892	633	85	85	15	846	1	227	2986
Output									
Heat Loss									72
Methane	95	71	24						593
Carbon Monoxide	1101	472				629			1273
Hydrogen	43		43						696
Carbon Dioxide	121	33				88			6
Inert Gas	103			103					6
Ethylene	2	2							12
Ethane	10	8	2						57
Ammonia	4		1	3					1
Hydrogen Sulfide	14		1		13				25
Carbonyl Sulfide	2				1	1			-
Tar	43	38	3		1	1			189
Naphtha	6	5	1						27
Liquor	146	1	16		1	128			52
Slag	228	1						227	44
	1918	631	91	106	16	847	0	227	3053
Input-Output Error, %	1.4	-0.3	7.1	24.7	6.6	0.1	-100.0	0	2.2

*Contains 6 percent fines (¼" x 0)

4. Data Used in Balance - Pittsburgh No. 8 Coal (6% fines)

Coal Heating Value, Btu/lb.	10812*

Coal Proximate Analysis	Wt. % *
Moisture	3.77
Ash	21.86
Volatile Matter	30.39
Fixed Carbon	43.98
	100.00

DAF Coal Ultimate Analysis	Wt. %
Carbon	81.50
Hydrogen	5.64
Nitrogen	1.66
Oxygen	9.14
Sulfur	1.97
Chlorine	0.09
	100.00

Gas Composition	Vol. %
Methane	8.039
Carbon Monoxide	53.126
Hydrogen	28.777
Carbon Dioxide	3.710
Inert Gas	4.960
Ethylene	0.100
Ethane	0.440
Hydrogen Sulfide	0.530
Ammonia	0.279
Carbonyl Sulfide	0.039
	100.000

Crude Gas Offtake Temperature	498^{o}C
Gasifier Pressure	350 psig
Heat Loss	13.1 therm/hour

*Includes flux

Byproducts

Composition Wt. %	Naphtha	Product Tar	Minor Liquor Components
Carbon	90.60	88.00	15.71
Hydrogen	8.90	7.20	-
Nitrogen	0.10	0.90	-
Sulfur	0.22	1.25	30.35
Oxygen	0.12	2.64	41.88
Chlorine	0.06	0.01	12.06
	100.00	100.00	100.00

Heating Value	Btu/lb.
Naphtha	18,170
Product Tar	16,279
Minor Liquor Components	0

5. Performance Data - Pittsburgh No. 8 Coal (6% fines)

Steam Consumption	3.27 lb/therm gas	
Steam Decomposition	80.97 %	
Oxygen Consumption	53.89 SCF/therm 15,526 SCF/ton DAF coal	
Crude Gas Production*	288 therms/ton DAF coal	
Gas Liquor Yield	1.43 lb/therm	
Thermal Efficiencies, %	Gas Only	Gas, Tar, Oil & Naphtha
Crude Gas / Coal	88.47	95.81
Crude Gas / Coal, Steam, & Oxygen	76.96	83.35

*Includes coal lock gas

6. Heat and Material Balance - Pittsburgh No. 8 Coal (1:1 Screened/Unscreened)* & Blast Furnace Slag Flux

Material Balance, Pounds (Basis: 1000 pounds dry coal & flux)

Input	Rate	Carbon	Hydrogen	Nitrogen	Sulfur	Oxygen	Chlorine	Ash	Heat Balance Therms/Hr.
Coal/Flux	1041	643	49	11	15	104	1	218	2664
Steam	339		38			301			108
Fuel Gas	4	3	1						22
Oxygen/Air	551			78		473			3
Recycle Tar	17	13	1			2		1	58
	1952	659	89	89	15	880	1	219	2855
Output									
Heat Loss									92
Methane	83	62	21						479
Carbon Monoxide	1098	471				627			1179
Hydrogen	46		46						699
Carbon Dioxide	175	48				127			9
Inert Gas	93			93					5
Ethylene	3	2	1						14
Ethane	8	7	1						45
Ammonia	4		1	3					1
Hydrogen Sulfide	15		1		14				26
Carbonyl Sulfide	2				1	1			-
Tar	50	43	4	1	1	1			200
Naphtha	5	5							23
Liquor	149	1	16		1	131			51
Slag	220	1						219	40
	1951	640	91	97	17	887	0	219	2863
Input-Output Error, %	-0.0	-2.9	2.2	9.0	13.3	0.8	-100.0	0	0.3

*Contains 15 percent fines (¼" x 0)

7. Data Used in Balance - Pittsburgh No. 8 Coal (15% fines)

Coal Heating Value, Btu/lb.	10890.37
Coal Proximate Analysis	**Wt. %**
Moisture	3.93
Ash	20.96
Volatile Matter	30.78
Fixed Carbon	44.33
	100.00
DAF Coal Ultimate Analysis	**Wt. %**
Carbon	82.22
Hydrogen	5.72
Nitrogen	1.43
Oxygen	8.59
Sulfur	1.95
Chlorine	0.09
	100.00
Gas Composition	**Vol. %**
Methane	6.840
Carbon Monoxide	51.711
Hydrogen	30.393
Carbon Dioxide	5.230
Inert Gas	4.429
Ethylene	0.129
Ethane	0.368
Hydrogen Sulfide	0.570
Ammonia	0.287
Carbonyl Sulfide	0.043
	100.000
Gas Offtake Temperature	516°C
Gasifier Pressure	350 psig
Heat Loss	14.21 therms/hour

Byproducts

Composition Wt. %	Naphtha	Product Tar	Minor Liquor Components	Tar Injected
Carbon	90.60	87.10	15.46	80.01
Hydrogen	8.90	7.90	-	6.58
Nitrogen	0.10	1.10	-	1.35
Sulfur	0.22	1.48	31.73	0.98
Oxygen	0.12	2.40	41.24	8.33
Chlorine	0.06	0.02	11.57	0.03
Ash	-	-	-	2.72
	100.00	100.00	100.00	100.00

Heating Value	Btu/lb.
Naphtha	18,170
Product Tar	16,309
Minor Liquor Components	0
Tar Injected	14,634

8. Performance Data - Pittsburgh No. 8 Coal (15% fines)

Steam Consumption	3.45 lb/therm gas	
Steam Decomposition	81.20 %	
Oxygen Consumption	56.95 SCF/therm 16,041 SCF/ton DAF coal	
Crude Gas Production*	278 therms/ton DAF coal	
Gas Liquor Yield	1.49 lb/therm	
Thermal Efficiencies, %	**Gas Only**	**Gas, Tar, Oil & Naphtha**
Crude Gas / Coal	86.73	92.65
Crude Gas / Coal, Steam, & Oxygen	75.08	80.20

*Includes coal lock gas

9. Heat and Material Balance - Pittsburgh No. 8 Coal Unscreened* & Blast Furnace Slag Flux

Material Balance, Pounds (Basis: 1000 pounds dry coal & flux)

Input	Rate	Carbon	Hydrogen	Nitrogen	Sulfur	Oxygen	Chlorine	Ash	Heat Balance Therms/Hr.
Coal/Flux	1032	646	50	10	16	93	1	216	2779
Steam	342		38			304			113
Fuel Gas	4	3	1						22
Oxygen/Air	549			75		474			3
Recycle Tar	26	22	2			2			99
	1953	671	91	85	16	873	1	216	3016
Output									
Heat Loss									81
Methane	89	67	22						534
Carbon Monoxide	1145	491				654			1276
Hydrogen	43		43						679
Carbon Dioxide	132	36				96			7
Inert Gas	89			89					5
Ethylene	2	2							13
Ethane	11	9	2						59
Ammonia	5		1	4					1
Hydrogen Sulfide	10		1		9				18
Carbonyl Sulfide	2				1	1			-
Tar	49	42	4	1		2			204
Naphtha	5	5							25
Liquor	147	1	16		1	128	1		51
Slag	217	1						216	41
	1946	654	89	94	11	881	1	216	2994
Input-Output Error, %	-0.4	-2.5	-2.2	10.6	-31.3	0.9	0	0	-0.7

*Contains 23 percent fines (¼" x 0)

10. Data Used in Balance - Pittsburgh No. 8 Coal (23% fines)

Coal Heating Value, Btu/lb.	11048

Coal Proximate Analysis	Wt. %
Moisture	3.08
Ash	20.94
Volatile Matter	30.60
Fixed Carbon	45.38
	100.00

DAF Coal Ultimate Analysis	Wt. %
Carbon	82.46
Hydrogen	5.81
Nitrogen	1.32
Oxygen	8.26
Sulfur	2.06
Chlorine	0.09
	100.00

Gas Composition	Vol. %
Methane	7.392
Carbon Monoxide	54.333
Hydrogen	28.623
Carbon Dioxide	3.983
Inert Gas	4.250
Ethylene	0.112
Ethane	0.472
Hydrogen Sulfide	0.390
Ammonia	0.407
Carbonyl Sulfide	0.380
	100.000

Crude Gas Offtake Temperature	520°C
Gasifier Pressure	350 psig
Heat Loss	14.56 therms/hour

Byproducts

Composition Wt. %	Naphtha	Product Tar	Minor Liquor Components	Tar Injected
Carbon	90.60	86.90	16.25	82.32
Hydrogen	8.90	7.60	-	6.73
Nitrogen	0.10	1.50	-	1.12
Sulfur	0.22	0.86	28.12	0.96
Chlorine	0.06	0.04	12.28	0.02
Oxygen	0.12	3.10	43.35	7.02
Ash	-	-	-	1.83
	100.00	100.00	100.00	100.00

Heating Value	Btu/lb.
Naphtha	18,170
Product Tar	16,125
Minor Liquor Components	0
Tar Injected	15,036

11. Performance Data - Pittsburgh No. 8 (23% fines)

Steam Consumption	3.41 lb/therm gas	
Steam Decomposition	80.19 %	
Oxygen Consumption	55.84 SCF/therm 16,021 SCF/ton DAF coal	
Crude Gas Production*	283 therms/ton DAF coal	
Gas Liquor Yield	1.41 lb/therm	
Thermal Efficiencies, %	Gas Only	Gas, Tar Oil & Naphtha
$\frac{\text{Crude Gas}}{\text{Coal}}$	88.09	92.46
$\frac{\text{Crude Gas}}{\text{Coal, Steam, \& Oxygen}}$	76.30	80.08

*Including lock gas

APPENDIX B
COAL AND COKE FEEDSTOCKS

Four gasifier feedstocks were evaluated in the Westfield Technical Support Program. These were: Ohio No. 9 coal, Pittsburgh No. 8 coal, Scottish Frances coal and blast furnace metallurgical coke. The Frances coal and the coke were purchased in the United Kingdom. The Ohio No. 9 and Pittsburgh No. 8 coals were purchased in the United States and shipped to Westfield Development Centre.

Ohio No. 9 Coal

Three shipments of Ohio No. 9 coal were sent to Westfield. The quantities shipped were 10,166; 10,089; and 5,108 short tons, respectively. The coal was surface mined at the Mt. Ephraim pit of the Orange Coal Company from a coal reserve owned by Union Carbide Corporation. The coal was double-screened to give a nominal size consist of 2" x 1/4". While a sized coal was prepared for shipment, the handling and shipping thereafter produced a considerable amount of 1/4" x 0 coal fines. The coal was rescreened at Westfield.

The coal was transported by truck to Marietta, Ohio; by rail to Baltimore, Maryland; by ocean vessel to Leith, Scotland; and by truck to Westfield Development Centre.

Properties of the first and second coal shipments as determined by the Research Division of Conoco Coal Development Company are given in Table B-1. Properties of screened fractions from the third shipment are given in Table B-2.

Pittsburgh No. 8 Coal

A single shipment of Pittsburgh No. 8 coal was sent to Westfield. The quantity shipped was 4,522 short tons. The coal was obtained from the Champion Plant of Consolidation Coal Company. This plant is supplied from several deep mines in southwestern Pennsylvania. The coal was washed and double-screened to give a nominal size consist of 1½" x 3/16." Handling and shipment of this coal also generated additional 1/4" x 0 coal fines. The coal was rescreened at Westfield.

The coal was transported by rail to Baltimore, Maryland; by ocean vessel to Leith, Scotland; and by truck to Westfield Development Centre. Properties of screened fractions as determined by the Research Division of Conoco Coal Development Company from a sample taken at Baltimore are given in Table B-3.

Frances Coal

The Frances coal was purchased from the National Coal Board from a deep-mine in Scotland near the Westfield Development Centre. Typical properties of this coal are given in Table B-4.

Metallurgical Coke

The blast furnace metallurgical coke was purchased from a coke oven plant in Scotland. The coke was prepared from Randolph Colliery coal. Typical properties of the coke are given in Table B-5.

TABLE B-1

Properties of Ohio No. 9 Coal Shipped to Westfield

Proximate Analysis, Wt. %*	First Shipment	Second Shipment
Moisture	3.14	3.65
Ash	24.50	20.96
Volatile Matter	36.45	37.70
Fixed Carbon	35.91	37.69
Ultimate Analysis, Wt. %*		
Hydrogen	4.42	4.52
Carbon	56.23	59.00
Nitrogen	0.90	0.84
Oxygen (Diff)	6.16	6.63
Sulfur	4.65	4.40
Water	3.14	3.65
Ash	24.50	20.96
Heating Value (Dry), Btu/lb	10,650	11,290
Ash Analysis, Wt. %		
Na_2O	0.28	0.25
K_2O	2.36	2.20
CaO	1.93	1.82
MgO	1.17	1.35
Fe_2O_3	16.91	18.40
TiO_2	1.07	1.02
P_2O_5	0.30	0.25
SiO_2	49.70	50.03
Al_2O_3	22.15	21.85
SO_3	1.36	2.42
Cl	0.01	0.01
Ash Fusion, °F		
Initial	2,040	2,030
Soft	2,230	2,240
Hemispheric	2,320	2,320
Fluid	2,440	2,420
Free Swelling Index	3 1/2	5
Gieseler		
Dial Div./Min.	740	200
Soft, °C	339	336
Solid, °C	451	454
Max, Fluidity, °C	417	422

*As received.

TABLE B-2

Properties of Ohio No. 9 Coal Third Shipment to Westfield

	Screened Fraction			
	2" x 1"	1"x ½"	½" x ¼"	¼" x 0
Proximate Analysis, Wt.%*				
Moisture	2.35	2.42	2.11	1.95
Ash	14.90	14.35	15.57	25.66
Volatile Matter	41.09	41.12	40.68	34.99
Fixed Carbon	41.66	42.11	41.64	37.40
	100.00	100.00	100.00	100.00
Ultimate Analysis (Dry), Wt.%				
Hydrogen	4.45	4.80	4.81	4.19
Carbon	65.93	66.63	65.62	57.19
Nitrogen	1.19	0.90	0.97	0.70
Sulfur	5.59	5.43	5.23	5.05
Chlorine	0.01	0.01	0.01	0.01
Ash	14.90	14.35	15.57	25.66
Oxygen (by diff.)	7.93	7.88	7.79	7.90
	100.00	100.00	100.00	100.00
Free Swelling Index	5	5 1/2	5	4 1/2
Ash Analysis, Wt.%				
Na_2O	0.26	0.27	0.28	0.31
K_2O	1.84	1.95	2.12	2.50
CaO	1.24	1.46	1.58	2.65
MgO	0.83	0.89	1.04	1.48
Fe_2O_3	30.20	29.31	26.26	18.88
TiO_2	1.14	1.24	0.82	0.53
P_2O_5	0.25	0.21	0.34	0.16
SiO_2	38.18	39.72	41.77	47.52
Al_2O_3	19.57	18.37	18.98	17.51
SO_3	2.21	1.18	1.03	1.97

*As received.

TABLE B-3

Properties of Pittsburgh No. 8 Coal Shipped to Westfield

Screen Fraction	2" x 1"	1" X 1/2	1/2" x 1/4	1/4" x 0
Proximate Analysis, Wt. % *				
Moisture	1.99	1.96	1.80	1.70
Volatile Matter	40.19	40.43	39.37	39.06
Ash	6.67	6.81	8.11	7.27
Fixed Carbon	51.15	50.80	50.72	51.97
Ultimate Analysis, Wt. % *				
Hydrogen	5.29	5.27	5.12	5.20
Carbon	76.46	76.73	74.54	75.94
Nitrogen	1.30	1.31	1.32	1.35
Sulfur	1.83	1.69	1.75	1.85
Ash Analysis, Wt. %				
Na_2O	0.52	0.42	0.42	0.45
K_2O	1.45	1.76	1.80	1.60
CaO	2.79	1.46	2.12	2.90
MgO	0.75	0.60	0.69	0.69
Fe_2O_3	20.50	20.43	16.32	18.50
TiO_2	0.97	1.05	1.15	1.05
P_2O_5	0.19	0.38	0.25	0.37
SiO_2	44.36	49.54	48.38	45.32
Al_2O_3	25.25	24.03	24.52	23.05
SO_3	2.84	1.01	1.81	2.19
	99.62	100.68	97.46	96.12
Free Swelling Index	8	8	7 1/2	7 1/2
Yield, Wt. %	21.7	39.4	27.7	11.2

*As received.

TABLE B-4
Properties of Frances Coal

Proximate Analysis (As Received), Wt. % *	
Moisture	7.2
Ash	5.7
Volatile Matter	33.1
Fixed Carbon	54.0
Ultimate Analysis (MAF Basis), Wt. % *	
Hydrogen	5.6
Carbon	80.0
Nitrogen	1.5
Oxygen (diff)	12.0
Sulfur	0.6
Chlorine	0.3
Free Swelling Index	<1½
Ash Elemental Analysis, Wt. % **	
Na_2O	0.4
K_2O	0.3
CaO	14.2
MgO	7.0
Fe_2O_3	13.2
TiO_2	0.7
P_2O_5	0.9
SiO_2	29.7
Al_2O_3	23.8
SO_3	8.5

* Average of analyses during TSP Run 1.

** Typical.

TABLE B-5
Properties of Randolph Colliery Coke

Proximate Analysis (As Received), Wt. % *	
Moisture	3.0
Ash	9.3
Volatile Matter	2.2
Fixed Carbon	85.5
Ultimate Analysis (MAF Basis), Wt. % *	
Hydrogen	1.1
Carbon	95.5
Nitrogen	1.2
Oxygen (diff)	0.9
Sulfur	1.2
Chlorine	0.1
Free Sweeling Index	0
Ash Elemental Analysis, Wt. % **	
Na_2O	1.1
K_2O	2.2
CaO	4.3
MgO	2.5
Fe_2O_3	14.9
TiO_2	0.8
P_2O_5	ND
SiO_2	47.2
Al_2O_3	25.9
SO_3	ND

* Average of analyses during TSP Run 7 and TSP Run 11.

** From TSP Run 11.

APPENDIX C
SAMPLING AND ANALYTICAL PROCEDURES

An outline of the analytical procedures used throughout the Westfield TSP is provided in this section. References to standard procedures or previously documented procedures are included where appropriate. Abbreviations used for the references are given below:

BSI	British Standards Institution
AGA	American Gas Association
ASTM	American Society for Testing and Materials
STPTC	Standardization of Tar Products Tests Committee

The AGA methods were published in 1974 by Woodall-Duckham Ltd. in their report of the "Trials of American Coals in a Lurgi Gasifier at Westfield, Scotland."(1)

Sampling Procedures

The side stream sampling apparatus was connected to the gasifier manway as shown in Figure 1.

The sample collection apparatus was located approximately 25 ft. below the manway on the ground level and was assembled as shown in Figure 2.

By sampling at the manway, plugging has been eliminated. The gas composition, with respect to carbon monoxide, carbon dioxide, hydrogen and methane, measured at the manway compared closely with the gas sampled at the flare, and the mass of heavy hydrocarbons, the tars and oils, and water were also roughly consistent during each pilot plant run, indicating that a representative sample of the gasifier products is obtained.

Gas and volatile organic components were collected at the gas sampling valves, and the tar, oils, and water were collected in the sample collection drum. The sample drum was drained to obtain the water and part of the organic material. The remaining organic material adhering to the walls of the tubing and the drum was removed with high pressure steam. When the sampling apparatus was not being used, high pressure steam was back-purged into the gasifier to prevent plug formation.

No other sampling procedures will be discussed. Sampling during the slagging program has been analogous to that used during the trials of American coals in a Lurgi gasifier for the AGA and has been reported by Woodall-Duckham, Ltd.(1)

Analytical Procedures

The analytical procedures are given in the same order as the data are given in each British Gas Corporation run report.

Coal

Size Analysis and Moisture

The coal sample is dried to constant weight in an oven maintained at 107°C, and the weight loss reported as moisture (BSI 1016, Part 1). The dried sample is sieved through British Standard Test Sieves, and the weight of each increment recorded as a percentage of the total sample (BSI 1293 and 2074).

Bulk Density

A tared steel box having a volume of one cubic foot is filled through a funnel from a height of six feet and reweighed (ASTM D291-60).

Proximate and Ultimate Analysis

The proximate and ultimate determinations, including calorific value (Btu), are made using air-dried samples crushed to -72 mesh (BSI 1016, Parts 3, 5, 6, and 16).

Ash

One gram of sample is heated to 825°C for at least one hour and the residue weight recorded as ash.

Free Water

The coal sample is allowed to dry at a temperature of 10°-20°C above ambient and the weight loss reported as free moisture.

Inherent Water

One gram of sample is heated to 107°C for at least one hour in a nitrogen atmosphere to prevent oxidation, and the weight loss is reported as inherent moisture.

Total Water

The total moisture is calculated from the free water and the inherent water results using Equation (1):

$$\% \text{ Total } H_2O = F + (100-F)\ (I)/100 \qquad (1)$$

where F is the % free moisture and I is the inherent moisture.

Volatile Matter, VM

A one gram sample is heated to 900°C for seven minutes in a covered crucible. The weight loss, corrected for moisture, is reported as volatile matter.

Fixed Carbon, FC

The fixed carbon is calculated by difference from Equation (2):

$$\% \text{ FC} = 100 - \% \text{ Ash} - \% \text{ VM} - \% \text{ H}_2\text{O} \qquad (2)$$

Heating Value, Btu

The sample is burned in oxygen using an adiabatic bomb calorimeter. Corrections are made for the firing wire and the heats of formation of sulfuric acid, sulfur dioxide, and nitric acid.

Carbon, Hydrogen and Nitrogen

A maximum of three milligrams of sample is combusted at 950°C in oxygen using a Perkin-Elmer Model 240 Elemental Analyzer equipped with an automatic sampler. Sulfur and halogens do not interfere, and each sample has been analyzed at least in triplicate.

Sulfur and Chlorine

The sample is burned at 1350° C in excess oxygen and the gases scrubbed with hydrogen peroxide. Sulfuric acid and hydrochloric acid are produced and titrated with soduim borate. Two end points are measured, one for the titration of the acids and a second for the titration of HSO_4^- ion. The sulfur content is calculated from the second end point. The chlorine content is calculated from the first end point after subtraction of the sulfuric acid.

