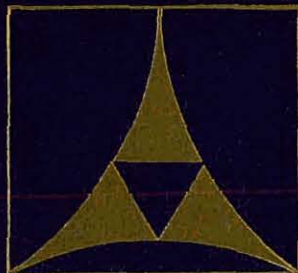


Industrial Fuel Gas Demonstration Plant Program

DOE/ET/13046--T13

OVERALL PROGRAM PLAN
FOR
TASK IX - TECHNICAL SUPPORT
VOLUME I - PLAN, SCHEDULE AND ORGANIZATION

Prepared For
The Department of Energy
Under Contract ET-77-C-01-2582



MEMPHIS LIGHT, GAS AND WATER DIVISION
P.O. BOX 430, MEMPHIS, TENNESSEE 38145

In Association with
FOSTER WHEELER ENERGY CORPORATION
INSTITUTE OF GAS TECHNOLOGY
DELTA REFINING COMPANY

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INDUSTRIAL FUEL GAS
DEMONSTRATION PLANT PROGRAM

DOE/ET/13046 -- T13

MASTER

OVERALL PROGRAM PLAN
FOR
TASK IX - TECHNICAL SUPPORT
VOLUME I - PLAN, SCHEDULE AND ORGANIZATION

Prepared for Department of Energy
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Memphis Light, Gas and Water Division
P. O. Box 430
Memphis, Tennessee 38145

August 1978

Prepared by
INSTITUTE OF GAS TECHNOLOGY

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MEMPHIS INDUSTRIAL FUEL GAS
DEMONSTRATION PLANT PROJECT

TECHNICAL SUPPORT REPORT
(Deliverable #46)

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PREPARED FOR THE
U. S. DEPARTMENT OF ENERGY
ASSISTANT SECRETARY OF FOSSIL ENERGY

UNDER CONTRACT DE-AC02-77ET13