Flux

Size Analysis and Moisture

Bulk Density

Both of these determinations are made as discussed in Sections 1.1 and 1.2 for coal.

Slag

The sample is dried at 105°C and crushed to 200 British Standard Sieve Mesh. Metallic iron lumps have been removed magnetically before crushing and analyzed separately.

Loss on Ignition, LOI

The sample is ignited at 815°C for one hour and the gain or loss in weight is recorded.

Mineral Analysis, SiO_2, Al_2O_3, CaO, MgO, Fe_2O_3

The ignited sample is fused with lithium metaborate, the melt dissolved in a hydrochloric acid and in tartaric acid mixture, and the resulting solution analyzed using atomic absorption spectrophotometry.

Silica Number

The silica number is calculated from the results of the mineral analysis using Equation (3):

$$\text{Silica No.} = \%\ SiO_2/(SiO_2 + Fe_2O_3 + CaO + MgO) \quad (3)$$

(Analyst 95, 124 (1970)).

Carbon

The dried sample is ignited at 1200°C in a flow of oxygen and the combustion products passed through silver gauze to remove sulfur and halogens, magnesium perchlorate to remove water, and finally through Ascarite to absorb the carbon dioxide. The weight of carbon dioxide absorbed is calculated as carbon.

Free Iron, Fe

The sample is warmed in an ammonical solution of cupric sulfate to oxidize the metallic iron and produce metallic copper according to the following equation:

$$FE + CuSO_4 \longrightarrow FeSO_4 + Cu$$

The copper is filtered from the solution, and the filtrate is titrated with potassium dichromate solution and reported as free iron.

Ferrous Iron, Fe^{+2}

The sample is dissolved in hydrochloric acid under a carbon dioxide atmosphere, and the solution is titrated with potassium dichromate solution. The free iron is titrated as well as the ferrous iron, and the appropriate correction is made for free iron.

Ferric Iron, Fe^{+3}

The concentration of ferric iron is calculated by difference according to Equation (4).

$$\%\ Fe^{+3} = \%\ \text{Total FE} - \%\ Fe - \%\ Fe^{+2} \quad (4)$$

where total Fe is determined by the mineral analysis procedure given above.

Sulfide, S

The finely ground sample is leached with boiling hydrochloric acid for 30 minutes to remove non-pyritic iron, filtered, and the pyritic iron residue is dissolved in boiling nitric acid. The iron from the pyrite is titrated with potassium dichromate and calculated as sulfide (BSI 1016 Part 11).

Total Sulfur

The sample is fused with sodium carbonate, leached with hydrochloric acid, filtered, and the filtrate solution treated with barium chloride to determine the sulfur gravimetrically.

Oxygen Purity

A Perkin-Elmer Model 452 Gas Chromotograph equipped with a molecular sieve column maintained at 35°C and a thermal conductivity detector was used to analyze the oxygen stream (BSI 3156).

Recycle Tar and Dust

Moisture Content

The moisture was determined by the classical Dean and Stark method (STPTC CT3-67).

Dust Content

The sample is dissolved in toluene, filtered, and the residue weighed as toluene insolubles or dust (STPTC CT4-67 and RT8-67).

Ultimate Analysis of Dust-Free Tar and Tar-Free Dust

Heating Value of Dust-Free Tar and Tar-Free Dust

The carbon, hydrogen, nitrogen, sulfur, chlorine, ash, moisture, oxygen, and heating value (Btu) are determined using the procedures previously outlined for coal.

Flare Gas Analysis

The major constituents determined are carbon dioxide, carbon monoxide, hydrogen, nitrogen, oxygen, argon, methane, ethylene, and ethane. Three Perkin-Elmer Model 452 Gas Chromatographs are involved (BSI 3156, Part 4).

Major Constituents

Chromatograph 1

A molecular sieve column maintained at 35°C, a thermal conductivity detector, and argon carrier gas are used to separate and elute hydrogen, oxygen, nitrogen, carbon monoxide, and methane in that order.

Chromatograph 2

Except for helium carrier gas in place of argon the same conditions are used as with Chromatograph 1, and hydrogen, oxygen plus argon, nitrogen, methane, and carbon monoxide are eluted in that order. Argon is determined by subtracting the concentration of oxygen determined on chromatograph 1 from the O_2 + A peak.

Chromatograph 3

Chromatograph 3 is equipped with a Chromosorb 102W column maintained at [illegible]50°C, and oxygen plus nitrogen plus carbon monoxide, methane, carbon dioxide, ethylene, and ethane are eluted in that order with hydrogen carrier gas. The hydrocarbons and carbon dioxide are determined under these conditions.

Hydrogen Sulfide

A measured volume of gas is passed through ammoniacal zinc sulfate solution and the sulfide precipitated as zinc sulfide. The precipitate is filtered, placed in excess acidified standard iodine solution, and back titrated with standard sodium thiosulfate solution to the starch end point (BSI 3156, Part 2).

A Tutweiler Burette is often used at the plant and involves capturing the gas and titrating the hydrogen sulfide directly with iodine solution with the reagents contained in the special Tutweiler apparatus (AGA G3).

Minor Constituents

Ammonia

A measured volume of gas is passed through boric acid solution and the solution titrated with sulfuric acid solution to the bromophenol end point (BSI 3156, Part 2).

Hydrogen Cyanide

The ammoniacal filtrate from the hydrogen sulfide determination is acidified and the hydrogen cyanide distilled through a [illegible] condenser into sodium hydroxide solution. The solution is subsequently titrated with silver nitrate solution to the potassium iodide end point (BSI 3156, Part 2).

Naphthalene

A measured volume of gas is passed through silica gel to absorb the naphthalene, which is subsequently eluted and determined by gas chromatography. The gas chromatographic analysis is made using a coated column of 20% silicone oil on Celite maintained at 185°C and nitrogen carrier gas (AGA G5).

Condensate

The dry gas is passed through a collecting trap maintained at about -78°C, and the collected residue weighed at 25°C as condensate (BSI 3156, Part 2).

Total Organic Sulfur

While a space is indicated in the British Gas Run Reports for total organic sulfur, the determination was not made, and no method outline will be given. The method considered is from BSI 3156, Part 2 and AGA G6.

Carbonyl Sulfide, Carbon Disulfide, and Thiophenes

A British Gas Odorant Chromatograph equipped with two coated columns containing 15% silicone OV17 on Chromosorb W at ambient temperature is used. One column, 1.6 meters in length, is used to measure carbonyl sulfide. A second column, 0.7 meter in length, is used for carbon disulfide and thiophenes.

Analysis of Naphtha (Condensibles)

Carbon, hydrogen, nitrogen, sulfur, chlorine, ash, oxygen, and heating value are determined using the analytical methods for feed coal described above. The moisture is determined by the Dean and Stark method discussed above for recycle tar and dust.

Flash Gas Analysis

Carbon Dioxide and Hydrogen Sulfide

A measured volume of gas is collected in a sample balloon, and the carbon dioxide and hydrogen sulfide are determined by Orsat methods (AGA G10).

Carbon Monoxide, Oxygen, Argon, Nitrogen Methane, Ethylene, and Ethane

The remaining gas after the Orsat analysis is analyzed with the three gas chromatographs as discussed above.

Ammonia

The ammonia is distilled from basic solution into excess sulfuric acid solution, and the excess sulfuric acid is titrated with standard sodium hydroxide solution (AGA L5).

Hydrogen Sulfide (Condensate)

The sulfide is precipitated with cadmium acetate solution as cadmium sulfide, and the precipitate filtered, placed in excess acidified standard iodine solution, and back-titrated with standard sodium thiosulfate solution. The method is analogous to that used to determine hydrogen sulfide in flare gas.

Carbon Dioxide (Condensate)

The carbonates are precipitated as calcium carbonate, filtered, and titrated with standard acid solution (AGA L7).

Naphthalene

The gas chromatographic procedure outline above is used.

Hydrogen Cyanide

The hydrogen cyanide is collected in basic solution, and depending upon the concentration, the cyanide is either titrated with silver nitrate solution or determined colorimetrically by bromination and reaction with pyridine and p-phenylenediamine.

Mainstream Liquors

Side-Stream Results

Except for the aqueous liquor, the side-stream samples were analyzed using analytical procedures outlined previously. Consequently, only the previous section will be mentioned.

Incremental Gas, Major Constituents

The gas chromatographic procedure given above is used.

Incremental Gas, Minor Constituents

The procedures given above for the analysis of flare gas is used.

Total Organic Sulfur

No determination has been made as mentioned above.

Carbonyl Sulfide, Carbon Disulfide, and Thiophenes

The Odorant Chromatographic procedure given above is used.

Analysis of Naphtha (Condensibles)

The procedures given above for the analysis of flare gas are used.

Hydrocarbon (Tar) Products and Heating Value

The procedures used to analyze recycle tar and dust for moisture, tar and dust content, ultimate analysis, and heating value are also used to analyze side-stream tar.

Liquor Analysis

The sample of tar and liquor is filtered through a tared, glass fiber filter, and the filtrate is extracted with benzene. The benzene is evaporated and the residue weighed as tar. The combined weight of the benzene extract and the tar on the filter are reported as total tar (AGA L1).

Total Dissolved Solids

The tar-free liquor is evaporated to dryness on a steam bath, placed in a drying oven at 105°C for one hour, cooled, and the residue weighed as dissolved solids (AGA L11).

Total Sulfur

The tar-free liquor is oxidized with alkaline bromine solution, and after acidification, the sulfate is precipitated as barium sulfate and determined gravimetrically (AGA L3).

Total Sulfide

The iodine titration of cadium sulfide outlined previously is used.

Total Ammonia

The distillation procedure given above is used.

Free and Fixed Ammonia

The free ammonia is distilled from the sample into excess standard sulfuric acid solution, and the excess acid titrated with standard sodium hydroxide solution. After the free ammonia has been removed, sodium hydroxide solution is added to the undistilled sample, and the remaining, fixed ammonia is distilled into excess standard sulfuric acid. The excess acid is titrated with sodium hydroxide solution (AGA L5).

Carbonate

The calcium precipitation and acid titration procedure given previously is used.

Chloride

The tar-free liquor is titrated with silver nitrate solution to precipitate silver chloride. Potassium chromate is used for end point detection (AGA L12).

pH

The pH of the tar-free sample is read potentiometrically using a glass electrode and reference electrode (AGA L6).

Specific Gravity

A hydrometer is inserted into the tar-free liquor at 15.5°C, and the specific gravity read directly.

Calcium and Magnesium

The tar-free sample is analyzed by atomic absorption spectrophotometry.

Location of Side Stream Sampler on Westfield Gasifier

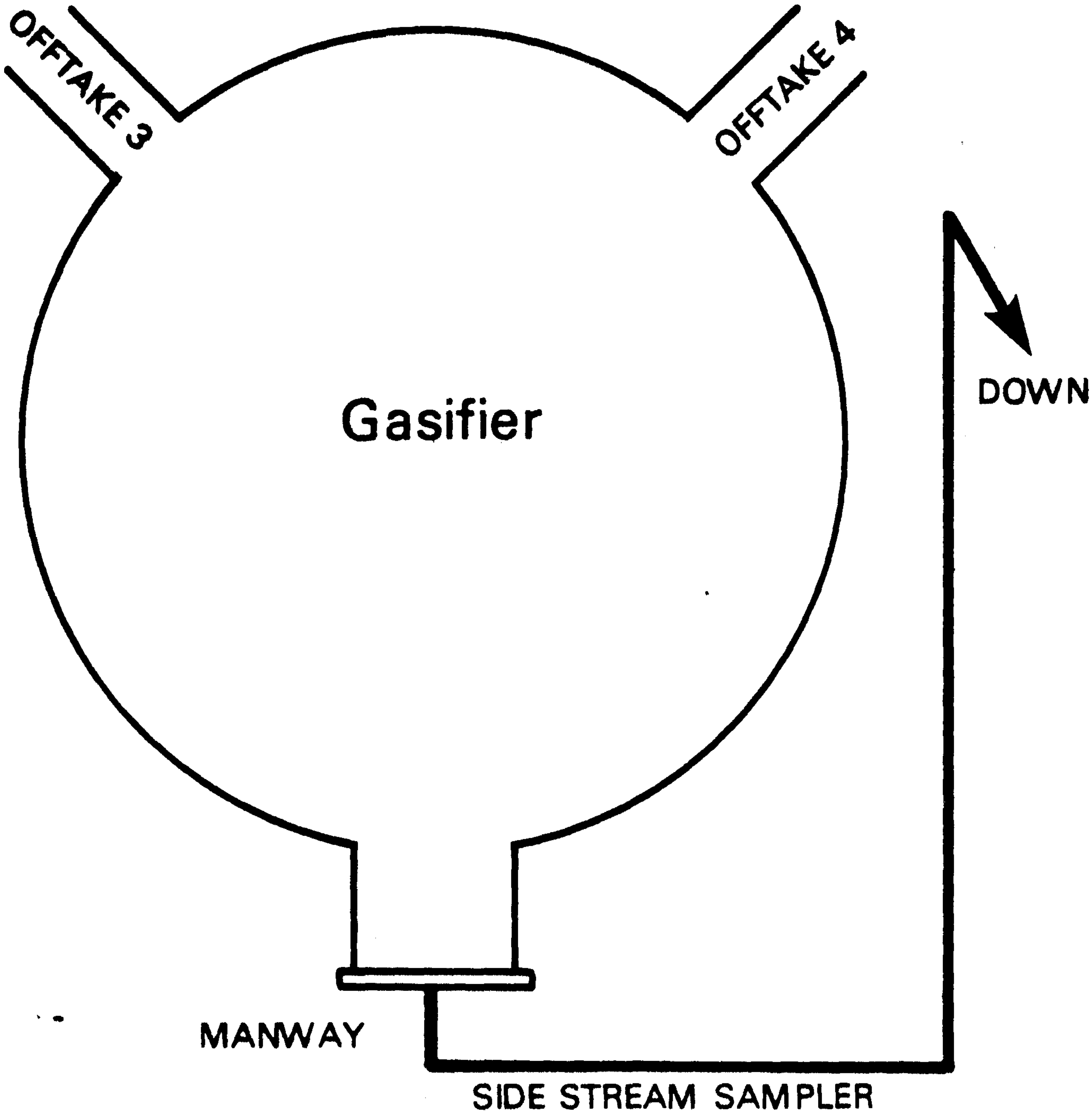


Figure 1 of Appendix C

Side Stream Sampling Apparatus

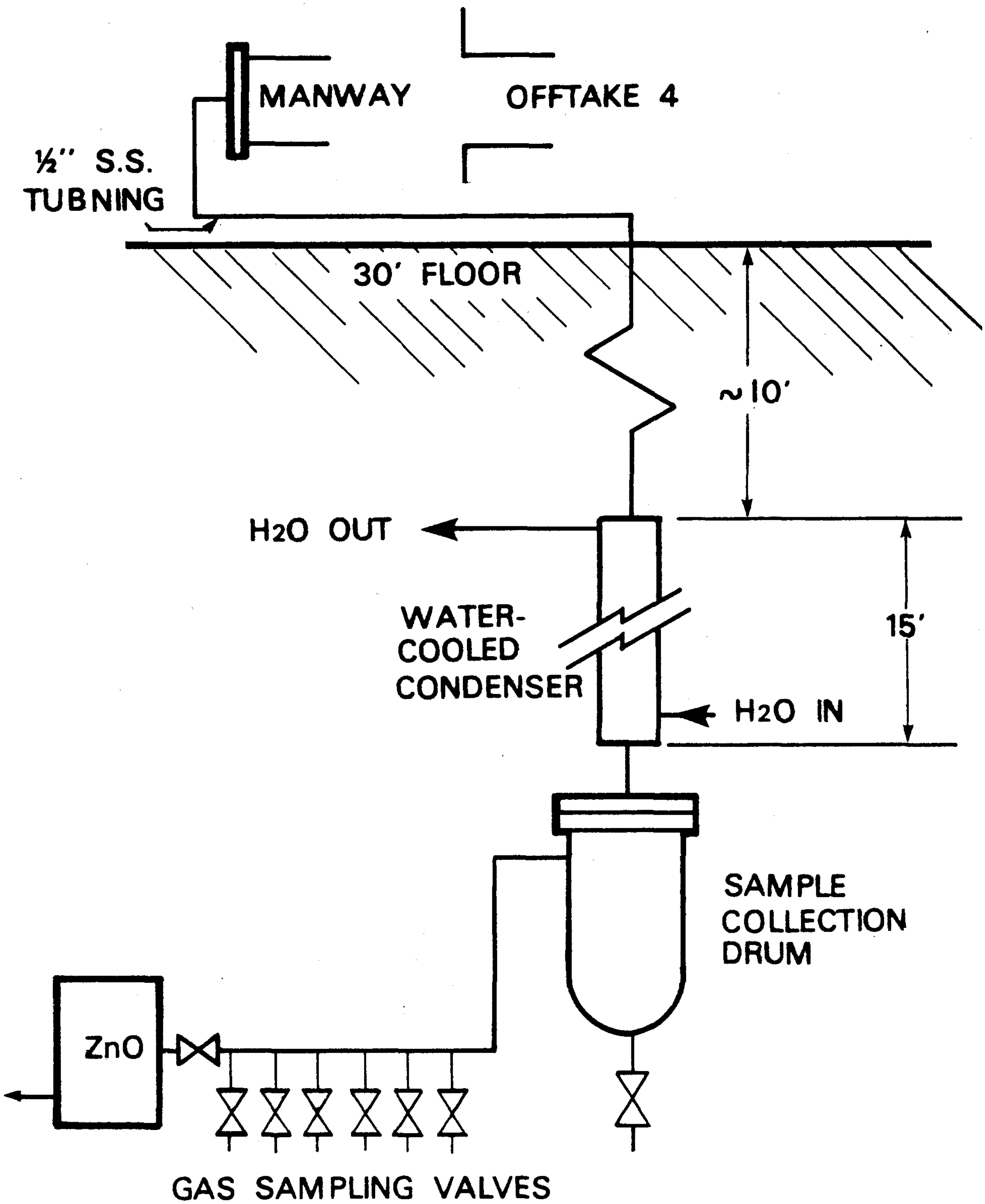


Figure 2 of Appendix C

APPENDIX D

MINUTES OF WESTFIELD PROGRAM COMMITTEE MEETINGS

The Westfield Agreement provides for a Program Committee which is responsible for all technical matters that may arise in implementing the technical support program. This committee routinely evaluated the results of pilot plant runs and planned the subsequent runs. The committee met usually on a monthly basis. A total of 13 meetings were held.

Members of the committee are listed below:

	Standing Members	Designate Members
Continental Oil Company	J. D. Sudbury W. B. Watson	G. P. Curran C. E. Fink
British Gas Corporation	J. McHugh D. Hebden	P. Faulkner J. A. Gray
Lurgi Kohle und Mineral-oeltechnik GmbH	P. F. H. Rudolph H. Vierrath	U. D. Marwig M. Bierbach
U.S. Department of Energy	C. L. Miller	R. A. Verner

The committee chairman is J. D. Sudbury, and the committee secretary is M. R. Tooley of British Gas.

Minutes of the Program Committee meetings are given in this appendix.

MINUTES OF TECHNICAL SUPPORT PROGRAM COMMITTEE MEETING NO. 1

Place: British Gas Corporation
326 High Holborn
London, U.K.

Date: June 13, 1977

Present: Dr. J. D. Sudbury, Continental Oil Company
Mr. R. A. Verner, U.S. Department of Energy
Dr. C. L. Miller, U.S. Department of Energy
Mr. J. McHugh, British Gas Corporation
Dr. J. A. Gray, British Gas Corporation
Mr. J. D. F. Marsh, British Gas Corporation
Mr. M. R. Tooley, British Gas Corporation

I. PROGRAMME COMMITTEE ORGANIZATION AND FUNCTION

(a) Designation of Membership

Dr. J. D. Sudbury was designated permanent Chairman of the Committee. Membership of the Committee was made up as follows:

Organization	Standing Committee Members	Designates
U.S. Department of Energy	C. L. Miller	R. A. Verner
Continental Oil Company	J. D. Sudbury	C. E. Fink
	W. B. Watson	G. P. Curran
British Gas Corporation	J. McHugh	P. Faulkner
	D. Hebden	J. A. Gray
Lurgi	P. Rudolph	not yet named
	H. Vierrath	

Attendance at the Programme Committee meetings is to be by members or their designates only, unless other persons are specifically invited to make representation.

(b) Committee Secretary

Mr. M. R. Tooley, BGC Production and Supply Division, was designated full time Secretary

(c) Decisions concerning future meetings

Following discussions, these dates and locations were agreed:

20th July, 1977	Washington 9:30 a.m. in Conoco office at 1130 17th Street, N.W. Suite 430.
3rd August, 1977	Westfield
14th September, 1977	Westfield
12th October, 1977	Westfield
3rd November, 1977	Chicago
7th December,1977	Westfield
11th January, 1978	Westfield
8th February, 1978	Westfield

It was agreed that Mr. McHugh would organize meetings held at Westfield and Dr. Sudbury would organize the meetings held in the United States.

It was agreed that an Agenda would be issued by the Chairman of the Committee, one week prior to each meeting, and that the Minutes would be presented for agreement with Carl Fink on site and would then be forwarded within 48 hours to the Committee Members for comments. If no comments were received within 7 days, agreement would be assumed.

Matters for action would be telexed to the person responsible within 48 hours.

(d) Roles of Members in Committee Participation

It was stated that detailed studies would be assigned to working groups, which would be set up for each particular task. The groups would not be Standing Groups but would report on their task to the main Committee, and would be disbanded when the task was completed. Committee Members would be responsible for disseminating information to the interested parties in their respective organizations.

(e) On-Site Representation at Westfield

The following representation was agreed:

DOE: Messrs. Hutchinson and Echinrode were nominated as the full time site representatives.

Continental Oil: Messrs. Fink, Aul and Spangler were nominated as full time representatives, with G. Heunisch as their fourth representative, but he would not be resided at Westfield, and only visit the site as and when required.

Lurgi:	No permanent representatives were nominated. Named personnel would attend site as required, in accordance with the Contract conditions.

Organizations would need to provide living accommodation locally to the site. Office accommodation on site would not be required before the 1st August, 1977.

(f) Plans for Handling Visitors at Westfield

Usual Westfield procedures with regard to visitors would be followed, and it was stressed that notification for all visitors would be required prior to arrival on site.

The Committee Secretary would be notified of all visits to site requested through Continental Oil or DOE, and he will be responsible for obtaining the necessary clearance. DOE requested that they should be notified of all visits to the site which could be politically sensitive. In order to facilitate speedy communication, the following telex numbers are given:

R. A. Verner	DOE	2307108229249+
J. D. Sudbury	Continental Oil	230812529+
J. McHugh	BGC	261710
M. R. Tooley	BGC	341493
J. A. Gray	BGC	27708
D. Hebden	BGC	27708
Lurgi	-	41236330
Westfield	-	727302

II. BUDGETARY ITEMS

(a) Decision to Begin BGC Charges at Westfield

Dr. Sudbury stated that Continental Oil Company was prepared to accept charges from June 13th.

The question of lining the gasifier was also discussed and it was noted that DOE had requested that the gasifier be accepted for the TSP in the lined condition and will be restored to a similar condition at the completion of the TSP.

(b) Decision to Begin Rental Charges at Westfield

It was required that a date for the commencement of rental charges be proposed by the Committee, with the approval of DOE, to the Administrative Committee for authorization. It was agreed that the Chairman should write to Mr. Bowden proposing a starting date for the commencement of rental charges.

(c) Discussion of Task Breakdown

Reference was made to a memo from Mr. W. B. Watson regarding the method of payment of invoices. It was required that Continental Oil Company and Mr. J. E. Scott should agree a method of clearing invoices.

(d) On-site Accommodation

This would be required at the earliest by 1st August 1977. Mr. J. E. Scott is to telex details of alternative quotations for Portacabin type accommodation to Continental Oil Company for approval.

IV. REPORTING

See Notes later.

This item was fully discussed following which the undermentioned representatives were called into the meeting.

George Curran, Carl Fink, Continental Oil Company
Helmut Vierrath and Uwe Marwig, Lurgi
D. A. Young, P. Faulkner, J. E. Scott, C. T. Brooks, and W. Wallace all from British Gas Corporation

The representatives were welcomed by the Chairman who explained the purpose of the preceding meeting, which was to finalize administration details.

Dr. Sudbury then summarized matters which had been discussed and decisions which had been taken.

The following items were then dealt with after lunch.

III. TECHNICAL SUPPORT PROGRAMME

(a) Status of Ohio No. 9 Coal

Dr. Sudbury reported that 20,000 tons (2" x 3/4") had been ordered and was being accumulated but was not yet available. The first shipment should be sufficient for the first two or three runs. The second coal will be shipped with the final shipment of Ohio No. 9 coal.

(b) Broad Goals of the TSP

The following areas were identified:

... To establish technical possibility of Gasifying Ohio No. 9 caking coal.

... To develop data needed by Process Engineers.

... To determine the feasibility of gasifying at least one more U.S. coal.

... To pinpoint critical or potential problem areas for the demonstration plant. DOE requested that questions be solicited on problem areas from interested parties, i.e., Foster Wheeler, and that these be included in the Agenda for discussion at the next meeting.

(c) <u>Westfield Plant</u>

In answer to questions, Mr. Scott stated that the Plant could be ready for commissioning by 15th July, 1977. The site would then be shut down for 2 weeks to accommodate annual holidays and commissioning would commence 1st August, 1977. It is intended that the Plant be started up on Frances coal on 9th August, 1977 and for 'on line' change to Ohio No. 9 coal to be made when conditions had stabilized - estimated to be 10th August, 1977.

In order to accommodate the above, Ohio No. 9 coal would be required at Westfield between 1st and 5th August, 1977 in order to allow time for screening.

Problems associated with plant start-up and operation such as side-stream sampling, analysis of O_2 and CO_2 and temperature fluctuations, were discussed and the following communications were handed out by J. D. Sudbury:

- Inter-office Memo dated 2/5/77 from V. H. Melquist to G. P. Curran.
- Inter-office Memo dated 2/6/77 from A. J. Morse to J. D. Sudbury.
- Inter-office Memo dated 10/6/77 from G. P. Curran to J. D. Sudbury.

In addition to the above, the following three documents were handed out by Mr. Verner:

- The TSP and Memo dated 16/5/77 from H. T. Reilly to R. A. Verner.
- Memo from H. T. Reilly to R. A. Verner dated 2/6/77.
- Memo from G. P. Curran to R. A. Verner dated 9/6/77.

It was proposed that these be studied by site staff on 14th June, 1977.

The following points were made regarding data and sampling requirements. Results must be accurate and prompt. Site can provide routine analyses and assistance is available from London Research Station (L.R.S.) for any non routine work as required.

Site to persue possibility of obtaining specialist instruments for use on site, following the production of an agreed schedule of instrumentation requirements by Continental Oil and British Gas.

Continental Oil asked that results be produced within two weeks following completion of runs.

DOE stressed the need for environmental sampling and analysis.

IV. REPORTING

(a) Mechanism for Technical Direction to Plant Ma[illegible] Westfield

Reference was made to Westfield Agreement which [illegible] requests for work on the Plant to be in writing, and acceptance also to be in writing.

The advantage of using telex (which satisfies the require- ment for written request) was stressed for expediency.

(b) Internal Communications Among On-Site Personnel

The use of a single contact by each organisation [illegible] General Manager was obviously needed. The organisation[illegible] contact would then be responsible for disseminating information throughout his company.

General Manager was asked to consider methods of [illegible] all personnel informed.

(c) Preparation of Programme Committee Meeting [illegible]

See I (c).

(d) Format for Protection of Proprietary Rights

The need for BGC to have all information available [illegible] site for inspection in accordance with the agreement was stressed.

The importance of run reports and other special [illegible] be completed and maintained at Westfield was empha[illegible]. It is recognized that DOE will receive only [illegible] information in reports issued by BGC.

V. MISCELLANEOUS

(a) Communications

DOE asked that a copy of all communications be sent to them for information.

(b) Reporting

Monthly reports would be calendar months, the first of which is required at the end of June.

M. R. Tooley
Secretary

MINUTES OF TECHNICAL SUPPORT PROGRAM COMMITTEE MEETING NO. 2

Place: Continental Oil Company
1130 17th Street, N.W.
Washington, D.C.

Date: July 20, 1977

Present:

Members:

Dr. J. D. Sudbury, Continental Oil Company
Mr. W. B. Watson, Continental Oil Company
Dr. C. Lowell Miller, U.S. Department of Energy
Mr. J. McHugh, British Gas Corporation
Mr. M. R. Tooley, British Gas Corporation (Secretary)
Mr. H. Vierrath, Lurgi Kohle und Mineraloeltechnik

Designates:

Mr. R. A. Verner, U.S. Department of Energy
Mr. C. E. Fink, Continental Oil Company
Mr. G. P. Curran, Continental Oil Company

In Attendance:

Mr. J. E. Scott, British Gas Corporation
Mr. J. D. F. Marsh, British Gas Corporation

Apologies were received from Dr. D. Hebden and Dr. J. A. Gray of BGC and Mr. P. Rudolph of Lurgi.

I. APPROVAL OF MINUTES OF TSP No. 1

It was decided that the meetings should be numbered commencing with TSP-1.

Distribution of Minutes would be to members of the committee who would be responsible for coordination of comments, etc.

The minutes of TSP-1, distributed on June 23, 1977, were approved.

II. STATUS OF PLANT

Mr. Scott stated that the plant was complete in accordance with previous state on July 15, 1977. Photographs were distributed showing the gasifier condition.

The following items of additional work were discussed and agreed in principle by the committee.

(a) Flux Addition System

This will be completed by August 1, 1977. Total estimate cost: 6000 UKL[1].

(b) Oxygen Preheater, Supply and Installation

Will be completed by September 1, 1977. Total estimated cost: 7500 UKL.

(c) Rationalization at Instrumentation

This item is complete and operator training is underway. Approximate total cost: 20,000 UKL.

(d) Installation of Additional Thermocouples

Provision for four extra thermocouples has been made utilizing an existing branch situated approximately 2 feet below base of the distributor pot. Only one thermocouple will be used for the first run. Estimated cost: 3000 UKL.

Mr. Scott stated that provision of further thermocouples as requested in Continental Oil Company memo of June 10, 1977, would not be possible without serious delay to the program.

BGC was asked to prepare a detailed scheme for fitting of six thermocouples, and Don Edwards of Continental Oil Company would liaise with site to assist with above.

Lurgi stated that although standard gasifiers did not use such temperature measurements, they would be useful for the TSP program. They have not considered the mechanical design.

(e) Continuous CO_2 and O_2 Analyzers

These will be completed by August 1, 1977.

The modified gas sample system will be available and work is still proceeding with improvements to this.

Approximate total cost: 6000 UKL.

(f) Provision of Accommodation for On-Site Representatives

BGC proposals in accordance with drawing number 81158, which was circulated at the meeting entail following costs:

(1) ULK is United Kingdom pounds sterling

Rental of Offices	380 UKL/month
Approximate purchase cost of furniture	2000 UKL
Supplies and services (drainage, water, gas, etc.)	3000 UKL

(g) Fines Injection System

Could be complete (if required) by November 1, 1977.

Much work has been carried out but approximately 30,000 UKL will be required to complete installation.

Final approval for this item was deferred.

(h) Provision of Analytical Data

Mr. Scott circulated two schedules (copies of which are attached) giving Category 1 data and Category 2 data. Category 1 data would be available within approximately two weeks following the completion of the run.

In order to achieve this, approximately 35,000 UKL would be required for extra equipment and four additional chemists would be needed. Requests for the extra personnel had been approved within BGC.

III. TRANSFER OF MATERIALS FROM PREVIOUS PROGRAMME TO TSP

The following items which were available from a previous program carried out at Westfield were discussed with a view to the use in the TSP:

3000 long tons Frances Coal
250 long tons Comrie Coal
Analytical Equipment
Stores Equipment, spares, etc.

The total value of these is about 150,000 UKL.

A schedule of items which will be purchased for the TSP will be agreed on by J. D. Sudbury and J. E. Scott.

IV. COAL SHIPMENT

Mr. Watson stated that 6000 short tons Ohio No. 9 coal had been loaded into rail cars. 10,000 tons would be transported in the first shipment which it was hoped would be loaded into the ship by August 1, 1977. The passage to Scotland would take 9 to 10 days.

The second shipment of 10,000 tons would follow about one month behind the first shipment.

The decision on the need for the Pittsburgh No. 8 coal would be deferred until experience had been obtained with Ohio No. 9 coal.

Preliminary tests of the size range of the first shipment indicated that the size may not be as expected in that there appeared to be more large sized coal. Lurgi (Paul Rudolph) had expressed concern on this and Conoco said they would provide a size analysis to Lurgi and BGC as soon as possible for comment.

V. PROGRAM FOR RUN 1

A memo (copy attached) from Carl Fink dated July 8, 1977, was circulated and discussed. Comments were requested from BGC and Lurgi on these matters.

VI. FORMULATION OF TSP

A draft Statement of Work and Program Plan, copy attached, was distributed by DOE for consideration and discussion at the next meeting. BGC stated that they noted the contents of this memo and that they would respond to this and also the memo dated July 5, 1977, from W. B. Watson.

Mr. Curran drew attention to a new item in the DOE memo in that Task V called for the preparation of scale-up data.

VII. MISCELLANEOUS

In answer to questions from Mr. Vierrath, it was agreed that:

a. Continental Oil Company would be responsible for stipulating run conditions and for decisions taken during each run.

b. Results obtained at site together with ELD's etc., would be available to nominated representatives on the site.

c. DOE stated that there was at present no intention to provide a program site representative. This may change later but there is currently no requirement for housing.

M. R. Tooley
Secretary

Attachment 1 for
TSP-2 Minutes

Data Necessary for Assessment of Slagger Performance, and the Construction of Heat and Mass Balances - Category 1 Data.

COAL:

Size Analysis (spot samples) - done during the Run.

Spot Moisture - done regularly during the Run.

Proximate Analysis - hourly increments for a daily sample.

Ultimate Analysis - two day combined sample.

Calorific Value - done on same samples as used for Ultimate Analysis.

SLAG:

Mineral Analysis - increments from each Slag Lock to give one daily sample.

Free Iron Content - from above daily samples, or could be on any one of the Locks sampled.

Carbon in Slag - as for Free Iron.

OXYGEN:

Need accurate levels of CO_2, N_2, and Argon - during the Run.

RECYCLE TAR:

Moisture - a result at least every 12 hours.

Dust Content - retain dust from measurement of dust content. Make up one representative sample for the whole Run - Require Ultimate Analysis and Calorific Value of this dust.

Dry - Dust Free Tar - from samples of Recycle Tar taken during the Mass Balance period, prepare one representative sample for the Run and do Ultimate Analysis and Calorific Value.

FLARE GAS:

Major Constituents + H_2S + COS, CS_2, C_4H_4S)- done during the Run.

Minor Constituents ($C_{10}H_8$, HCN, Ammonia) - done during the Run.

Total Sulfur content of the gas (distinguish from H_2S).

Dust in Flare Gas - take samples from the gas during Mass Balance periods, make up one representative sample for the whole Run and do Ultimate Analysis and Calorific Value.

St. Clair de Ville Condensables - samples to be taken during Mass Balance periods, make up one representative sample for Ultimate Analysis and Calorific Value.

LOCK AND FLASH GAS: Major Constituents + H_2S + Naphthalene (NH_3 in Flash Gas)

TAR/OIL MAINSTREAM: It is expected that limited samples only will be required from the Mainstream as far as Category 1 is concerned. In the event of a side-stream malfunction, one sample of sales tar and one of sales oil will be taken. These would then be treated as Category 1 - otherwise they are Category 2.

From the samples, would require:

Dust Content
Moisture Content
Ultimate Analysis
Calorific Value

LIQUOR (MAINSTREAM): One (spot) sample only would be taken of tar water, and one of oil water. At least 36 hours should elapse from the start of the Run to the time of sampling. We would require:

TDS
Sulfur (total) Content
Ammonia
Carbon as Carbonates
Chlorine as Chlorides

on each sample

SIDE-STREAM: Gas (incremental sample taken during the Side-stream Period) (Probably 1 period of 12 hours each day)

Analysis of Major Constituents + H_2S, COS, CS_2, and C_4H_4S

Analysis of Minor Constituents ($C_{10}H_8$, HCN, Ammonia)

Total Sulfur Content (distinguish from H_2S)

St. Clair de Ville Condensables - samples to be taken for each Mass Balance period, make up one representative sample for Ultimate Analysis and Calorific Value

Tar/Oil/Liquor - Separate into hydrocarbon and liquor layers.

On the Hydrocarbon we would require:

Dust Content (keep dust)
Moisture Content
Ultimate Analysis
Calorific Value

SIDE-STREAM

On the liquor we would require:

TDS
(Total) Sulfur Content
(Total) Ammonia
(Total) Carbon as Carbonate
(Total) Chlorine as Chlorides

Dust Content - prepare samples of dust and do Ultimate Analysis and Calorific Value on one representative sample.

Ultimate Analysis of Coals and Dust should have results expressed as:

% Moisture
% Ash
% Carbon
% Hydrogen
% Nitrogen
% Sulfur
% Chlorine
% Oxygen + Errors

Ultimate Analysis of Tars, Oils and Naphthas should have results expressed as:

% Carbon
% Hydrogen
% Nitrogen
% Sulfur
% Chlorine
% Oxygen + Errors

J. E. Scott
General Manager, Westfield

Attachment 2 for
TSP-2 Minutes

Data Necessary for Assessment of Slagger Performance,
Category 2 Data

COAL:	Bulk Density.
	Fisher Assay.
	Sulfur Distribution (Organic, Pyritic, Inorganic).
	Caking No. (Gray King No.)
	Swelling Index.
	Reactivity.
	Trace Elements: Al, As, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Mg, Mn, Mo, Na, Ni, Sb, Se, U, V, Zn (Be and Pb?)
	Independent checks on ultimate analysis of coal.
COAL ASH:	Mineral Analysis: Al_2O_3, SiO_2, Fe_2O_3, CaO, MgO, Na_2O, K_2O, (SrO, BaO, TiO_2, P_2O_5, S as SO_3). LOI, Silica No.
	Ash Fusion Temperature (Reducing and Oxidizing conditions).
	Trace Elements (as for coal).
SLAG:	Independent checks on mineral analysis; to include SrO, BaO, TiO_2, P_2O_5 and S as SO_3, LOI.
	Trace Elements (as for coal).
BED SAMPLES:	Ultimate Analysis (C, H, O, N, S, Cl, Ash). Iron Determination.
NAPHTHAS, OIL AND TAR QUALITY:	(e.g. characterization of sales tar, St. Clair de Ville condensate, recycle tar, sales oil).
	Distillation (0 - 200°C, 200 - 320°C, 320° - Solid).

Specific Gravity.

Toluene Insolubles.

Tar Acids.

Paraffins.

Naphthenes.

Aromatics.

Viscosity at two temperatures.

Trace Elements: Al, As, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Mg, Mn, Mo, Na, Ni, Sb, Se, U, V, Zn. (Be and Pb?)

GAS LIQUOR, LIQUOR FROM SIDE-STREAM, SLAG QUENCH WATER (TRACE ELEMENTS ONLY): BOD

COD

Total Organic Carbon.

Tar Content.

T.D.S. + Ignited T.D.S.

Total Sulfur as S.

Sulphide as S.

Sulphate as SO_4.

Thiocyanate as CNS.

Fatty acids as acetic.

Fixed ammonia.

Free ammonia.

Total unoxidized nitrogeneous NH_3.

Total Phenols as phenol.

Monohydric phenols as phenol.

Carbonate as CO_2.

Cyanide as CN.

Chloride as Cl.

Fluoride as F.

Nitrate as NO_3.

Phosphate as PO_4.

SG.

PH.

Trace Elements: Al, As, Be, Ca, Cd, Co, Cr, Cu, Fe, Hg, X, Mg, Mn, Mo, Na, Ni, Pb, Sb, Se, U, V, Zn.

J. E. Scott
General Manager, Westfield

Interoffice Communication

Attachment 3 for TSP-2 Minutes

To John D. Sudbury - Library

From Carl E. Fink - Westfield

Date July 8, 1977

Subject Program for Run 1 of the Technical Support Program

Run 1 of the Technical Support Program is scheduled to begin August 9, 1977. It has been agreed that this run will be made using Frances coal initially. Ohio No. 9 coal may or may not be introduced during the run depending on whether a satisfactorily sized stock is available at Westfield at that time. Beginning with this basic agreement, a more detailed program for Run 1 will be proposed below.

Objectives

The primary objective of Run 1 must be to demonstrate the mechanical integrity of the slagging gasifier as it has been rebuilt for the TSP program. Several changes have been made as improvements to the gasifier and these changes should be evaluated.

The run should provide a bridge between the recently concluded program and the TSP program. A period of 60 hours operation is desired.

The properties of Ohio No. 9 coal are such that some changes in the operation of the slagging gasifier may be required. The second objective of Run 1 should be to gain experience where possible that will ease the transition from Frances coal to Ohio No. 9 coal. The two properties of Ohio No. 9 coal which might give problems are:

1. Its caking potential, and
2. The amount and composition of its ash.

Experience in previous Westfield programs suggest that smooth gasifier operation is favored by lower loads and that lower loads are particularly desirable with caking coals. The nature of the Ohio No. 9 ash is such that fluxing is required. The effectiveness of fluxing is improved by the presence of a slag pool in the hearth of the gasifier.

A second part of the run should be made in which conditions desirable for introduction of Ohio No. 9 coal are established while feeding Frances coal. The newly installed fluxing system should also be operated to demonstrate its effectiveness. Two methods of flux addition should be studied:

1. Mixing the flux and coal as they are added to the lock hopper, and

2. Adding flux to the lock hopper batchwise followed by coal addition.

It is estimated that this part of the run would require four days operation.

The final objective of Run 1 would be to demonstrate operation while feeding Ohio No. 9 coal to the gasifier. A pre-requisite to this, of course, is to have a suitable stock of coal at Westfield. The purpose of this part of the run would not be to optimize operation of the gasifier with this feedstock but rather to find a condition where the gasifier operation is stable. It is envisaged that two days operation would be required during this phase of the run.

<u>Run Program</u>

A. <u>Start-Up</u>

The start-up for Run 1 would be carried out using the standard start-up procedure. This procedure will be spelled out in the report of Run 1.

B. <u>Gasifier Evaluation Phase</u>

The conditions of the gasifier evaluation phase of Run 1 are listed below:

System Pressure	350 psig
O_2 Loading	160,000 SCFH (96% O_2 purity)
Steam/O_2 ratio	1.45 V/V nominal
Feedstock	1" x 5/8" Frances Coal

A period of 12 hours would be allowed to establish the run conditions and allow the system to come to equilibrium. Then a 48 hour period of operation as steady-state would be made. During this period, performance data such as gas make rate and composition, feed rate (locks per hour and lbs/hour) and side stream analysis would be obtained. In addition, the offtake temperature fluctuations and hearth and slag tapping behavior would be characterized.

Dr. John D. Sudbury
July 8, 1977
Page 3

C. Preparation for Ohio No. 9 coal phase

This phase of the run is broken down into four distinct parts. These are as follows:

1. Load reduction
2. Reduction of steam/oxygen ratio
3. Flux trials
4. Slag tapping trials

Each part will be conducted independently. Changes will be made in a reversible manner such that should a limit be reached, the change could be negated and stable operating condition could be regained.

1. Load Reduction

During this part of the run the oxygen loading will be reduced from 160,000 SCFH to 130,000 SCFH or to minimum stable load whichever is higher. Small reversible changes will be made with four hour pause periods at 155,000 SCFH, 150,000 SCFH, 145,000 SCFH, 140,000 SCFH, and 135,000 SCFH. A 12 hour period will be carried out at the lowest stable load.

Reduction in load is expected to improve the operation of the gasifier with repsect to offtake temperature fluctuations. It is important that the offtake temperature fluctuations and slag tapping behavior be evaluated at each level of load.

2. Reduction of Steam/Oxygen Ratio

With low gasifier loading the steam/oxygen ratio will be reduced from 1.45 to 1.25 or to the minimum stable level in small reversible steps. Pause periods of four hours each will occur at levels of 1.40, 1.35, and 1.30. A 12 hour period will be used to evaluate conditions at the lowest stable steam/oxygen ratio.

Reducing the steam/oxygen ratio should make the raceway hotter but may decrease blast penetration and could also lead to some instability of the gasifier offtake temperature. Both offtake temperature fluctuations and slag tapping performance will have to be carefully monitored.

3. Flux Trials

Unlike Frances coal, Ohio No. 9 coal requires the addition of flux to allow operation in the slagging gasifier. A fluxing system has been installed and it is desirable to check the performance of this system. It is felt that flux in the form of blast furnace slag can be added to the gasifier while feeding Frances coal without having a detrimental effect. In this part of Run 1 the fluxing system would be tested.

Two techniques for adding flux have been proposed. In the first of these, flux is added batchwise to the bottom of the coal lock hopper after which the lock hopper is filled with coal. In the second, flux and coal are charged simultaneously to the lock hopper. The first technique is most secure from the standpoint of feeding the proper amount of flux into each lock hopper. The second approach offers superior mixing in the lock hopper and should lead to more even fluxing. The run should test both these techniques to allow a choice to be made prior to feeding Ohio No. 9 coal.

It is proposed that a feed mixture containing 5 wt. % blast furnace slag as flux should be fed. Calculations or viscometer test should confirm that this feed mixture is operable. A period of at least eight hours duration should be devoted to testing each of the fluxing methods. Each period should contain a balance period in which a pre-weighed batch of flux is charged.

The slag tap performance will be used to evaluate the effectiveness of flux addition as the fluxed slag should be less viscous than that which is not fluxed.

If possible, the most desirable method should be chosen and a fluxing test should be carried out with a higher flux rate, say 10% flux in the feed.

4. Slag Tapping Trials

The performance of a flux added to the gasifier will be improved if a slag pool is maintained at all times. A deeper slag pool allows more time for fluxing reactions to occur. However, deep slag pools can lead to operating problems. It is advantageous to systematically vary the slag level by altering the slag tap ΔP trip and vary the amount of slag removed during a tap by altering the tap duration. Fluxing reactions will be favored by high slag levels (high slag tap ΔP trips) and for more frequent, faster taps.

Dr. John D. Sudbury
July 8, 1977
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During this period of the run an attempt will be made to optimize the tap time and slag tap ΔP settings. It is recognized that the tap time required to withdraw a given amount of slag is dependent on the characteristics of the slag and that the tap time setting cannot be applied to operations on Ohio No. 9 coal. The slag tap ΔP's before and following a tap should be applicable to operations with Ohio No. 9 coal.

These tests should be carried out at maximum fluxing rate and at the low load, low steam/oxygen ratio conditions. The object of the exercise will be to determine a range of operation of the slag tap DP consistent with maintaining slag in the hearth at all times while avoiding dangerously high levels.

D. Feeding Ohio No. 9 Coal

This step assumes having a supply of Ohio No. 9 coal available at Westfield. Also critical assessment of the preceding parts of Run 1 is a pre-requisite.

The conditions are to be used for feeding Ohio No. 9 coal are listed below:

System Pressure	350 psig
O_2 Loading	130,000 SCFH O_2 or per item C-1, above
Steam/O_2 Ratio	1.25 or per item C-2, above
Feedstock	2" x 1/4" Ohio No. 9 coal
Flux	Blast furnace slag @ 15 wt. % of feed or per slag viscometer tests.

Potential problems include caking at the top of the bed and freezing conditions in the hearth. Minor adjustments to top conditions (stirrer speed, tar injection, etc.) or fluxing level may be required to achieve operability. The goal of the run is to achieve a period of operation at some level and no attempt will be made to optimize conditions. A run period of two days is envisaged.

During this period, off-take temperature fluxuations and slag tapping behavior will be evaluated. The feed rate, gas make, and product yield via side stream sampling will be determined.

E. Shutdown

An orderly shutdown should be performed in such a way as to preserve the fuel bed as much as possible. This precludes steaming out the bed as is routinely done. A new procedure should be developed to accomplish this goal.

Carl E. Fink

Attachment 4 for
TSP-2 Minutes

First Draft 7/20/77

BRITISH GAS/LURGI SLAGGING GASIFIER DEVELOPMENTAL PROGRAM

STATEMENT OF WORK AND PROGRAM PLAN

During the defined contractual period of performance, the contractor will operate the British Gas/Lurgi Slagging Gasifier located at Westfield, Scotland to achieve the following objectives:

a. establish the mechanical integrity and operational characteristics of the gasifier (e.g., optimum stirrer rate, tapping control, etc.)

b. establish the operational performance parameters of the gasifier (e.g., feed rate, product yield data, heat and material balances, temperature control as related to elimination of observed erratic fluctuations, tar injection)

c. definition of coal/flux ratios required for control of slag characteristics

d. collection and correlation of data required in associated assessments of materials of construction, performance of auxilliary systems, effluent characterization and assessment of environmental impact.

These objectives are considered essential to the development of data required in the design of a commercial/demonstration coal gasification facility utilization full-scale British Gas/Lurgi Slagging Gasifiers. The following tasks include the work required to accomplish the objectives.

I. Task I - Initial Shake-Down and Test of Mechanical Integrity of Gasifier

The contractor will initiate the operation of the gasifier using a locally available coal (i.e. Frances) to shake-down and stabilize the modified gasifier (e.g., new stirrer/distributor, tapered upper shaft, use of oxygen preheat, etc.) and relate it to previous experience. This task will include:

a. operation of the gasifier at conditions within the ranges known as required to gasify the local coal with variation of these test parameters as necessary to establish operability.

b. once operability is achieved, complete a baseline run of sufficient length to establish the parameters required in the tests of Task II.

c. observe conditions and performance of the mechanical parts/components of the gasifier (stirrer/distributor slag tap hole, tuyeres and hearth refractory) as required to designate mechanical repairs or improvements needed to prepare the gasifier for use in Task II.

<u>Task II - Operation of the Gasifier with Ohio No. 9 Coal</u>

Upon completion of Task I, or upon the direction of the DOE program manager, the contractor will initiate operation of the gasifier with an Ohio No. 9 coal feed. The gasifier will be operated as required to:

a. establish a set of acceptable operational parameters (i.e., baseline set of conditions) for operation of the gasifier with this coal.

b. demonstrate the suitability of selected materials for flux, as well as acceptable flux/coal ratios, and if possible, relate the observed characteristics of the molten slag in the gasifier with predicted viscosities of the applicable system as determined by laboratory test.

c. study the effect of the steam/oxygen ratio, as well as oxygen loading on gasifier performance, and investigate the inter-relationship of these parameters with the gasifier coal feed rate.

d. determine if the gasifier can be operated with a run-of-mine coal.

e. examine and compare, if the tests of (d) above demonstrate the existence of a fines problem, the feasibility of alternate ways/techniques to utilize coal fines. Direct injection will be the first technique to be so evaluated.

f. evaluate the operational feasibility and determine the impact upon the yield data and product characterization of feeding a supplementary liquid fuel (e.g., tar) through the tuyeres.

Task III - Operation of the Gasifier with a Second Coal

Upon completion of Task II and/or upon direction by the DOE program manager, the contractor will begin operation of the gasifier with the second coal specified by the Technical Support Program Committee. The gasifier will be operated with this coal as required to repeat tasks (a) through (e) of Task II above.

Task IV - Preparation of Technical and Environmental Assessments

Concurrent with the performance of Tasks I, II and III above, the contractor will collect, correlate and present operational test data that may be required to perform technical and environmental assessments. These assessments will include but not necessarily be limited to:

a. characterization of all effluents and/or in process streams that may be considered significant to the control of such effluents.

b. determination of the corrosion characteristics of candidate materials of construction and operating equipment as required in the selection of materials for subsequent design work establishing

c. the reliability of operation of critical mechanical components

d. establishing the inter-relationships between the number and composition of effluent streams and the potential impact of a commercial/demonstration facility as may be required to specify effluent control equipment and/or systems.

Task V - Preparation of Scale-Up Data

In a number of areas critical to the scale-up of this gasifier system such as gasifier diameter, slag tap, geometric configuration of the tuyeres and the number as well as the diameter of the nozzles, the observations of the operational engineers of the participating organizations will be particularly significant to design decisions. Accordingly, the contractor will provide the services of those engineers most suited to participate in related discussions and assist in preparing these or other scale-up data.

These discussions should be initiated at a date early enough in the performance period plan for operation of the gasifier as may be necessary to generate additional data required to resolve key design problems.

C. L. Miller
U.S. Department of Energy

MINUTES OF TECHNICAL SUPPORT PROGRAM COMMITTEE MEETING NO. 3

Place: Westfield Development Centre, Cardenden, Scotland

Date: August 3, 1977

1. PRESENT

Members:

Dr. J. D. Sudbury - Continental Oil Company
Mr. W. B. Watson - Continental Oil Company
Dr. C. L. Miller - U.S. Department of Energy
Mr. J. McHugh - British Gas Corporation
Dr. D. Hebden - British Gas Corporation
Dr. H. Vierrath - Lurgi Kohle und Mineraloeltechnik

Designates:

Mr. C. E. Fink - Continental Oil Company
Dr. J. A. Gray - British Gas Corporation
Mr. P. Faulkner - British Gas Corporation
Mr. U. Marwig - Lurgi Kohle und Mineraloeltechnik

In Attendance:

Mr. J. Scott - British Gas Corporation
Mr. J. D. F. Marsh - British Gas Corporation

Secretary:

Mr. M. R. Tooley - British Gas Corporation

2. ATTENDANCE

Lurgi announced the appointment of their second designate who is to be Mr. H. Bierbach.

Mr. McHugh introduced Mr. M. Hosker to the meeting stating that Mr. Hosker would be responsible for BGC design aspects.

It was agreed that in future, only Members or Designates should attend meetings. The only permanent exceptions being Messrs. Scott and Fink who would normally be expected to attend.

3. MINUTES OF LAST MEETING

The minutes of TSP 2 which were distributed on 22 July 1977 were agreed and accepted.

In order to keep communications as simple as possible, minutes would be distributed only to Members of the Committee whether they were present at the meeting or not.

4. STATUS OF PLANT PREPARATION

The position was reviewed as follows by Mr. Scott:

a) Commissioning was now under way and certain ancillary items of equipment were being put to work.

b) It was expected that the gasifier would be ready for start up on Tuesday, 9 August.

c) The flux addition system is complete.

d) The latest date for the completion of the oxygen preheater installation was still at September 1977 as announced at the last meeting.

e) The modification of the instrument panels was complete. Checking and operator training are progressing.

f) One extra thermocouple had been installed as proposed at the last meeting. Continental Oil Company indicated that Don Edwards and Ron Folks would be arriving on site on 23 August 1977 in order to assist with the evaluation of a scheme for the installation of further thermocouples. It was also hoped that Ron Folks would be able to provide assistance in connection with analyzers and instrumentation.

g) It was expected that the CO_2 and O_2 analyzers would be available for the first run although a slight snag had occurred with one oxygen analyzer.

h) It was noted that the provision of on-site accommodation was complete and Dr. Sudbury commented that the buildings were entirely satisfactory. The provision of secretarial assistance is to be arranged between Mr. Scott and Mr. Fink. Telephone communication with the accommodation was provided via the main Westfield switchboard.

i) No further work was being carried out on the fines injection system. It was pointed out that if a decision was not taken on this matter in the near future, the system may not be available as required by the run programme. Messrs. Scott and Fink were asked to study this problem and to report to the next meeting.

j) Continental Oil Company has studied the category 1 and 2 data schedules as presented by BGC at the last meeting. They agreed with the schedules adding that they should be regarded as preliminary and subject to modification as the programme progresses. Analytical equipment had been ordered and some had been received on site. One item will be initially installed at LRS (included on the list of items to be charge to Continental Oil Company) and later moved to site. The recruitment of four temporary Chemists for work on site is progressing.

Lurgi stated that in some cases they would be obtaining their own analytical data with respect to category 2 items eg fatty acids and tar distillation curves. In order to avoid duplication of effort, BGC and Lurgi would liaise on site to determine who would carry out tests. Continental Oil Company offered the services of G. Heunisch to assist with this work.

k) Reference was made to letter number CB-8007 from Continental Oil Company to BGC approving of the expenditure involved with the above items as detailed in the minutes of the last meeting.

5. ACTIONS ARISING FROM PREVIOUS MEETINGS

The provision of materials from a previous programme to TSP was awaiting an Auditors Report.

The size analysis of the Ohio No. 9 coal was discussed and the following three papers (copies attached) were handed out for comment by Continental Oil Company:

(i) Analysis of Composite Sample Ohio No. 9 Coal Shipped to Westfield

(ii) Size Analysis of Ohio No. 9 Coal Shipped to Westfield

(iii) Viscosity Curves of Ohio No. 9 Coal Ash

Lurgi has carried out some work on the design for a metal liner and had telexed Continental Oil Company with their proposals. Continental Oil Company state that they had telexed a reply authorizing the necessary expenditure. Lurgi was requested to produce proposals at the next meeting indicating their recommendations which should be agreed beforehand by BGC.

6. STATUS OF COAL SHIPMENT

Mr. Watson reported that the ship had been loaded and was due to depart on the evening of 2 August 1977. The shipment was scheduled to arrive at Leith by 12 August 1977.

The second shipment was being mined and was scheduled for loading on 27 August 1977.

The decision with regard to Pittsburgh No. 8 coal was deferred.

7. PROVISION OF PROGRAMME FOR RUN 1

Continental Oil Company tabled a document entitled "Time Schedule for Run TSP-1" and BGC tabled a document by Dr. Hebden entitled "Comments on Proposed Programme for Run TSP 1". The subject was fully discussed and it was proposed that Run 1 would be carried out using Frances coal with the following objectives:

(i) To prove satisfactory operation of the plant

(ii) To establish that load can be reduced from 160,000 to 130,000 SCFH O_2 rate.

(iii) To establish that the steam oxygen ratio could be reduced from 1.45 to 1.25.

(iv) To prove satisfactory operation of the fluxing system.

Following further discussion, the need for (i), (ii) and (iv) above was agreed. The need for item (iii) was deferred and the meeting requested that Continental Oil Company and BGC should meet on site in order to produce a detailed schedule for Run 1.

8. DISCUSSION OF DRAFT TSP

It was agreed that as far as the Programme Committee was concerned, the TSP should be assumed to commence on 1 August 1977.

Continental Oil Company reported that the following document should be withdrawn - "British Gas/Lurgi Slagging Gasifier Development Program - Statement of Work and Program Plan - First Draft, 7/20/77" (see minutes of TSP-1).

It was noted that this document could be of use if it proved to be necessary for the contract to be revised.

Mr. C. Fink tabled a document entitled "Technical Support Program" (copy attached). Comments were requested on this Program within one week.

The following comments were made at the meeting:

(i) Mr. Vierrath requested that a maximum coal size of 1 1/2" and not 2" was preferred for the first Run. BGC stated that this would not present a screening problem.

(ii) The flux size was queried and was stated to be 1/4" to 1/2".

(iii) Mr. Watson pointed out that in order to concur with contractual requirements the document should be entitled "Support Engineering Plan".

It was stated that this document should supersede the programme indicated in the Westfield Agreement.

9. MISCELLANEOUS

Continental Oil Company asked that run readings should be available within 30 days following completion of the Run. This was accepted by BGC.

The date of the next meeting is 14 September 1977 at Westfield.

M. R. Tooley
Secretary

Attachment 1 for
TSP-3 Minutes

ANALYSIS OF COMPOSITE SAMPLE OF OHIO NO. 9 COAL SHIPPED TO WESTFIELD

Proximate Analysis, Weight Percent

Moisture	3.14
Ash	24.50
Volatile Matter	36.45
Fixed Carbon	35.91
	100.00

Ultimate Analysis (Dry Basis), Weight Percent

Hydrogen	4.20
Carbon	58.02
Nitrogen	0.93
Oxygen (diff.)	6.75
Sulfur	4.80
Chlorine	0.01
Ash	25.29
	100.00

Heating Value (Dry Basis), Btu/lb. 10,650

Ash Analysis, Weight Percent

Na_2O	0.28
K_2O	2.36
CaO	1.93
MgO	1.17
Fe_2O_3	16.91
TiO_2	1.07
P_2O_5	0.30
SiO_2	49.70
Al_2O_3	22.15
SO_3	1.36
	97.23

Attachment 2 for
TSP-3 Minutes

SIZE CONSIST OF OHIO NO. 9 COAL SHIPPED TO WESTFIELD (1)

	#1	#2	#3
+2 inches, (2) wt. %	0	0	0
2 x 1-1/2	8.0	7.7	10.8
1-1/2 x 1	28.1	25.7	28.7
1 x 1/2	37.9	37.9	36.0
1/2 x 1/4 (3)	26.0	28.7	24.5

NOTES:

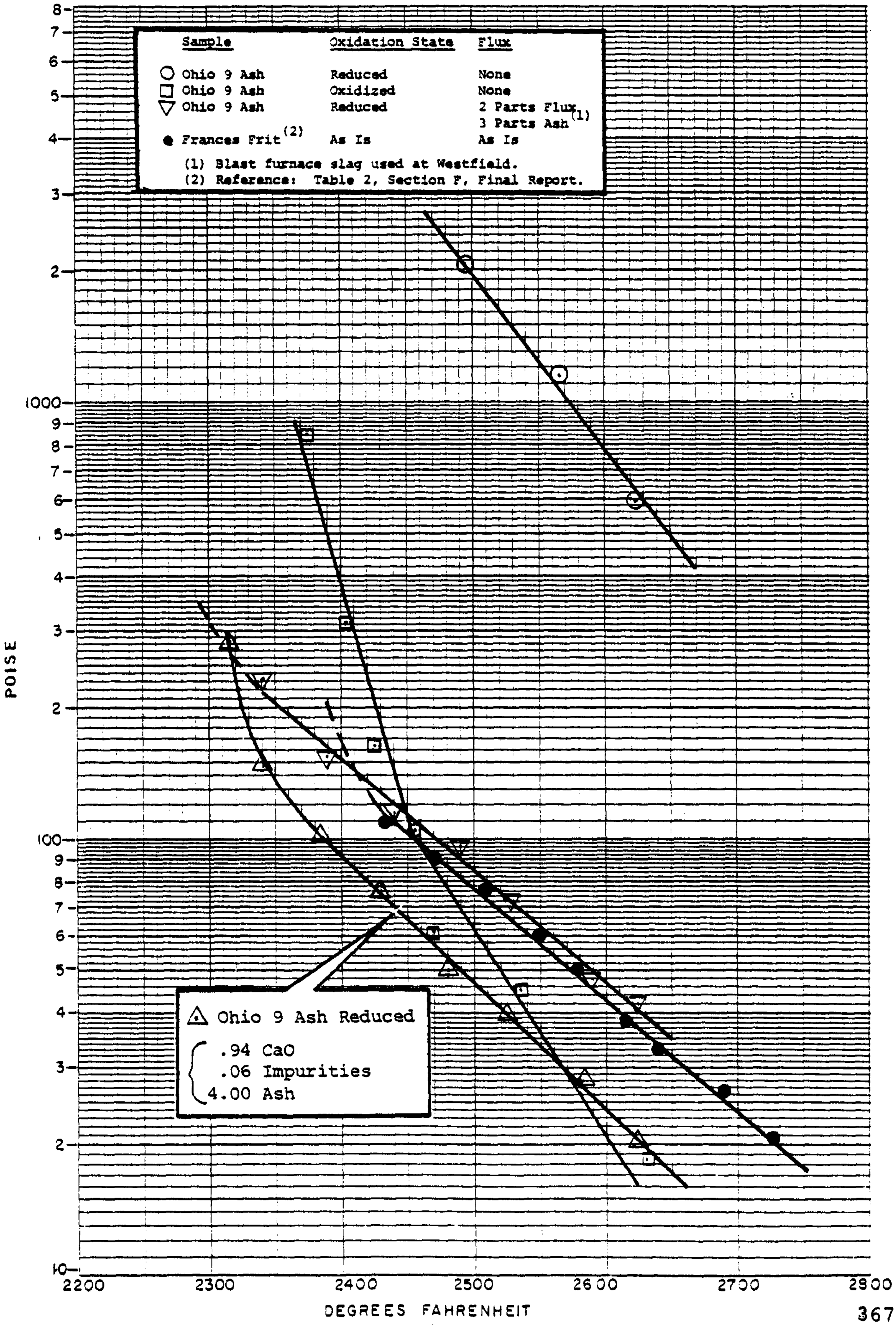
(1) These are 8-hour continuous samples taken every day while both the pit and the +2 inch crusher were operating.

(2) Square mesh openings.

(3) Analyses adjusted to 100% +1/4 inch on assumption that coal will be screened at Westfield at 3/8 inch, thereby giving negligible -1/4" in feed to bunker.

ATTACHMENT 3 FOR TSP-3 MINUTES

Viscosities of Ohio #9 Coal Ash



TECHNICAL SUPPORT PROGRAM
August 1977 through March 1978

Run No.	Begin	End	Duration Days	O_2 Load MSCFH	H_2O/O_2 Ratio	Coal Feed	Flux	GOAL
1	15 Aug.	18 Aug.	4	160-110	1.33-1.15	Frances 1 x 5/8	None BFS	1 Verify integrity of refurbished Westfield gasifier by operating at standard conditions using Frances coal. "Dress rehearsal" for feeding Ohio 9 coal.
2	5 Sept.	8 Sept.	4	Per Run 1		Ohio 9 1 x 5/8	BFS	2 Demonstrate an operation of the slagging gasifier using Ohio 9 coal as feedstock and blast furnace slag as flux. Although conditions will not be optimized, detailed data will be obtained.
3	26 Sept.	29 Sept.	4	Per Run 2		Ohio 9 2 x 1/4	Limestone	3 Demonstrate use of limestone as flux for the Ohio 9 ash and study effect of addition rate (amount of flux per unit amount of ash) on operability and performance.
4	17 Oct.	21 Oct.	5	130-180	1.05-1.60	Ohio 9 2 x 1/4	Limestone	4 Evaluate effects of variations of O_2 loading and steam/O_2 ratio on performance and operability of the gasifier while feeding Ohio 9 coal.
5	7 Nov.	10 Nov.	4	Per Run 4	Per Run 4	Ohio 9 2 x 1/4 + Fines	Limestone	5 Determine maximum allowable fines content for processing Ohio 9 coal.
6	28 Nov.	8 Dec.	10	Per Run 4	Per Run 4	Ohio 9 2 x 1/4 + Fines Per Run 5		6 Demonstrate long term steady-state operation at conditions determined in 2 through 5 above.
7	9 Jan.	13 Jan.	5	Per Run 6	Per Run 6	Ohio 9 2 x 1/4 + Fines Per Run 5	Limestone	7 Operate gasifier to solve critical problems as defined by the engineering subcontractors.
8	28 Jan.	1 Feb.	5	Per Run 6	Per Run 6	2nd Coal 2 x 1/4	BFS, Limestone	8 Demonstrate operability using a second Eastern U.S. coal as feedstock and obtain yield data as in 2 above.
9	16 Feb.	20 Feb.	5	130-180	1.05-1.60	2nd Coal 2 x 1/4	Limestone	9 Evaluate effects of steam and O_2 rates on performance of second coal as in 4 above.
10	1 Mar.	4 Mar.	4	Per Run 6	Per Run 6	Ohio 9 2 x 1/4 + Fines Per Run 5	Limestone	10 Evaluate introduction of liquid fuel (e.g. tar) through the tuyeres.
11	20 Mar.	23 Mar.*	4	Per Run 6	Per Run 6	Ohio 9 2 x 1/4 + Fines per Run 5	Limestone	11 Conditional on results of 5 above evaluate alternate means of feeding fines to the gasifier (e.g. through tuyeres).

*The time sequence above does not allow for any major mechanical changes such as a metal top shaft or stirrer/distributor revisions. This document will be revised to reflect these changes and/or any others which are needed.

August 1, 1977

MINUTES OF WESTFIELD TECHNICAL SUPPORT PROGRAM COMMITTEE MEETING NO. 4

Place: Westfield Development Centre, Cardenden, Scotland

Date: September 14, 1977

1. PRESENT

Members:

Dr. J. D. Sudbury - Continental Oil Company
Mr. W. B. Watson - Continental Oil Company
Dr. C. L. Miller - U.S. Department of Energy
Mr. J. McHugh - British Gas Corporation
Dr. D. Hebden - British Gas Corporation
Dr. H. Vierrath - Lurgi Kohle und Mineraloeltechnik

Designates:

Mr. C. E. Fink - Continental Oil Company

In Attendance:

Mr. J. E. Scott - British Gas Corporation

Secretary:

Mr. E. F. Aul, Jr. - Continental Oil Company

2. ATTENDANCE

Mr. W. B. Carter will take Mr. Fink's place as a designate to future TSP meetings.

Mr. Aul acted as secretary for TSP 4 due to the absence of Mr. M. R. Tooley from BGC.

3. MINUTES OF TSP-3 MEETING

The minutes of TSP-3 were distributed for approval. No corrections to the minutes were voiced. The minutes stand approved as submitted.

4. REVIEW OF RUN 1 RESULTS

The operating history of Run 1 was reviewed by Mr. Fink:

(a) Start-up for the Run began on 17 August. Steam and oxygen were introduced to the gasifier at 1107 hours. The gasifier was brought to planned conditions (160,000 SCFH O_2, 1.35 steam/O_2) and allowed to run at these conditions for 48 hours.

(b) During the next 10 hours, blast furnace slag (BFS) was added to the gasifier at a rate of 15 weight %, based on coal feed rate. Minor problems were initially encountered with the flux feed system to the coal lock but these were easily overcome, allowing the feed system to operate satisfactorily for the remainder of the run.

(c) Reduced load trials established the minimum stable load at 122,000 SCFH O_2 at 1.35 steam/O_2. Since gasifier operation at this loading was slightly irregular, the O_2 rate was increased to 130,000 SCFH.

(d) During the remaining 16 hours of operation, operating variables were systematically adjusted to achieve the desired conditions for Ohio No. 9 feed: 130,000 SCFH O_2, 1.15 steam/O_2, and 15% BFS addition.

(e) Post run inspection showed some slag deposits on the walls of up to 2 inches thickness. Slag deposits were observed as high as 8 feet above tuyeres. This slag was easily chipped away, however, maintaining the physical integrity of the gasifier lining. No mechanical problems were noted during post-run inspection.

5. <u>REVIEW OF ADMINISTRATIVE REPORTING</u>

Dr. Sudbury summarized administrative reporting to date:

(a) Continental Oil Company has submitted a proposed run schedule for the TSP. No formal approval for this schedule has been received from DOE.

(b) Prior to each run, a run program is written by Mr. Fink based on the proposed run schedule and discussions with Dr. Vierrath and Dr. C. T. Brooks of BGC. This program is approved by Continental Oil Company, Library, and is submitted to BGC as a guide to the next run. Copies are submitted to all committee members.

(c) Dr. Sudbury suggested that formal discussions between BGC, Continental Oil, and Lurgi on-site personnel should take place before the run report is distributed. It may be possible to submit a draft of the BGC run report to Mr. Fink and Dr. Vierrath for their comments. Mr. Scott objected that these procedures might hamper BGC's ability to write and distribute the run report within the 30 days limit called for in the TSP agreement. Mr. McHugh stressed that the report should be BGC's statement of the incidents and results of each run, as called for in the agreement. Dr. Miller stated that DOE must have a single document which represents the consensus opinion of the parties involved and that majority and minority reports could not be tolerated. Dr. Sudbury deferred further discussion on the matter.

Mr. Scott stated that mechanical failures will be reported in incident reports appended to the run reports.

6. REVIEW OF RUN 2 RESULTS

Mr. Fink reviewed the events of Run 2:

(a) Start up for Run 2 commenced on 7 September. After a 4 hour start up period and 16 hour lineout period on Frances coal, O_2 feed to the gasifier was lost due to a rupture at the interstage cooler of the air compressor.

(b) Mr. Scott stated that during initial moments of stand-by, steam flow to the gasifier may not have been immediately halted due to lack of communication between oxygen plant and gasifier control room.

(c) After returning from stand-by, one tuyere went black and gas flow down the tuyere was turned off.

(d) Conditions were re-established at 130,000 SCFH O_2 and 1.15 Steam/Oxygen. Ohio No. 9 coal was charged to the bunker at 1148 hours on 9 September. Noticeable changes occurred in the gasifier 1 1/2 hours later in the form of erratic bed ΔP and an increase in slag tapping frequency. Gasifier performance improved slightly with continued operation. At 0300 on 9 September, No. 1 tuyere went black. This tuyere was turned off although gas flow down the tuyere was still evident. Smooth operation continued from 0400 to 0900 when slag tapping became more erratic. At 1030, slag ceased flowing from the tap hole. At this point, the gasifier was shut down and Run 2 terminated.

(e) Post run inspection of the slag quench chamber showed that a layer of slag had built up across the quench ring. Some slag was also found on the sides of the vessel above the quench ring and on the underside of the burner.

(f) In general, Run 2 was encouraging since no major problems were encountered with caking coal in the upper section of the bed nor were extreme offtake temperature excursions observed. Pressure drop across the bed was slightly higher than that than that observed with Frances coal and more erratic. Slag tapping control was reasonably good until the very end of the run. Both Dr. Vierrath and Mr. R. Kohlen of Lurgi were pleased with gasifier performance for the run.

(g) Mr. Watson inquired about the concentration of dissolved solids in the quench water recirculation system. No data are being taken at the time. Mr. Scott said he would look into the matter if he receives a written request from Mr. Fink.

7. COAL SUPPLIES

(a) Mr. Scott stated that 9,000 tons of Ohio No. 9 coal had arrived at Westfield in August. Of this quantity, 3,000 tons had been screened to yield 1,000 tons in the desired size range. The off-size material was divided into 1,500 tons of fines (-5/8") and 500 tons of oversize (+2"). Mr. Scott felt the yield of 1/4" x 2" fraction from the remaining 6,000 tons on site would amount to nearly 4,000 tons. If the same yield is obtained from the second shipment of 9,000 tons of Ohio No. 9 coal, the total amount of coal suitable as gasifier feedstock will be 11,000 tons. Mr. Scott said this supply would be adequate to maintain operation as scheduled to the end of 1977, but not beyond.

(b) Dr. Sudbury stated that the Ohio No. 9 coal size as shipped from the U.S. was not as desirable as hoped. He asked for additional data that relate coal size to ash content. Dr. Sudbury inquired as to capabilities on site at Westfield for crushing oversize coal. Mr. Scott stated that no facilities were available at present but that BGC would look into the matter.

8. PLANT MODIFICATIONS

(a) Mr. Scott stated that the continuous O_2 and CO_2 analyzers had been commissioned for Run 2. The analyzers sampled the make gas stream at a point between the waste heat boiler and demister. Both analyzers worked for several hours during the run before plugs developed in the sample line. The sampling system will be modified before the next run to eliminate these plugs.

(b) Mr. Scott reported that the present flux feeding system performed adequately during Run 1 and Run 2. For plant reliability reasons, however, it would be desirable to install a duplicate flux system as back-up to the first. This system could also be used to add fines or coke to the gasifier, if desired.

Total cost of the duplicate system was estimated by Mr. Scott to be near £3,000. Dr. Sudbury instructed Mr. Scott to send him a request for procurement which will be forwarded to DOE for approval.

(c) Mr. Scott discussed Lurgi's recommendations that non-caking coal be fed to the gasifier during stand-by operation. To do this, a divider will have to be inserted in the coal bunker. Mr. Scott estimated the cost of such a divider at approximately £10,000. Dr. Sudbury instructed Mr. Scott to send him a request for procurement which will be forwarded to DOE for approval.

(d) Mr. Scott reported that insurance inspectors, British Engine, had refused to accept the BGC design for the O_2 preheat system. The preheater will not be available until Run 5.

9. <u>OBJECTIVES FOR RUN 3</u>

(a) Mr. Fink reported that the run schedule called for the use of wide-sized Ohio No. 9 coal and limestone as the fluxing agent in Run 3. He recommended the same start-up procedure as used for Run 2. After the system has lined out, he recommends that wide-size Ohio No. 9 coal be introduced to the gasifier fluxed with BFS. After the system has achieved steady operation, limestone will be substituted for BFS and the flux ratio ranged to identify optimum operation.

(b) Dr. Hebden stressed the need to range the steam/O_2 ratio with Ohio No. 9 coal. He stated that this secondary objective had not been accomplished during Run 2 because of the forced shut-down.

(c) Dr. Miller stated that the primary objectives of this TSP are to demonstrate the operability of the slagging gasifier using Ohio No. 9 coal and limestone. Since operation with Ohio No. 9 coal was demonstrated during Run 2, Run 3 should be planned to demonstrate the use of limestone as flux.

(d) Dr. Sudbury stated that the ranging of steam/O_2 ratio should be a secondary objective for Run 3 and primary objective for Run 4. The final decision as to primary objectives of Run 3 will be delayed until 19 September.

10. AD HOC COMMITTEE REPORTS

(a) Mr. Scott reported that the Lurgi drawing for a metal liner in the top section of the gasifier had been received by him on 13 September, 1977. A contractor had been contacted to estimate the cost, time requirements and practicality of the installation. Mr. Scott estimated that liner installation would cost up to £50,000 and require one month of downtime. Mr. Scott stated that the drawings would be submitted to insurance inspectors and competitive bids obtained for construction. Dr. Vierrath stated that he would like to wait until after Run 3 before making recommendations for metal liner installation.

(b) Mr. Scott summarized the work that has proceeded on the proposed fines injection system. A process flow diagram of the system designed by BGC was tabled. A 200 ton storage bunker has been constructed in place, but remains to be insulated. The feed hopper has been fabricated and located in place. The remaining work includes fabrication and erection of the lock hopper and piping. Approximate cost of remaining construction and commissioning was estimated by Mr. Scott at £50,000. Mr. Fink expressed reservations about the capacity of the current design and the ability to control the injection rate. Dr. Miller offered to forward operating reports for the fines injection system installed at the BIGAS coal gasification pilot plant.

(c) Mr. Scott stated that recommendations for installation of additional thermocouples in the gasifier had been received from D. Edwards of Continental Oil Company and D. Lightower of BGC. Mr. Scott felt the installation would be feasible but would require 3 weeks of downtime and cost approximately £10,000.

11. TIME PERIOD FOR TSP

The Committee supported the recommendation of Dr. Sudbury to request a 4 month extension to the Program. Specific recommendations for this time period will be drawn up on 19 September, 1977, and submitted to Mr. J. R. Bowden for his use in negotiations with DOE.

E. F. Aul
Acting Secretary

15th September 1977

MINUTES OF WESTFIELD TECHNICAL SUPPORT PROGRAMME COMMITTEE MEETING NO. 5

Place: Westfield Development Centre, Cardenden, Scotland

Date: October 12, 1977

1. PRESENT

Members:

Dr. J. D. Sudbury - Continental Oil Company
Dr. C. L. Miller - U.S. Department of Energy
Mr. J. McHugh - British Gas Corporation
Dr. D. Hebden - British Gas Corporation
Dr. H. Vierrath - Lurgi Kohle und Mineraloeltechnik

Designates:

Mr. W. B. Carter - Continental Oil Company
Mr. C. E. Fink - Continental Oil Company

In Attendance:

Mr. J. E. Scott - British Gas Corporation

Secretary:

Mr. M. R. Tooley - British Gas Corporation

2. MINUTES OF TSP 4

These were approved.

3. CONTRACTUAL MATTERS

(a) Mr. McHugh raised the question of the termination of the Westfield TSP contract on 31 March 1978. Although he recognized that contractual matters were outside the scope of the Committee, Mr. McHugh went on to express the concern that existed within BGC following the receipt of a copy of the DOE letter terminating the contract without any indication as to why this action was being taken. Although Continental Oil Company and DOE had previously expressed their satisfaction regarding progress of the TSP, BGC were not to know if the reason for DOE's action was financial, political or dissatisfaction with the programme. It appeared that the DOE action was also taken prior to any consideration of the recommendation for an extension of contract made at the last meeting of the Programme Committee.

(b) The Chairman then also made reference to the previous decision of the Programme Committee to propose a four months extension of the contract. It was noted that Mr. J. R. Bowden had written to DOE proposing a two month extension to the contract. Dr. C. L. Miller had proposed a three month extension. The Chairman stated that the DOE decision to allow no extension of the contract was made on budgetary considerations only and was brought about by the fact that DOE would not decide until the 1 July 1978 as to which gasification process to follow. The choice lay between a process being developed by the Illinois gas project and the BGC/Lurgi based project.

(c) Mr. McHugh asked that all concerned should be made aware of the difficulty that BGC faced with respect to labour relations on the site and that any decision to extend the contract may now be the subject of fresh negotiations - he stated that BGC could not operate a unit such as Westfield on a possible "stop-go" policy by DOE.

[illegible]. <u>REVIEW OF UNFINISHED ACTION ITEMS</u>

(a) <u>O_2 and CO_2 Analyzers</u>

Minor modifications were made to the sampling system to these instruments prior to Run 3 during which both instruments operated satisfactorily. Costs would be approximately as per budget estimates.

(b) <u>Oxygen Preheater</u>

Following problems with the insurance company on the original design, the preheater had been redesigned and verbal approval had been obtained from the insurers. The materials are on order and the unit should be available for Run 5. Conoco asked that the unit be available at the earliest opportunity.

(c) <u>Additional Thermocouples</u>

Work on the installation of four extra thermocouples was proceeding following approval by Continental Oil Company of the estimated expenditure of £3,000. A further cost of £10,000 would be required to provide extra branches allowing more thermocouples to be fitted. The installation time for this work would be about three weeks. The meeting accepted the desirability of this work and asked that it proceed.

(d) Duplicate Flux Addition System and Coal Bunker Divider

Approval had been received from Continental Oil Company to proceed with this work and materials were on order. It was anticipated that the modifications would be installed following Run 4 and should be ready for use on Run 5. Installation time was approximately two weeks.

(e) Crusher for Oversize Coal

Two crushers have been found on the site and these will be utilized at minimal cost.

(f) Fines Injection System

The cost of the outstanding work on this sytem was approximately £50,000 and the work would take three months to complete. These estimates were approximate and could well be exceeded as designs proceeded. A draft proposal had been produced on site and would be circulated for comment. It was noted that a decision must be taken at the next meeting of the Programme Committee as to whether this modification was to be pursued.

(g) Coal Shipment

Ohio No. 9 coal is available in the USA for a third shipment. This will be required on site during January 1978. The shipment must, therefore, be made during December 1977 and it was noted that a coal miners strike was due to begin 6 December 1977 with an anticipated duration of six weeks. The shipment of Pittsburgh No. 8 coal could be made with the third shipment of Ohio No. 9 coal and a decision would require to be taken on this matter before the next Programme Committee Meeting.

(h) New Liner

Dr. Vierrath stated that a modified drawing had been forwarded to BGC who had submitted the details to their insurers and had obtained a total budget price for this work of about £50,000. Lurgi stated that a new design of liner was now recommended and that this design would be submitted before the next meeting of the Programme Committee thereby enabling British Gas to supply estimates of cost and time required to implement the new design. These estimates would be provided at the next Programme Committee Meeting.

(i) Lurgi/BGC Modifications Following Run 3

Six modifications were recommended by Lurgi/BGC following experiences gained during Run 3. All these modifications have been completed with the exception of the following two items:

i) Nitrogen Purge

This would cost approximately £5,000 and the money should be available within the existing budget. It was noted that experience gained with this system would be useful in evaluating the use of CO_2 on the demonstration plant.

ii) Hydraulic Drive

The estimate for this work was £10,000 and it was generally accepted that the modification was required in order to improve shortcomings with the existing drive mechanism which were highlighted during Run 3. Lurgi would write to BGC indicating the advantages of the new type of drive and BGC would forward a justification to Continental Oil Company.

5. RUN 1 REPORT

This had been received and Conoco stated that it was satisfactory in all respects.

6. RUN 2 REPORT

A preliminary copy of Category 1 analytical data had been received. The Run report was complete and would be distributed on programme.

7. RUN 3 RESULTS

The reasons for the shutdown of the plant during Run 3 were discussed. Subsequent examination of the gasifier internals showed that it was due to one of three causes and actions to prevent a repetition of the problems encountered were agreed.

8. OPTIONS FOR RUN 4

(a) Dr. Hebden proposed the following procedure for Run 4:

Start up on Frances coal and establish settled conditions at 130,000 SCFH oxygen and 1.35 steam/oxygen ratio.

Change to Ohio No. 9 coal fluxed with dolomite or limestone.

Range and optimize first the steam/oxygen ratio and then the load. Run the gasifier under the resultant optimized conditions to prove stability and then shutdown.

In the event of an upset, a load reduction procedure should be followed, i.e., reduce load to about 80,000 SCFH oxygen as quickly as possible and then restore the load again as quickly as possible while always retaining full control over rates, pressures, etc.

In the event that this procedure is not successful, the plant should be shutdown and the gasifier examined.

Continental Oil Company agreed that the above procedure was compatible with their thoughts on the subject.

(b) Following discussion on the fluxing arrangements to be adopted for Run 4, the following procedure was suggested:

Start up should be on Frances coal with blast furnace slag. The flux should be changed to limestone coincident with the admission of Ohio No. 9 coal. Messrs. Scott and Fink were asked to finalize details of the scheme which would accomplish this changeover as quickly as possible without upsetting the gasifier. A time of three lock hoppers was proposed for the changeover to occur.

(c) Final details for Run 4 will be prepared by Continental Oil Company for submission to BGC.

9. REVISIONS OF TSP RUN SCHEDULE

Reference was made to the Run programme attached to the DOE letter of 24 August 1977. This programme indicated that Run 11 would be carried out in order to evaluate fines injection. It was agreed that if it were necessary to omit any Runs, then Run 11 should be cancelled.

Dr. Miller proposed that if a further reduction in the number of Runs were necessary, then Runs 8 and 9 (evaluation of the second coal) be omitted in order to maximize information obtained on Ohio No. 9 coal.

The need to omit the use of Frances coal for start up was noted and it was agreed that this could be done following the first successful Run on Ohio No. 9 coal.

The Run programme would be modified by Continental Oil Company and resubmitted at the next Programme Committee Meeting.

With respect to Run 10, it was noted that modifications may be needed to the tar injection system in order that this aspect may be fully evaluated during this Run. Mr. Scott was asked to submit a paper for presentation at the next meeting detailing the modifications together with costs which he thought to be necessary.

10. ANALYTICAL ITEMS

(a) Storage and Handling of Slag

The Chairman referred to two areas which were giving cause for concern with respect to slag handling and storage.

i) Leaching of substances out of slag during storage.

ii) The provision of additional analytical information on sulfur and solids concentrations in the slag quench water.

The Chairman agreed to write to BGC requesting additions to the existing analytical schedule together with an indication of what leaching tests are required on the slag.

(b) The Chairman stated that information is also needed on the phenol content of the waste water. Following discussion on the ways in which this information could be provided, Dr. Hebden drew attention to an existing programme operated by IEA which evaluates dephenolation and biological degradation of the waste water.

The Chairman agreed to write to Mr. Scott detailing specific requests for data.

(c) Iron and Nickel Carbonyl

Continental Oil Company asked if these could be added to the analytical schedule for offtake gases.

(d) Iron

Continental Oil Company requested that a distinction is made between elemental and combined iron in the analytical schedule.

11. NEXT MEETING

This is scheduled for Thursday, 3 November 1977 at 0930 hours at the O'Hare Inn, Chicago.

M. R. Tooley
Secretary

21 October 1977

MINUTES OF WESTFIELD TECHNICAL SUPPORT PROGRAMME COMMITTEE MEETING NO. 6

Place: Ramada O'Hare Inn, Chicago, Illinois

Date: November 3, 1977

1. PRESENT

Members:

Dr. J. D. Sudbury - Continental Oil Company
Mr. W. B. Watson - Continental Oil Company
Dr. C. L. Miller - U.S. Department of Energy
Mr. J. McHugh - British Gas Corporation
Dr. D. Hebden - British Gas Corporation
Dr. P. Rudolph - Lurgi Kohle und Mineraloeltechnik
Dr. H. Vierrath - Lurgi Kohle und Mineraloeltechnik

Designates:

Mr. C. E. Fink - Continental Oil Company
Mr. G. P. Curran - Continental Oil Company

In Attendance:

Mr. J. E. Scott - British Gas Corporation

Secretary:

Mr. M. R. Tooley - British Gas Corporation

2. MINUTES OF TSP 5

The Minutes which were distributed on 21 October 1977 were accepted.

3. REVIEW OF UNFINISHED ACTION ITEMS

(a) Oxygen Preheater

Mr. Scott stated that further problems had been experienced with the insurers but approval had now been received for the work to proceed. This delay would result in the preheater being available for Run 6 and not Run 5 as previously anticipated.

(b) Additional Thermocouples

Mr. Scott reported that material procurement, design and the necessary approval had all been obtained - installation as originally envisaged can therefore proceed. It was agreed to delay installation of thermocouples until major refractory repair to the shaft was needed. The present glazed refractory surface is in good condition and there is therefore a reluctance to disturb it. Installation of the metal liner (see 3 (f) below) has again been delayed and has no bearing on the thermocouple addition.

(c) Duplicate Flux Addition System

This work was proceeding and the anticipated completion date was Sunday, 6 November 1977.

(d) Coal Bunker Divider

This work should also be complete by Sunday, 6 November 1977.

(e) Hydraulic Drive for Stirrer

Mr. Scott reported that a quotation had been received from Lurgi. This indicated a price for the Lurgi equipment of DM 33,600 and a maximum delivery time of four weeks. BGC estimated that the total price for the complete installation would be £10,000.

Justification for the installation of this equipment would be forwarded to BGC by Dr. Vierrath during week commencing 7 November 1977.

(f) New Liner for Gasifier

A telex had been received from Lurgi, the contents of which were summarized by Dr. Vierrath who stated that the short liner design had been withdrawn in view of experience gained on Runs 2 and 4. There is insufficient information available to date to enable the design for the second liner to be completed. In view of the time required to install the new liner, further design work should await a decision to extend the programme.

(g) Proposal for Phenolic Waste

A letter is awaited from the Chairman to Mr. Scott detailing specific requirements for the data required.

(h) Fines Injection System

As requested at the last meeting, Mr. Scott presented a report to Committee Members giving proposed details of the anticipated system. Committee Members were asked to comment to Mr. Scott on these proposals.

(i) Coal Shipment

Mr. Watson reported that invitations to tender had been issued by Continental Oil Company for the procurement of 6,500 tons of Pittsburgh No. 8 coal. Tenders would be received on the 14 November and a decision would then be made on whether this coal would be shipped to Westfield.

It was noted that further supplies of Ohio No. 9 coal were available for shipment.

It was also noted that the maximum capacity of the harbour facilities at Leith were 18,000 long tons.

In answer to a query, Mr. Scott stated that facilities are available on site to stock further shipments of both Ohio No. 9 and Pittsburgh No. 8 coals. Mr. Scott asked if preparation of coals prior to the next shipment could be improved in so far as screening and blending were concerned.

(j) Tar Injection System

As requested at the last meeting, Mr. Scott presented a paper to Committee Members which gave details of a proposed system for the injection of tar at the tuyeres. Continental Oil Company, DOE, and Lurgi were asked to comment to Mr. Scott on this paper. Mr. Scott indicated that work was proceeding with the installation of equipment as detailed in the paper.

4. STATUS OF RUN REPORTS

(a) Run 2 Report

The general reports had been issued on schedule as required. Continental Oil Company expressed their satisfaction with these reports.

(b) Run 3 Report

Reports are essentially complete and will be distributed as per programme during week commencing Monday, 7 November 1977.

5. RUN 4 RESULTS

Mr. Scott gave a brief summary of events leading up to the termination of this Run. Problems were experienced at an early stage with burner operation and with slag-tap DP. The Run proceeded through flux addition, changeover to Ohio No. 9 coal and flux changeover. The burner problems and trouble with slag handling resulted in a premature shut down of the gasifier after running for 11 1/2 hours on Ohio No. 9 coal and 9 1/2 hours on limestone flux. No problems were experienced with the distributor.

The post mortum examination of the gasifier internals had shown damage to the slag-tap, but no indication as to what had caused the burner problems. The slag-tap would be changed prior to the next Run.

6. OPTIONS FOR RUN 5

Mr. Fink presented a programme for Run 5. The programme was discussed and BGC were asked to consider the implications of the proposals contained therein especially with respect to the effect of the size limitations of Ohio No. 9 coal and the limestone flux. Mr. McHugh requested an indication of the maximum acceptable delay in start up in view of the change in coal and flux sizes. The Chairman stated that a delay of one day would be acceptable - BGC stated that they would immediately put in hand the necessary investigation to assess any likely delay.

7. REVIEW OF TSP RUN SCHEDULE

A revised Run programme dated November 1, 1977 (copy attached) was distributed by Continental Oil Company. The programme was based on the decisions taken at the last meeting to omit the original Fines Injection Run and the two Runs on the second coal.

This revised programme would be submitted to Mr. Bowden for possible editing and forwarded to DOE.

Dr. Vierrath stated a preference by Lurgi to select Illinois coal as the second coal rather than Pittsburgh No. 8 coal.

8. METHACOAL PROJECT

Mr. Watson reported that the Keller Corporation had offered a system of using methanol as a means of transporting the fines to be injected. The Chairman indicated that this work would be carried out on the Demonstration Plant.

9. FINES BRIQUETTING

In answer to a query by Dr. Miller, Mr. Watson stated that an evaluation of this subject was included in the statement of work and any experimental work that may be required will evolve from Task XII studies.

M. R. Tooley
Secretary

PROPOSED REVISED TECHNICAL SUPPORT PROGRAM
August 1977 through June 1978

Attachment for TSP-6 Minutes

Run No.	Begin	End	Duration Days	O_2 Load MSCFH	H_2O/O_2 Ratio	Coal Feed	Flux	Goal	Results	Run Report Issued
1	17 Aug	21 Aug	4	160-122	1.35-1.15	Frances 1 x 5/8	None, BFS	Verify integrity of refurbished Westfield gasifier by operating at standard conditions using Frances coal. "Dress rehearsal" for feeding Ohio 9 coal.	All goals accomplished.	9/28/77
2	7 Sept	9 Sept	2+	130	1.15	Ohio 9 1 x 5/8	BFS	Demonstrate an operation of the slagging gasifier using Ohio 9 coal as feedstock and blast furnace slag as flux. Although conditions will not be optimized, detailed data will be obtained.	1. Operability shown for 22.7 hrs. with Ohio 9 and BFS as flux. 2. Excellent slag removal, moderate temperature excursion. 3. Run lost due to slag buildup in Quench Chamber.	10/26/77
3	27 Sept	28 Sept	1	130	1.15	Ohio 9 1-3/4 x 1/2	BFS	a. Effect of wide size range Ohio 9. b. Eliminate slag buildup in Quench. c. Use of limestone as flux. d. Effect of flux rate. e. Effect of steam/O_2.	1. Bed instabilities with Ohio 9 and BFS flux. 2. Run lost due to massive caking and loss of distributor drive. 3. Limestone addition not tried.	
4	19 Oct	20 Oct	1	130-180	1.05-1.60	Ohio 9 2 x 1/4	Limestone	a. Eliminate slag buildup in Quench. b. Effect of limestone. c. Effect of flux rate. d. Effect of steam/O_2. e. Effect of O_2 load. f. Evaluate load reduction as means of maintaining bed stability during period of upset.	1. Poor burner operation led to erratic tapping with Frances coal. 2. Slag buildup severe. 3. Limestone addition accomplished for 10 hours. 4. Load reduction to stabilize bed shown effective. 5. Slag pool in hearth very viscous. Probably steam/O_2 too high. 6. No problems in distributor drive.	
5	8 Nov	11 Nov	4	130 Range	1.25 Range	Ohio 9	BFS Limestone	a. Select operable steam/O_2 and load condition for Ohio 9 with BFS. b. Add limestone as flux.		

Attachment for
TSP-6 Minutes

PROPOSED REVISED TECHNICAL SUPPORT PROGRAM
August 1977 through June 1978

Run No.	Begin	End	Duration Days	O_2 Load MSCFH	H_2O/O_2 Ratio	Coal Feed	Flux	Goal	Results	Run Report Issued
6	28 Nov	2 Dec	4	Range	Range	Ohio 9	Limestone	a. Startup on blast furnace coke. b. Optimize steam/O_2, load, and limestone flux addition rate.		
7	19 Dec	23 Dec	4	Range	Range	Ohio 9	Limestone	Maximum load run.		
8	14 Jan	18 Jan	4			Ohio 9 2 x 1/4 + fines	Limestone	Determine maximum allowable fines content for processing Ohio 9 coal.		
9	9 Feb	20 Feb	10			Ohio 9 2 x 1/4 + fines	Limestone	Demonstrate long term steady state operation at conditions determined in 2 through 7 above.		
10	1 Mar	4 Mar	4			Ohio 9 2 x 1/4 + fines	Limestone	Operate gasifier to solve critical problems as defined by the engineering subcontractors.		
11	20 Mar	23 Mar	4			Ohio 9 2 x 1/4 + fines	Limestone	Evaluate introduction of liquid fuel (e.g. tar) through the tuyeres.		
						RUNS SUSPENDED DUE TO DECISION NOT TO EXTEND PROGRAM BEYOND MARCH 31, 1978				
12	April		4			2nd Coal 2 x 1/4	BFS Limestone	Demonstrate operability using a second Eastern U.S. coal as feedstock and obtain yield data.		
13	May		4	130-180	1.05-1.60	2nd Coal 2 x 1/4	Limestone	Evaluate effects of steam and O_2 rates on performance of second coal.		
14	June		4			Ohio 9 2 x 1/4 + fines per Run 8	Limestone	Conditional on results of 8 above evaluate alternate means of feeding fines to the gasifier (e.g. through tuyeres).		

MINUTES OF WESTFIELD TECHNICAL SUPPORT PROGRAMME COMMITTEE MEETING NO. 7

Place: Westfield Development Centre, Cardenden, Scotland

Date: December 7, 1977

1. PRESENT

Members:

Dr. J. D. Sudbury - Continental Oil Company
Mr. W. B. Watson - Continental Oil Company
Dr. C. L. Miller - U.S. Department of Energy
Dr. P. Rudolph - Lurgi Kohle und Mineraloeltechnik
Dr. H. Vierrath - Lurgi Kohle und Mineraloeltechnik
Dr. D. Hebden - British Gas Corporation

Designates:

Mr. P. Faulkner - British Gas Corporation
Mr. C. Fink - Continental Oil Company

In Attendance:

Mr. J. E. Scott - British Gas Corporation
Mr. U. Marwig - Lurgi Kohle und Mineraloeltechnik

Secretary:

Mr. M. R. Tooley - British Gas Corporation

2. APOLOGIES

Apologies were received from Mr. McHugh.

3. INTRODUCTORY REMARKS

The Chairman referred to a meeting held on 23 November 1977 between DOE and Continental Oil Company at which Mr. Lloyd of DOE stated that a decision will be made by DOE in June 1978 between the Illinois group project and the BGC/Lurgi based project. DOE have yet to announce the final date by which all information and data are to be presented to them for consideration in deciding which of the two projects are to be selected for further development.

Continental Oil Company presented BGC's proposals to DOE for extending the Westfield TSP. DOE are required to make a decision on these proposals by 31 December 1977. The option of extending the TSP to May 1978 is available to meet the anticipated June date imposed by DOE for the presentation of information.

DOE stressed the importance of obtaining a prolonged satisfactory run at Westfield on Ohio No. 9 coal and also the need to carry out test runs on a second U.S. coal in addition to Ohio No. 9.

4. MINUTES OF TSP 6

The minutes which were distributed on 17 November 1977 were agreed and accepted.

5. REVIEW OF UNFINISHED ACTION ITEMS

(a) Oxygen Preheater

Mr. Scott reported that this item was being fabricated. Designs had been cleared by the Insurance Company and the unit was due to be installed on site by 16 December 1977.

The Chairman stressed the importance of this item stating that DOE had indicated that Run 7 should not be commenced until the preheater had been installed and was ready for use.

(b) Hydraulic Drive for Stirrer

Continental Oil Company had telexed BGC agreeing to the expenditure of approximately £10,000 for the purchase from Lurgi and the installation of this equipment which had been despatched to the UK and should be installed by 16 December 1977.

(c) Phenolic Waste Studies

The Chairman tabled Letter No. CC-4022 from R. E. Schlessman to J. D. Sudbury (copy attached) detailing information required on this subject. Approaches to Panhandle Eastern had indicated that for about $125,000, Continental Oil Company would be given reports of Panhandle's researches in this field - negotiations are still proceeding.

A programme at BGC London Research Station (LRS), Sponsored by IEA was discussed. This programme includes a pilot sized phenosolven plant at Westfield which will treat phenolic streams from the gasifier and submit samples to LRS for biological degradation studies, it is suggested that this programme should include at least 1 run developing data needed by the Demonstration Project. Mr. Kelly James, EPA (USA) agrees to support this position. Dr. Hebden is to arrange for Dr. Sudbury to visit appropriate LRS personnel on 10 January 1978.

In addition, the Chairman will write to J. D. Sudbury and P. Rudolph to solicit any further proposals for developing adequate process design for disposing of phenolic waste.

(d) Coal Shipment

Mr. Watson reported that 5,000 tons of Ohio No. 9 and 5,000 tons of Pittsburgh No. 8 coal were in Baltimore awaiting shipment which would be carried out by a U.S. carrier. The SS Yellowstone had been selected and this was due at Baltimore on 18 December 1977 to commence loading. The cost of shipment would be $49 per ton.

(e) Liquid Fuel Injection

Responses were awaited on the paper presented by Mr. Scott at the last meeting.

6. REPORT ON RUN 3

Reports on this Run have been circulated as required. The Chairman expressed both Continental Oil Company's and DOE's satisfaction with these reports.

7. RESULTS OF RUN 5

Mr. Scott reported that analytical data was available for issue.

Mr. Fink summarized the Run which consisted of 11 hours on Frances coal followed by 7 hours on Ohio No. 9 coal. Problems were then experienced with tuyeres and difficulty in slag tapping. The feedstock was changed to Frances coal which ran satisfactorily for 3 hours at which time the change was again made to Ohio No. 9 coal which ran steadily for a further 6 hours when a load increase led to problems with tuyeres and slag tapping. After a further period of 6 hours, the feedstock was changed over to Frances coal and 35 minutes later the run was terminated due to problems within the gasifier.

Subsequent inspection of the gasifier internals revealed a column of coke in the centre of the gasifier together with damage to some gasifier internal equipment.

8. PROGRAMME FOR RUN 6

The programme to run for two days on Frances coal was completed at 2100 hours on 6 December 1977 when the feedstock was changed to Ohio No. 9 coal. At 0400 hours on 7 December 1977 problems with tuyeres and slag tapping necessitated a change back to Frances coal. Ohio No. 9 coal was again charged at 12 Noon on 7 December 1977 and the run was continuing on Ohio coal at the termination of the meeting.

In considering the possible causes of problems encountered when running on Ohio No. 9 coal, Mr. Rudolph suggested that the main problem was due to intermittent flow of coal down the gasifier shaft. It was suggested that it may ultimately be possible to cope with this by stirrer modifications.

Dr. Hebden agreed that uniform distribution of coal and gas and steady descent of fuel down the gasifier were essential to good gasifier operation and went on to say that the solution to the problem could lie in varying operating parameters. Dr. Hebden added that sufficient time was obviously not available for an evaluation of these possibilities.

Mr. Scott stated that further detailed discussion did not appear to be meaningful until the results of the current run (No. 6) had been evaluated.

9. REVISION OF TSP SCHEDULE

A revised Run schedule was presented to the meeting by the Chairman (copy attached). It was pointed out that this schedule did not make provision for a Run before Christmas as it was thought that Lurgi may need time to effect mechanical changes to the gasifier. Lurgi agreed that no mechanical changes were now envisaged and consequently, a Run before Christmas was a distinct possibility. Mr. Scott agreed that this was acceptable depending upon the findings following Run 6.

The Chairman asked that BGC, Lurgi and Continental Oil Company agree the goals for Run 7 as soon as Run 6 was evaluated.

Lurgi was asked to prepare a design only for a modified Stirrer/Distributor which would result in improved decent of fuel down the gasifier shaft.

10. DEWATERING OF SLAG AND COAL/FLUX MIXING

The Chairman tabled two letters - FC-162 and a memo from W. B. Carter to J. D. Sudbury, dated 14 November 1977 (copies of both are attached) and stated that Mr. Fink would be writing to Mr. Scott on these subjects.

11. IRON/WATER INTERACTION IN THE QUENCH CHAMBER

In reply to a question from Mr. Watson, Dr. Hebden stated that formation of hydrogen in the quench chamber by the interaction of iron and water was theoretically possible but hydrogen had not been detected.

12. BURNER FLAME TEMPERATURE

Mr. Watson was asked to submit a request for this information in writing following the agreed contractual procedure.

13. ANALYTICAL DATA

A full inventory of Category 2 data had not yet been obtained due to the limited time which had been available on Ohio No. 9 coal at steady operating conditions. In future, every effort would be made to obtain a full set of Category 2 data as soon as possible.

14. DATE OF NEXT MEETING

The next meeting will be held at Westfield on 11 January 1978.

M. R. Tooley
Secretary

CONOCO

Attachment 1
for TSP-7 Minutes

Interoffice Communication

To Dr. John D. Sudbury, Library, PA

From R. E. Schlessman, Ponca City, OK

Date December 1, 1977

Subject Letter No.: CC-4022
Conoco Job No.: ERDA-2542
Task IX: Biological Treatment Design Support Information

In reply to your telecon request for the laboratory data needed to establish parameters for designing the Demonstration Plant biological oxidation treatment facility, the following is submitted:

Wastewater from the gasifier overhead quench pot, treated to equal the effluent from a Phenosolvan unit, will be analyzed as follows:

1. Characterize the sample, i.e., BOD, COD, TOC, pH, TDS, TSS, chlorides, phenols, NH_3, etc.

2. Run bio-treatability studies to determine its bio-treatability.

3. To establish design parameters for the biological oxidation facility, we will need residence time, sludge coefficience, oxigenation requirements, temperature coefficient, removal rate constant (kinetics).

4. If laboratory analytical capabilities exist, powdered activated carbon addition to the bio-reactor should be tested.

5. Characterize effluent similar to the feed sample.

6. Investigate tertiary treatment of the biologically treated sample, assuming it is required. Carbon column testing or carbon isotherm tests, if facilities for column testing are not available, are preferred for the tertiary treating tests. Additional ozonation or other tertiary treating tests which the laboratory are equipped to perform, would be nice to have if not too costly.

7. If money available, test the effluent for metals and define the organic content by GCMS. Otherwise, use bio-assay toxicity tests at several dilutions.

8. If the work can be done by IEA, we would want a detailed outline of the work they would do and the analytical methods to be used, in order to relate the data received to our regulatory or design constraints, which may require some modification of their program or test procedure.

R. E. Schlessman
Senior Process Engineer
Design Division
Process Engineering Department

mdn
CC: AJM
W. B. Watson, Stamford, Connecticut
W B. Carter, Stamford, Connecticut

Attachment 2 for TSP-7 Minutes

TECHNICAL SUPPORT PROGRAM
August 1977 through March 1978

Run No.	Begin	End	Duration, Days	O_2 Load MSCFH	H_2O/O_2 Ratio	Coal Feed	Flux	Goal	Results	Run Report Issued
1	17 Aug	21 Aug	4	160-122	1.35-1.15	Frances 1 x 5/8	None BFS	Verify integrity of refurbished Westfield gasifier by operating at standard conditions using Frances coal. "Dress rehearsal" for feeding Ohio 9 coal.	All goals accomplished.	9/28/77
2	7 Sept	9 Sept	2+	130	1.15	Ohio 9 1 x 5/8	BFS	Demonstrate an operation of the slagging gasifier using Ohio 9 coal as feedstock and blast furnace slag as flux. Although conditions will not be optimized, detailed data will be obtained.	1. Operability shown for 22.7 hrs. with Ohio 9 and BFS as flux. 2. Excellent slag removal, moderate temperature excursion. 3. Run terminated due to slag buildup in Quench Chamber.	10/26/77
3	27 Sept	28 Sept	1	130	1.15	Ohio 9 1-3/4 x 1/2	BFS	a. Effect of wide size range Ohio 9. b. Eliminate slag buildup in Quench. c. Use of limestone as flux. d. Effect of flux rate. e. Effect of steam/O_2.	1. Bed instabilities with Ohio 9 and BFS flux. 2. Run terminated due to massive caking and loss of distributor drive. 3. Limestone addition not tried.	
4	19 Oct	20 Oct	1	130-100	1.05-1.60	Ohio 9 2 x 1/4	Limestone	a. Eliminate slag buildup in Quench. b. Effect of limestone. c. Effect of flux rate. d. Effect of steam/O_2. e. Effect of O_2 load. f. Evaluate load reduction as means of maintaining bed stability during period of upset.	1. Poor burner operation led to erratic tapping with Frances coal. 2. Slag buildup severe. 3. Limestone addition accomplished for 10 hours. 4. Load reduction to stabilize bed shown effective. 5. Slag pool in hearth very viscous. Probably steam/O_2 too high. 6. No problems in distributor drive.	
5	9 Nov	10 Nov	2	130-140	1.25	Ohio 9	BFS	a. Select operable steam/O_2 and load for Ohio 9 with BFS. b. Add limestone as flux.	1. Internal equipment damaged. 2. Massive monolithic coke column in shaft. 3. Limestone addition not tried.	
6	6 Dec	10 Dec	5	100	1.25	Frances Ohio 9	None, BFS	a. Low load run. b. Again confirm operability on unfluxed Frances coal. c. Demonstrate that low load will eliminate coke column with Ohio 9 and BFS Flux. d. Demonstrate that elimination of coke column will prevent damage to internal gasifier equipment.		

Attachment 2 for TSP-7 Minutes

TECHNICAL SUPPORT PROGRAM
August 1977 through March 1978

Run No.	Begin	End	Duration, Days	O_2 Load MSCFH	H_2O/O_2 Ratio	Coal Feed	Flux	Goal	Results	Run Report Issued
7	9 Jan	13 Jan	5	130-160	Range	Ohio 9	BFS Limestone	a. Demonstrate that modified stirrer will allow higher loadings without formation of coke column. b. Optimize steam/O_2 and limestone addition rate.		
8	30 Jan	2 Feb	4	Opt.	Opt.	Ohio 9 + Fines	Limestone	Determine maximum allowable fines content for processing Ohio 9 coal.		
9	20 Feb	1 Mar	10	Opt.	Opt.	Ohio 9 + Fines per Run 8	Limestone	Demonstrate long term steady state operation on Ohio 9 coal.		
10	13 Mar	16 Mar	4			Pitts. #8 Seam	BFS, Limestone	Demonstrate operability of Pittsburgh #8 coal and obtain yield data.		
								RUNS IF TWO MONTH EXTENSION IS AVAILABLE		
11	3 Apr	6 Apr	4	Range	Range	Pitts. #8 Seam	Limestone	Evaluate effects of steam and O_2 rates on performance of Pittsburgh #8 coal.		
12	24 Apr	27 Apr	4	Opt.	Opt.	Ohio 9	Limestone	Evaluate introduction of liquid fuel (e.g. tar) through tuyeres.		
13	10 May	15 May	4			Ohio 9	Limestone	Operate gasifier to solve critical problems as defined by the engineering contractors.		

Attachment 3 for
TSP-7 Minutes

FOSTER WHEELER ENERGY CORPORATION

November 16, 1977

Mr. W. B. Carter
Conoco Coal Development Company
High Ridge Park
Stamford, CT 06904

Letter No.: FC-162
FWEC File: 15-1910
Conoco File: DOE-2542
Task II & VI: Section 1000-Slag Handling System

Dear Mr. Carter:

In order to prepare a definitive design of the slag handling system we will require the following data:

1. Slag dewatering rate.

2. Characteristics of the slag handling water, i.e., ph, component analysis, clarity.

3. Temperature of slag water slurry.

4. Details of any objectionable odors that must be accommodated.

We would also like confirmation of the following information received at the Lurgi meeting in Frankfurt on November 8 thru 10.

1. Only one gasifier is required to dump at one time. This would apply to both the commercial plant and the demonstration plant.

2. The slag lock hopper must be able to discharge in 3 secs. While this rate does not appear realistic to us, we will nevertheless provide a sluiceway with sufficient volume at each gasifier to accommodate one batch of slag.

We are presently investigating the various methods of dewatering the slag. The preferred method at the moment appears to be the use of ash pumps to deliver the slag/water slurry to a dewatering hydrobin. The slag is filled into trucks from the bins and the water is clarified and recycled. This method is used commercially in this country for slagging boilers.

Please advise when we might be able to receive the above data. It would be useful if we could receive a 5 gal. sample of the slag and water produced in Westfield from Ohio No. 9 coal.

Very truly yours,

FOSTER WHEELER ENERGY CORP.

D. E. Smith
Project Director

DES/eas
cc: A. J. Morse, Ponca City

Interoffice Communication

Attachment 4 for TSP-7 Minutes

To J. D. Sudbury

From W. B. Carter

Date November 14, 1977

Subject Technical Assistance for Plant Design

Recent discussions with Lurgi and Foster Wheeler have revealed two technical design problems that require your assistance. These are:

(1) Slag dewatering. In order to dispose of the slag, we need to know the dewatering rate and the amount of water remaining on the slag after a decent drain interval.

(2) Flux/coal separation. We believe it would be best to mix the flux and coal on the ground, then convey it to the bunkers, where it will fall to the lock hoppers and gasifiers. However, there is the possibility that serious separation of the solids will occur such that the gasifier will not operate properly.

Confirming our discussions, I would appreciate your consideration of these problems, which may involve some work at Westfield.

Please let me have your thoughts on how to proceed and the likely time for solution by the end of November, so we can adjust our design timetable accordingly.

W. B. Carter
Project Manager

WBC:paw
CC: J. R. Bowden
W. B. Watson
A. J. Morse
I. L. Zuber
U. Marwig
J. E. Scott
R. A. Verner
File (2)

MINUTES OF WESTFIELD TECHNICAL SUPPORT PROGRAMME COMMITTEE MEETING NO. 8

Place: Westfield Development Centre, Cardenden, Scotland

Date: January 11, 1978

1. PRESENT

Members:

Dr. J. D. Sudbury - Continental Oil Company
Mr. W. B. Watson - Continental Oil Company
Dr. C. L. Miller - U.S. Department of Energy
Mr. J. McHugh - British Gas Corporation
Dr. D. Hebden - British Gas Corporation
Dr. H. Vierrath - Lurgi Kohle und Mineraloeltechnik

Designates:

Mr. C. Fink - Continental Oil Company

In Attendance:

Mr. J. E. Scott - British Gas Corporation

Secretary:

Mr. M. R. Tooley - British Gas Corporation

2. INTRODUCTORY REMARKS

The Chairman presented two letters (copies attached) from DOE to Continental Oil Company. He stated that these letters indicated the feeling that was prevalent in the DOE with respect to the Westfield TSP. A reply will be formulated by Continental Oil Company during week commencing 16 January 1978.

See item 12.

3. APPROVAL OF MINUTES OF TSP NO. 7

The minutes were agreed and accepted.

4. UNFINISHED ACTION ITEMS

Mr. Scott reported progress on these as follows:

(a) Run Reports

The report for Run 4 had been issued on 10 January 1978. The reports for Runs 5 and 6 have yet to be issued.

(b) Oxygen Preheater

The unit was now on site and was being installed. It will be available for the next Run.

(c) Frit Sampling

A 1000 lb. sample of Ohio No. 9 coal slag would be forwarded to Continental Oil Company when available from the next Run. The Chairman agreed that some contamination of coke slag could be tolerated.

Dewatering tests had commenced and were continuing. The Chairman asked that results were required indicating the analysis of the waste water during the first hour.

(d) Thermocouple Installation

This was proceeding and will be completed prior to the start of the next Run.

(e) Modified Drive for Stirrer

This had been installed and tested. Results obtained so far had showed that this item was completely satisfactory and gave no problems whatsoever.

(f) Coal Shipment (copy of test results attached)

5000 tons of Ohio No. 9 and 5000 tons of Pittsburgh No. 8 had arrived at Leith and unloading was in progress.

Mr. Scott stated that the size analysis of the Ohio No. 9 coal appeared to be inferior to that previously received but the appearance of the Pittsburgh No. 8 coal appeared to be excellent.

(g) Liquid Fuel Injection

There was no possibility of installing this equipment before 31 March 1978.

Mr. Scott agreed to write to Continental Oil Company on this subject.

(h) Preheating of Coal

Although it was accepted that preheating of coal could not be progressed on site before 31 March 1978 the Chairman asked that BGC make an assessment of the effect of feeding dried preheated coal to the gasifier.

Dr. Hebden stressed the need to evaluate all the options available for improving gasifier operation including the deepening of the fuel bed.

Mr. McHugh stated that BGC were in the process of reviewing their future actions and availability of resources after the 31 March 1978. Mr. McHugh requested that Continental Oil Company write to him setting down proposals for a "non-detailed" type of study to be carried out by BGC on this subject.

In reply to a question from the Chairman, Messrs. Scott and Fink agreed that no problems had been experienced due to high moisture content of coal or flux.

5. ENVIRONMENTAL ANALYSIS

Mr. Watson stated that EPA required Continental Oil Company to advise them of the concentration of 129 primary compounds in waste water discharged from the gasifier site.

The Chairman proposed that Continental Oil Company would review the whole question of samples of all materials required for analysis and BGC would be advised of their requirement by letter.

6. RESULTS OF RUN 6

Mr. Fink summarized the results of this Run which had lasted for 80 hours during which Ohio No. 9 coal had been fed to the gasifier for 2 periods of 7 and 16 hours duration.

During both these periods, problems had been experienced with gasifier internals which had ultimately resulted in the termination of the Run. No mechanical damage had been found to the gasifier upon subsequent inspection.

During the times when the gasifier was operating on Frances coal, no difficulty had been experienced whatsoever.

7. RESULTS OF RUN 7

During this Run, modification had been made to the method of alternatively charging Ohio No. 9 coal and metallurgical coke.

The Run consisted of a total of 9 eight hour periods during which the proportions of coal and coke were varied.

The gasifier preformance was monitored and changes noted following variation in fuel concentrations. The gasifier was shut down while still operating satisfactorily although some irregularities in the quench chamber were apparent. Subsequent internal inspection showed that the condition of the gasifier bed was excellent.

8. PROGRAMME FOR RUN 8 AND SUBSEQUENT RUNS

The Chairman stressed that the remaining runs should be designed to obtain the best results in order to influence the DOE in their decision as to which gasification process should be adopted. This decision is to be taken during June 1978.

The Chairman proposed that Run 8 should follow similar operating parameters to Run 7 in order that the design changes indicated under item (4) could be evaluated.

Dr. Sudbury proposed that Run 9 should consist of an extended Run for a period of about 10 days.

It was also proposed that Run 10 should consist of an evaluation of Pittsburgh 8 coal.

Mr. Scott stated that there was no possibility of achieving more than 3 Runs before the 31 March due to shortage of time.

Mr. McHugh stated that as Continental Oil Company were now proposing to concentrate the remaining Runs on a coal/coke mix, BGC considered the proposed programme to be acceptable.

The above Run programme had been previously agreed by Dr. Rudolph. Dr. Vierrath stated that he strongly recommended a test period using a wide size range of non caking fuel at the end of one of the above Runs. The reason for the proposal was that the smoothest gasifier operation had been achieved using non or weakly caking coals in a narrow size range. As the stirrer will not produce such a narrow size range from strongly caking coals, it would appear to be essential to investigate the effect of the size range on slagger performance.

9. EXPERIENCES AT MORGANTOWN

The Chairman reported that operation of the dry-bottomed gasifier at Morgantown had been substantially improved by the use of an adjustable stirrer while running on Pittsburgh No. 8 coal. During recent operation, use had also been made of a cobalt 60 source for the detection of voids in the gasifier bed.

10. MODIFICATION INVENTORY

Mr. Watson asked if BGC could produce the following two inventories:

(a) A schedule of all items installed on the gasifier as modifications.

(b) A schedule of all items which have been purchased during the TSP and were recoverable.

Mr. Watson would make the above request in writing and would also indicate the procedure for "tagging" of these items.

11. SLAG CHAMBER DEPOSITS

In reply to a question from the Chairman, BGC stated that the equipment previously used for clearing the tap hole was not suitable for removing the deposits now being formed in the slag chamber.

12. LETTER FROM MR. LLOYD TO DR. SUDBURY DATED 14 DECEMBER 1977

Dr. Sudbury stated that Continental Oil Company would reply to the above indicating the programme outlined under item number (8).

Mr. McHugh stressed the need to highlight the successes which had been achieved to date with the TSP programme adding that the reply to DOE should be in simple non-technical language.

13. DATE OF NEXT MEETING

This is to be held at Westfield on Wednesday, 8 February 1978.

M. R. Tooley
Secretary

25 January 1978

Attachment 1 for
TSP-8 Minutes

DEPARTMENT OF ENERGY
WASHINGTON, D.C. 20545

January 6, 1978

EC-72 Corrected Copy
Conoco-DOE 2542
DOE-Conoco 2542

Mr. W. B. Carter
Conoco Coal Development Company
High Ridge Park
Stamford, Connecticut 06904

Dear Mr. Carter:

Recent test results from the Westfield Test Program indicate a lack of success in accomplishing contract objectives and proving successful operation of the process. The confirmation of the operability of the slagging Lurgi gasifier with an agglomerating major U.S. coal resource, and the completion of the commercial conceptual design and economic evaluation are the two essential elements in the program. Since the Westfield program is now some three months behind schedule, it is essential that other work be curtailed. Continued expenditure of funds for other, potentially wasted effort is unwarranted.

Accordingly, under Article (4) I (pages 30 and 31) of the contract, all work on tasks other than Task I and those trade-off studies of Task XII required for the commercial economic evaluation, Task IX, and Task XI (reduced in accordance with the reduced scope) shall be changed essentially as outlined in your letter CE-141. Exceptions should be recommended for work in other tasks in progress and nearing completion that would be less costly to complete than to change. A conference will be held one week after the date of this letter to determine those efforts in the suspended tasks which will be permitted to be continued. This change is effective as of the date of this letter.

The 22-month (Phase I) contract performance period will be adjusted as appropriate for the delay occasioned by this action.

The above direction will be confirmed by a modification to your contract.

Sincerely,

E. F. Callaghan
Contracting Officer
Operations Branch
Division of Procurement

CC: USAEDH (HNDED-M/
J. Mullinix)
CE(Conoco Liaison/F. Crouse
ARRADCOM (R. Hutchinson)

Attachment 2 for
TSP-8 Minutes

DEPARTMENT OF ENERGY
WASHINGTON, D.C. 20545

EC-75
Conoco File No. 2542
DOE File No. 2542
Task IX

December 14, 1977

Dr. J. D. Sudbury, Vice President
Conoco Coal Development Company
Research Division
Library, Pennsylvania 15129

Dear Dr. Sudbury:

Tests to date at Westfield have failed to demonstrate the operability of the BG-Lurgi slagging gasifier with Ohio 9 coal. The Department of Energy (DOE) must assess the likelihood of achieving success in the remaining TSP period. In order to make this assessment, we request that CCDC formally submit to DOE a test plan for the remaining Westfield runs. The plan should clearly indicate the problems preventing operability and a systematic plan for overcoming the problems. The original TSP objectives that have or can be achieved in the remaining period and a reconciliation of objectives deleted and their impact on the Demonstration Plant should be addressed.

We request that this plan be submitted to DOE prior to making future runs in 1978 at Westfield.

Sincerely,

E. A. Lloyd
Program Director

cc:USAEDH (HNDED-M/J. Mullinix)
CE (CONOCO Liaison/F. Crouse)
ARRADCOM (R. Hutchinson)

Date: December 12, 1977

Attachment 3 for
TSP-8 Minutes

CONOCO COAL DEVELOPMENT COMPANY
Research Division
Library, Pennsylvania

Pittsburgh No. 8 Coal - Champion Mine

Screen Fraction	2" x 1"	1" x 1/2"	1/2" x 1/4"	1/4" x 0
Proximate Analysis, Wt.%				
Moisture	1.99	1.96	1.80	1.70
Volatile Matter	40.19	40.43	39.37	39.06
Ash	6.67	6.81	8.11	7.27
Fixed Carbon	51.15	50.80	50.72	51.97
Ultimate Analysis, Wt.%				
Hydrogen	5.29	5.27	5.12	5.20
Carbon	76.46	76.73	74.54	75.94
Nitrogen	1.30	1.31	1.32	1.35
Sulfur	1.83	1.69	1.75	1.85
Ash Analysis, Wt.%				
Na_2O	0.52	0.42	0.42	0.45
K_2O	1.45	1.76	1.80	1.60
CaO	2.79	1.46	2.12	2.90
MgO	0.75	0.60	0.69	0.69
Fe_2O_3	20.50	20.43	16.32	18.50
TiO_2	0.97	1.05	1.15	1.05
P_2O_5	0.19	0.38	0.25	0.37
SiO_2	44.36	49.54	48.38	45.32
Al_2O_3	25.25	24.03	24.52	23.05
SO_3	2.84	1.01	1.81	2.19
	99.62	100.68	97.46	96.12
Free Swelling Index	8	8	7 1/2	7 1/2
Yield, Wt.%	21.7	39.4	27.7	11.2

MINUTES OF WESTFIELD TECHNICAL SUPPORT PROGRAMME COMMITTEE MEETING NO. 9

Place: Westfield Development Centre, Cardenden, Scotland

Date: February 8, 1978

1. PRESENT

Members:

Dr. J. D. Sudbury - Continental Oil Company
Dr. C. L. Miller - U.S. Department of Energy
Mr. J. McHugh - British Gas Corporation
Dr. D. Hebden - British Gas Corporation
Dr. H. Vierrath - Lurgi Kohle und Mineraloeltechnik

Designates:

Mr. C. Fink - Continental Oil Company
Mr. U. Marwig - Lurgi Kohle und Mineraloeltechnik

In Attendance:

Mr. J. E. Scott - British Gas Corporation
Dr. R. W. Hutchinson - U.S. Department of Energy

Secretary:

Mr. M. R. Tooley - British Gas Corporation

2. INTRODUCTORY REMARKS

The Chairman introduced Dr. R. W. Hutchinson of DOE to the meeting and it was unanimously agreed that Dr. Hutchinson should attend this meeting.

The Chairman reported that the recent February oral briefing had indicated a more optimistic attitude to the Westfield project than DOE had previously shown.

BGC and Continental Oil Company are at present negotiating a two month extension to the programme which would be financed by the Electric Power Research Institute.

The Chairman referred to the need for all concerned with the project to appreciate that there had always been a requirement to run Westfield as a development project within a demonstration programme in order to solve potential problems which had been recognized from the onset. Mr. McHugh and Dr. Hebden agreed with this view.

Dr. Miller expressed the need to accurately specify to the DOE the role of the demonstration plant as a continuation of the development of the project.

3. APPROVAL OF MINUTES OF TSP NO. 8

The minutes as distributed on 25 January 1978 were agreed and accepted.

4. UNFINISHED ACTION ITEMS

(a) Oxygen Preheater

Mr. Scott reported that this had been installed and cleaned and was due for commissioning on 9/10 February.

(b) Installation of New Stirrer

This had been installed and tested. Problems had been experienced during installation with welding the unit.

(c) Thermocouples

Four additional thermocouples had been installed as previously agreed.

(d) Frit Sample

Arrangements were in hand to obtain a 1000 lb frit sample during the next Run.

(e) Procurement of Wide Size Range of Blast Furnace Coke

The Chairman asked that this material be obtained. Lurgi requested that sufficient material be procured for a 24 hour running period as part of a Run following Run 8.

(f) Equipment Inventory

The production of the two schedules requested by Continental Oil Company at the last meeting and confirmed by them in telex number CB-73X was almost complete. Mr. Scott anticipated the schedules would be completed and forwarded to Mr. Watson during week commencing 13 February 1978.

(g) Transfer of Items Remaining from Previous Programme

An audited list of items was now available and had been approved. This would be valued before the next meeting.

(h) Flux Segregation Trials

Mr. Scott reported that trials on the effectiveness of blending coal and flux on the ground were proving difficult as were the means of determining the degree of separation which may occur following delivery of the fuel to the gasifier.

(i) Biological Treatment Studies

The Chairman had discussed this topic with BGC's London Research Station and stated that he would be attending the forthcoming meeting of the Executive Committee of the IEA Coal Gasification Liquor Effluent Project on Friday, 10 February 1978 as the EPA representative.

(j) Material Samples

Continental Oil Company would write to BGC detailing a schedule of materials and quantities which they required to be sampled.

5. LETTER FROM J. D. SUDBURY TO DOE

The letter from J. D. Sudbury to DOE dated 19 January 1978 had been received by DOE who had accepted the programme outlined in the letter.

The Chairman noted that there could be a need to update this type of communication periodically.

Mr. McHugh stated that BGC agreed with the content of the letter which was also accepted by Lurgi.

6. PROGRAMME FOR RUN 8

The goals for Run 8 together with those for subsequent Runs are detailed in the programme attached to the letter from J. D. Sudbury to DOE dated 19 January 1978.

In supporting this programme for the remaining Runs, Mr. McHugh stressed the need to recognize the importance of the political aspects associated with this programme, adding that this aspect must be considered alongside the technical requirements in deciding the choice of feedstock and the mixtures of coal and coke to be used.

Dr. Hebden suggested that in order to evaluate the effectiveness of the modifications carried out to the gasifier, it would be better to run on 100% Ohio No. 9 coal but at the same time retain the facility to change over to coke as required. Should deleterious conditions develop this facility, as already demonstrated, would allow the fuel bed to be purged with non-caking fuel and satisfactory operation to be re-established before attempting further running on Ohio No. 9 coal. He proposed a cautious approach of feeding four or five locks of coke following each of 4, 6, etc. hours continuous operation on Ohio No. 9 coal, the periods of operation on coal being increased as fuel bed and raceway conditions indicated. This would be preferable to using single lock hoppers of coke which were too frequent and too small to allow any meaningful pattern of behavior to develop which could be identified as an improvement or no improvement.

Dr. Vierrath stated that layering of coal/coke was undesirable and was an unsuitable method of achieving satisfactory fuel bed conditions. Lurgi would prefer to use the blending approach as a better alternative to counter the caking problem.

The Chairman stated that the Run programme could be varied as required in order to evaluate the above factors.

Mr. Scott stated that at the moment, fuel feeding in increments of one-half lock hopper was not practical.

7. DATE OF NEXT MEETINGS

These were arranged for 20 March 1978 and 26 April 1978, both meetings to be held at Westfield.

M. R. Tooley
Secretary

23 February 1978

MINUTES OF WESTFIELD TECHNICAL SUPPORT PROGRAMME COMMITTEE MEETING NO. 10

Place: Westfield Development Centre, Cardenden, Scotland

Date: March 20, 1978

1. PRESENT

Members:

Dr. J. D. Sudbury - Continental Oil Company
Mr. W. B. Watson - Continental Oil Company
Mr. J. McHugh - British Gas Corporation
Dr. D. Hebden - British Gas Corporation
Dr. H. Vierrath - Lurgi Kohle und Mineraloeltechnik

Designates:

Mr. C. Fink - Continental Oil Company

In Attendance:

Mr. J. E. Scott - British Gas Corporation
Dr. R. W. Hutchinson - U.S. Department of Energy

Secretary:

Mr. M. R. Tooley - British Gas Corporation

2. INTRODUCTORY REMARKS

Dr. Hutchinson attended the meeting in place of Dr. C. L. Miller for whom apologies were received.

The Chairman stated that he anticipated two further Runs (No. 9 a. and 10) could be carried out under the present programme.

Mr. McHugh agreed that BGC had no objection in principle to the two Runs being carried out on the same basis as the previous Runs even though this could extend the programme beyond 31 March 1978.

The Chairman went on to say that an extension of the programme by a period of two months was considered to be realistic by Continental Oil Company and tabled a letter from DOE dated 14 March 1978 (copy attached) requesting a programme which would be followed should a two month extension be given. A meeting had been arranged between Continental Oil Company and BGC for 3 April 1978 at which this matter would be discussed. The meeting would also formulate a reply to the DOE letter.

Following the Continental Oil/BGC meeting, a similar meeting would be held between Continental Oil and Lurgi.

3. APPROVAL OF MINUTES OF TSP 9

These were approved as distributed on 22 February 1978.

4. LETTER - LLOYD TO SUDBURY DATED 23 FEBRUARY 1978

A copy of this letter is attached.

5. CONSIDERATION OF RUN REPORTS NOS. 5 AND 6

Dr. Sudbury expressed Continental Oil's disappointment with the technical contents of these two reports which Continental Oil Company considered inferior to previous reports.

Mr. McHugh explained that the content of reports from the point of view of commercial security was the ultimate responsibility of BGC's International Consultancy Service who had negotiated the original contract and was subsequently responsible for the administration of the contract. This matter would be discussed between Continental Oil Company and BGC on 3 April 1978.

6. STATUS OF REPORTS ON RUNS 7 AND 8

The report for Run 7 was presented to Members of the Committee at the meeting by Mr. Scott. Mr. Scott also stated that the report for Run 8 will be available on schedule.

7. STATUS OF CATEGORY II ANALYTICAL DATA

Data collected from Runs 4 and 8 was tabled at the meeting. Discussion between Westfield site staff and Continental Oil Company would be held later in order to discuss the content of the report and to determine if further data was required.

8. REVIEW OF UNFINISHED ACTION ITEMS

(a) 1000 lb. Frit Sample

Two drums of frit had been received by Continental Oil Company, a 250 lb. sample will be delivered to Oak Ridge National Laboratories.

(b) Wide Size Range Coke

The first consignment of Coke had been received and rejected. A second consignment had been delivered and would be charged to the gasifier during the next Run.

Mr. Scott stated that the cost of this material was approximately £67 per ton.

(c) Equipment Inventory

Mr. Scott tabled an inventory for consideration by Continental Oil Company. Mr. Watson agreed to forward a tagging and disposal procedure to Mr. Scott.

(d) Transfer of Items Remaining from Previous Programme

Mr. Scott tabled a copy of a telex to Dr. Sudbury dated 17 March 1978 which lists materials which were available to the TSP project. Dr. Sudbury stated that he would reply to the telex as requested.

(e) Material Samples

Mr. Scott tabled a copy of a memo dated 17 March 1978 which enumerated samples which had been taken.

(f) Environmental Analysis

Dr. Sudbury agreed to respond to the request by EPA for analysis of concentrations of 129 primary compounds in the gasifier waste water.

9. RUN 9 REVIEW

Mr. Scott summarized the Run details indicating that slagging conditions were noticeably cooler than usual and that the Run had to be terminated (while still charging coke) following rapid deterioration of conditions at the base of the gasifier. It was not clear whether the reduced fluxing rate had been a contributory factor to the premature termination of the Run. Mr. Scott also reported that confusion on site had arisen due to the delay in receiving the Run programme from Continental Oil Company. The programme was not presented until the day before the Run was due to start.

Dr. Vierrath stated that he considered the heat flux into the system may not have been normal and the reason could have been due to the numerous changes in process conditions which had been made for this Run.

Mr. Scott reported that no damage to the refractory had occurred during the Run.

In answer to a question from the Chairman, Mr. Scott stated that the flux addition rate had been as required (at the reduced rate) - this was later verified by frit analysis.

Run 9 was due to be repeated - Run 9 a. commenced at 0800 hours on 20 March 1978. The Run was programmed with the normal fluxing rate.

Dr. Sudbury requested information on the probability of obtaining gas samples at more frequent intervals in order to determine the fluctuations in gas composition which occurred due to layering of coal and coke.

Dr. Vierrath suggested that variations in gas composition may be indicated by continuous calorific value measurement.

Dr. Hebden stressed the need to base sample times on the gasifier cycle and not merely on a time basis.

Mr. Scott agreed to investigate the maximum frequency at which samples could be taken and also the availability of calorific value recorders etc.

10. RUN 10 PROGRAMME

The primary objective of this Run was an extended Run of about ten days duration.

11. PLANS FOR REFURBISHING FACILITY FOLLOWING TSP

In answer to a question from the Chairman, Mr. Scott confirmed that the above work would take two weeks. Discussion would require to take place between Continental Oil Company and BGC on the detail of the action to be taken with respect to the gasifier refractory lining. The discussions would be programmed following completion of the TSP.

Mr. Scott reported that problems were being experienced with contamination of local waterways due to leaching from the Ohio No. 9 coal which was being stocked on site. Continental Oil Company accepted that they had a responsibility for disposal of this coal and Dr. Sudbury agreed to look into this matter.

12. TENTATIVE AGENDA FOR TSP 11

Dr. Sudbury re-affirmed the possibility that DOE may extend the programme by a period of two months. Dr. Sudbury also stated that Electric Power Research Institute were interested in the possibility of carrying out a programme with an expected duration of about two months.

Mr. McHugh stated that BGC intended to retain the site in an operational state until at least March 1979. Mr. McHugh asked when BGC would be told if DOE intended to extend the present TSP programme. The Chairman replied that this matter would be discussed at the meeting on 3 April.

13. DATE OF NEXT MEETING

The next meeting will be held at Westfield on 26 April 1978.

M. R. Tooley
Secretary

3 April 1978

Attachment 1 for
TSP-10 Minutes

DEPARTMENT OF ENERGY
WASHINGTON, D.C. 20545

Letter No.: EC-118
DOE File No.: 2542
CONOCO File No.: 2542

March 14, 1978

Mr. W. B. Carter
CONOCO Coal Development Company
High Ridge Park
Stamford, Connecticut 06904

Dear Mr. Carter:

Your request for an extension of the Westfield Technical Support Program and the reasons for extension has merit because of the nearness to which the contracted eight month program has approached our contract objectives.

The original objectives were outlined under Appendix A.1 of the Westfield agreement which was recognized "as the minimum program that must be carried out in Phase I." These objectives were not met for any of several possible reasons, but fundamentally the gasifier has not performed as expected to confirm that coking eastern U.S. coals could be handled in the Lurgi/British Gas developed slagging gasifier. Instead, the program and the equipment have been altered, and we share the view that we are in a research and development mode, not sufficiently convincing to invest $371,000,000 in a demonstration plant.

The responsibility to prove to all parties concerned that the process is worthy of demonstration was never a responsibility of Government, but rather a burden of Continental Oil Company and subcontractors. However, Government is willing to consider sharing in the program under conditions which it considers reasonable to all interested parties.

Government is prepared to discuss a proposal to jointly fund the extension of the program which will satisfy the minimum requirements of DOE and Continental Oil Company as formulated by the Technical Advisory Committee under the existing contracts.

Government is also prepared to discuss a reasonable extension (not more than two months) to satisfy the DOE, Continental Oil Company and offeror confidence to a sufficient level to proceed with the ultimate objectives to design, construct and operate a demonstration plant. Any extension of effort requiring operation beyond two months should be included in the proposed plan before DOE approval, and shall be funded from other than Government sources. Accordingly, it is DOE's position that this would require changes, or modifications to the Westfield Agreement Work Statement.

Should these suggestions appear reasonable enough for further discussion, we want to be assured by British Gas Corporation that provisions under 15.3 of the Westfield agreement need not apply, and that the DOE equipment and personnel on-site can remain until the current situation is resolved.

Sincerely,

E. A. Lloyd
Program Director

Eugene F. Callaghan
Contracting Officer
Office of Procurement Operations

Attachment 2 for
TSP-10 Minutes

DEPARTMENT OF ENERGY
WASHINGTON, D.C. 20545

Letter EC-95
CONOCO Ref. No. 2542
DoE Ref. No. 2542
Task IX - Westfield TSP

23 February 1978

Dr. John D. Sudbury
Vice-President
CONOCO Coal Development Company
Research Division
Library, PA 15129

Dear Dr. Sudbury:

Thank you for your letter CE-8004 presenting the status of the Westfield tests and your test plan for the remaining TSP period. Your letter is an acceptable response to our request for a test plan and we advise you to proceed with the work you have outlined.

As your plan emphasizes, the critical need is to demonstrate operability of the slagging gasifier with Eastern caking coals. Your initial results with mixtures of coke and Ohio No. 9 coal are encouraging, and the technique does provide a systematic means to approach the gasification of straight Ohio No. 9 coal. However, our primary goal is to demonstrate the gasification of all portions of this or any Eastern caking coal in the Demonstration Plant under conditions which project favorable economics for the Commercial Plant relative to other second generation processes. The need to have a portion of the feed non-caking will, we assume, have an adverse impact on economics, but the magnitude of the impact is what is critical. It is most important that if coke is a necessary feed ingredient, that the source of coke and the overall impact on the price of gas be addressed as rapidly as possible. We must consider the overall economics of your process relative to other processes on a basis substantiated by successful pilot tests.

The goals which you mention on page 7 of your letter — use of limestone as flux; demonstrate maximum load; and assess fines tolerance — are quite important to overall plant economics. We encourage you to emphasize the achievement of these goals whenever possible during the future tests. The testing of Pittsburgh No. 8 coal in Run 10 will, we presume, be contingent on success with Ohio No. 9 coal in Runs 8 and 9.

As your letter includes interpretations and conclusions based on test results upon which others may draw different conclusions, our acceptance of your test plan does not mean that the Department of Energy agrees with each and every statement in your letter.

Sincerely yours,

E. A. Lloyd
Program Manager

cc: USARDM (HNDED-M/Hellier)
CE (Conoco Liaison/Crouse)
ARRADCOM (R. Hutchinson)

MINUTES OF WESTFIELD TECHNICAL SUPPORT PROGRAMME COMMITTEE MEETING NO. 11

Place: British Gas Corporation, Marble Arch, London, UK

Date: April 26, 1978

1. PRESENT

Members:

Dr. J. D. Sudbury - Continental Oil Company
Dr. C. L. Miller - U.S. Department of Energy
Mr. J. McHugh - British Gas Corporation
Dr. D. Hebden - British Gas Corporation
Dr. H. Vierrath - Lurgi Kohle und Mineraloeltechnik

Designates:

Mr. C. Fink - Continental Oil Company

In Attendance:

Mr. J. E. Scott - British Gas Corporation
Mr. R. W. Hutchinson - U.S. Department of Energy

Secretary:

Mr. M. R. Tooley - British Gas Corporation

2. INTRODUCTORY REMARKS

It was agreed that Dr. Hutchinson should attend the meeting.

The Chairman stated that difficulties of financial procurement within DOE had meant that there were insufficient funds available for further Runs under the present programme.

Mr. McHugh stated that British Gas had now embarked upon a programme of Runs using Scottish coals; the first of these Runs was in progress at that time.

3. APPROVAL OF MINUTES OF TSP 10

These were approved as distributed on 3 April 1978.

4. REVIEW OF UNFINISHED ACTION ITEMS

(a) Wide Size Range Coke

The necessary Runs had been completed on this material and the required information had been obtained. No further Runs were envisaged using this feedstock.

(b) Equipment Inventory

This had been presented to Continental Oil Company by BGC but details of the required tagging procedure were still awaited from Continental Oil.

(c) Environmental Analysis

Dr. Sudbury reported that the analysis of 129 primary compounds required by EPA could be carried out for less than 1000 dollars. It was agreed that a sampling procedure for the waste water to be tested would need to be obtained from EPA.

5. REVIEW OF RUN 9(b)

Mr. Fink reported that the No. 9 series of Runs were designed to evaluate wide size range coke and Pittsburgh No. 8 coal.

During Run 9(b) coke was fed to the gasifier for 50 hours before being terminated as a result of failure of an air compressor. During this period wide range coke was fed to the gasifier for 3.5 hours. Use of the wide range coke was unsatisfactory due to downstream problems caused by elutriated fines.

6. REVIEW OF RUN 9(c)

Mr. Fink reported that this Run consisted of five days of entirely satisfactory operation on a 1 to 1 ratio of layered blast furnace coke and Pittsburgh No. 8 coal. The Run was initially intended to be of three days duration but further quantities of coke were obtained to enable the Run to be extended to five days. The gasifier was finally shutdown due to a shortage of suitable coke while still operating satisfactorily. The shutdown was carefully controlled to allow examination of bed conditions using Pittsburgh No. 8 feedstock.

Subsequent internal inspection of the gasifier showed the bed condition to be very good with evidence of very slight damage to the hearth. Mr. Scott reported that the quick gas sampling system had been successfully carried out during this Run and results obtained would be reported in the normal way.

Mr. Scott stated that in the event of further Runs being carried out, he considered that Run 9(c) should be repeated using Ohio No. 9 coal. He also noted that while Frances and Pittsburgh No. 8 coals were both washed, Ohio No. 9 coal was unwashed run-of-mine, adding that if Ohio No. 9 coal were required to be washed, the necessary facilities may be available locally from the National Coal Board.

Dr. Hebden remarked that the demonstration plant design was based on washed Ohio No. 9 coal and that Continental Oil Company had previously been asked for details of washed coal data. Dr. Sudbury agreed to pursue the availability of this data.

7. DISCUSSION OF ANALYTICAL DATA

Mr. Scott stated that the data presented at the last meeting was not complete and that all data with the exception of trace element analysis will be forwarded with Run 9 Reports. Samples for the determination of trace elements had been despatched and results would be available in six to eight weeks.

8. DISCUSSION ON OPTIONS FOR FURTHER TSP RUNS

Continental Oil Company proposed four further Runs be carried out as follows:

(a) A Run on Ohio No. 9 coal layered 1 to 1 with coke as in Run 9(c). The Run would be of three days duration.

(b) A Run of ten days on the most suitable feedstock at the most favorable conditions.

(c) A blending Run ranging from 4 parts coke and 1 part coal to 4 parts coal and 1 part coke.

(d) A Run on 100% Pittsburgh No. 8 coal encompassing data and experience obtained from the previous three Runs.

It was also suggested that a further Run to evaluate the effect of pulsing tuyeres could be carried out at a future date.

The above proposals had been presented by DOE following general support by BGC and Lurgi at a recent meeting held in Frankfurt.

Mr. McHugh agreed that the proposed programme was the best approach so long as data was required from two coals, but a simpler programme would be possible if only one coal had to be evaluated. Dr. Vierrath stated that Lurgi considered that each particular coal required a tailor-made gasifier to accommodate differing coal characteristics. The existing gasifier appeared to be tailored more to the requirements of Frances and Pittsburgh No. 8 coals than to Ohio No. 9 coal.

The need for a ten day Run was discussed and Dr. Vierrath stated that Lurgi considered such a Run to be very desirable in order to provide the necessary experience. However, following discussion on this subject, Dr. Sudbury agreed that an approach be made to DOE in order to determine if they considered that the Runs carried out to date obviated the need for a ten day Run.

9. DISCUSSION ON MARCH CHARGES

Mr. Scott gave the following figures for costs which have been incurred during March:

Normal monthly costs	£ 300,000
Transfer of materials	£ 200,000
Committed expenditure and accurals	£ 350,000
TOTAL	£ 850,000

A full statement of March costs is attached.

Mr. Scott queried whether finance would continue to be made available to cover such work as the provision of analytical data (e.g. trace elements), refurbishing of gasifier, general administration costs, etc. Dr. Sudbury stated that the principle of making payments after the TSP had been completed had been accepted and agreed. Mr. McHugh stated that this item would be the subject of further discussion between BGC and Continental Oil.

10. ANY OTHER BUSINESS

Stoker Coker System

Four 70 ton samples of various coals were being evaluated currently by Peabody and Continental Oil Company. The first two evaluations should be complete by mid May 1978. If these evaluations were successful, a further two tests would be carried out. The overall results will be made available to this Committee. Availability of detailed experimental results will depend on whether DOE elects to support this work.

M. R. Tooley
Secretary

9 May 1978

BRITISH GAS CORPORATION

WESTFIELD DEVELOPMENT CENTRE

ANALYSIS OF COSTS TO BE SUBMITTED IN CONNECTION WITH TASK IX SUB TASK A FOR MARCH 1978

	£000
Payments made during month	363
Committee expenditure at 31st March 1978 (includes £150,000 for Coke and Coal delivered at the end of March)	389
Transfers from Sponsors Project	107
TOTAL TO BE INVOICED	859

MINUTES OF WESTFIELD TECHNICAL SUPPORT PROGRAMME COMMITTEE MEETING NO. 12

Place: Essex Hotel, New York, New York

Date: June 8, 1978

1. PRESENT

Members:

Dr. J. D. Sudbury - Continental Oil Company
Dr. C. L. Miller - U.S. Department of Energy
Mr. J. McHugh - British Gas Corporation
Dr. D. Hebden - British Gas Corporation
Mr. W. B. Watson - Continental Oil Company
Dr. H. Vierrath - Lurgi Kohle und Mineraloeltechnik

Designates:

Mr. R. A. Verner - U.S. Department of Energy
Mr. G. P. Curran - Continental Oil Company

In Attendance:

Mr. J. E. Scott - British Gas Corporation

Secretary:

Mr. M. R. Tooley - British Gas Corporation

2. INTRODUCTORY REMARKS

It was agreed by all present that Mr. G. Curran should attend the meeting.

Dr. Sudbury stated that the aim of the meeting was to determine a programme for the forthcoming Runs at Westfield.

3. APPROVAL OF MINUTES OF TSP 11

The minutes as distributed on 9 May 1978 were accepted.

4. REVIEW OF UNFINISHED ACTION ITEMS

(a) Equipment Inventory

Mr. W. B. Watson agreed to forward the required tagging procedure to Mr. J. E. Scott.

Mr. Watson then raised various queries with respect to the disposal of materials including Ohio No. 9 coal which were currently held at Westfield.

Mr. Verner stated that DOE would require a schedule showing all the options available for the disposal of equipment, plant and coal at Westfield.

Mr. Watson then asked if BGC would indicate if they required any of the equipment or materials; he also asked BGC to indicate what means were available for disposal of the Ohio No. 9 coal. Mr. Scott agreed to forward such a schedule to Continental Oil Company together with BGC's bid price for the material and equipment where applicable.

(b) Environmental Analysis

Dr. Sudbury has now obtained from EPA the latest list of the primary compounds.

(c) Stoker Coker System

Dr. Sudbury stated that Peabody were proceeding with two further Runs using Ohio No. 9 and Pittsburgh No. 8 run-of-mine coals. 30 drums of Product were already available from preceding runs and the Product appeared to be similar to the coke currently being used at Westfield.

Heat and material balances were available from the process.

The average concentration of fines was still being evaluated - further tests were to be carried out during week commencing 12 June 1978.

Dr. Sudbury stated that overall results of the trials would be made available to DOE through the Programme Committee.

5. RESULTS OF RUN 10 (NOW DESIGNATED RUN A)

Mr. Scott reported that the objectives of this Run were to repeat Run 9(c) using Ohio No. 9 coal in place of Pittsburgh No. 8 coal. Following normal start up procedures, the plant ran for 54 hours on layered 1 to 1 coal/coke before being voluntarily shutdown to investigate slight anomalies at the base of the gasifier.

Following shutdown, subsequent inspection of the gasifier bed indicated that a monolith was present in the centre of the gasifier. No damage to the slag tap or tuyeres had occurred although some slight damage to hearth refractory was evident.

In answer to a question from Mr. Verner, Dr. Hebden stated that the hearth damage was due to operational changes which had been made during the last Run and that he did not regard the slight damage as a problem.

6. PROGRAMME FOR RUN B

Mr. Curran tabled a document - "Notes on Future Programme" dated June 8, 1978. This document briefly summarized progress to date and suggested Run programmes for three further Runs numbered 11, 12 and 13. It should be noted that these Runs should now be numbered B, C and D. Mr. Scott pointed out that one possible constraint governing further Runs was the presence on site of only nine days supply of Pittsburgh No. 8 coal.

Mr. Verner pointed out the advantages of achieving a satisfactory long duration Run on Pittsburgh No. 8 coal before July 1978 when DOE would carry out a process evaluation exercise.

Dr. Miller stressed the advantages of demonstrating that the plant was capable of achieving repeatability, Dr. Miller was also of the opinion that it was important to evaluate the maximum load which the gasifier could handle.

Mr. McHugh stated that the original main aim of the TSP was to produce design data and in order to provide this, subsequent Runs should concentrate on assessing the affects of varying process conditions such as steam/ oxygen ratio and load. Dr. Hebden supported this view.

Mr. Scott stated that it was not possible to commence start up for the next Run before Thursday, 15 June 1978. Mr. Scott also stressed the need to know the length of the Run before it was started in order that the necessary staffing arrangements and attention to plant and equipment could be achieved.

Following further discussion, it was agreed that Run B should consist of a four day Run made up of two days on 100% Pittsburgh No. 8 coal followed by a two day ranging period. Operating conditions during the ranging period would be decided by personnel on site. This programme would thereby incorporate two main requirements in one Run, i.e. demonstration of the capability of handling 100% Pittsburgh No. 8 coal and the provision of design data during the ranging period. Continental Oil Company agreed to produce a Run programme for Run B and subsequent Runs incorporating the above.

Dr. Miller asked what arrangements Continental Oil Company would propose for Runs C and D. Dr. Sudbury will submit a proposal for Runs A, B, C and D to DOE.

7. DATE OF NEXT MEETING

This was to be held at Westfield on Tuesday, 25 July 1978 to commence at 0930 hours.

M. R. Tooley
Secretary

22 June 1978

MINUTES OF WESTFIELD TECHNICAL SUPPORT PROGRAMME COMMITTEE MEETING NO. 13

Place: Westfield Development Centre, Cardenden, Scotland

Date: July 25, 1978

1. PRESENT

Members:

Dr. J. D. Sudbury - Continental Oil Company
Dr. C. L. Miller - U.S. Department of Energy
Mr. J. McHugh - British Gas Corporation
Dr. D. Hebden - British Gas Corporation
Mr. W. B. Watson - Continental Oil Company
Dr. H. Vierrath - Lurgi Kohle und Mineraloeltechnik

Designates:

Mr. C. E. Fink - Continental Oil Company

In Attendance:

Mr. J. E. Scott - British Gas Corporation

Secretary:

Mr. M. R. Tooley - British Gas Corporation

2. MINUTES OF TSP 12

The minutes of this meeting as distributed on 22 June 1978 were approved.

3. INTRODUCTORY REMARKS

The Chairman referred to the complete success of the previous two Runs (Nos. B1 and B2) which had attained all the goals of the TSP. Mr. McHugh stated that BGC appreciated the praise which had been received from Continental Oil Company following these Runs.

The Chairman tabled a letter, No. EC-167-A from DOE ratifying the Westfield II Agreement. The meeting agreed to assume that the Technical Support Programme would terminate on 15 August 1978. It was also noted that the DOE letter had reduced the fee from 7 1/2% to 7%.

4. RESULTS OF RUNS B1 AND B2

Mr. Fink reported that Run B1 had been carried out using Pittsburgh No. 8 coal fluxed with blast furnace slag. The Run had been of 4 days duration and had been entirely successful in all respects - no problems had been experienced throughout the Run although throughputs had been varied considerably. Run B2 had been carried out using Ohio No. 9 coal and had been of 2 days duration. As in Run B1, no problems had been experienced with the gasifier although difficulty had been caused by sticking of the wet coal in the bunker. All the goals of the Run had been attained and it was noted that there was no evidence of a monolith. The need for adequate washing and fluxing of Ohio No. 9 coal was highlighted by this Run.

In answer to a question from the Chairman, Dr. Vierrath stated that Lurgi were investigating how tar addition may adversely effect fuel bed behavior and contribute to monolith formation.

Dr. Hebden expressed the view that start up procedure was important to the establishment of satisfactory fuel bed conditions and closely graded coke was not the ideal fuel on which to start up prior to the addition of a caking coal. Mr. Fink pointed out that earlier Runs on neat Ohio No. 9 coal had used Frances coal during start up and that Pittsburgh No. 8 Run had used coke for start up. It was hoped that Run C would produce data indicating the ideal start up material and procedure.

5. REVIEW OF UNFINISHED ACTION ITEMS

(a) Tagging Procedure

Mr. Watson stated that no procedure was required prior to disposal of the items.

6. RUN C PROPOSAL

The Chairman proposed that this Run should be carried out using the remaining Pittsburgh No. 8 coal. It was suggested that the load should be varied and that fines addition should be carried out at 10% for a period and then at 30% for a further period using neat stock coal.

Dr. Miller asked if it were intended to carry out tar injection during this Run. Dr. Vierrath replied that if fines addition were to be carried out, then tar injection would be essential.

Mr. Scott stated that he would prefer to mix the 50/50 screened and unscreened coal rather than add fines to screened coal. This blending would thereby produce 15% of fines. This proposal was accepted by the meeting.

The Chairman stressed the importance of completing the Run even if fines addition were to be discontinued. Further consideration of the importance of completing a satisfactory Run resulted in the meeting agreeing that fines injection should commence at 7 1/2% using a 3 to 1 blend of screened coal with stock coal.

7. SAMPLES

In order to avoid duplication of samples from various Runs, Mr. Scott offered to produce a schedule of samples which were available to date. Mr. Fink would then decide which of these samples were to be shipped to the USA and appropriate shipping arrangements would then be made.

The Chairman tabled a letter from DOE requesting 35 drums of frit for analysis by Oak Ridge National Laboratories. Messrs. Scott and Fink were asked to liaise on the production of the necessary samples and Mr. Fink suggested that duplicate samples be taken and retained on site for future investigation should this prove necessary.

8. FINAL REPORT

Mr. Scott stated that all reports had been submitted on Run 9C and that the report on Run A was complete and ready for circulation. Reports on Runs B1 and B2 were being produced and the analytical data from these Runs would be available on 27 July 1978.

Dr. Sudbury stated that Continental Oil Company were required to produce a final report covering Task IX for submission to DOE. It was intended that this report be produced in outline, draft and final form, the final report being made available to DOE by October 1978. Mr. McHugh stated that BGC would assist in the preparation of this report.

The Chairman tabled a summary of progress and problems to date and asked that comments on the document be forwarded to Continental Oil Company.

Dr. Hebden and Dr. Vierrath expressed reservations on this document stating that a misleading impression may be formed from the data presented.

9. DISPOSAL OF GOVERNMENT EQUIPMENT

Mr. Watson had written to DOE making recommendations on this matter. Disposal of the coal appeared to be the only problem. DOE were prepared to give coal to BGC on condition that if BGC subsequently gasified the coal, DOE would have access to the data obtained. Mr. McHugh stated this proposal was not acceptable to BGC. A further alternative was to bury the coal - Mr. McHugh estimated that this could cost at least 50,000 dollars. Mr. McHugh stated that BGC would consider accepting this coal without conditions.

It was agreed that BGC would make an offer to Continental Oil Company covering removable items and installed equipment. The offer would also include an estimate of the cost of refurbishing the gasifier together with practical alternatives for disposal of the items and materials.

10. ANY OTHER BUSINESS

Mr. Watson stated that Continental Oil Company intended withholding the outstanding fee for 13,000 dollars until the majority of the invoices had been submitted by BGC.

It was agreed that no further meetings of the TSP Programme Committee would be scheduled.

M. R. Tooley
Secretary

4 August 1978

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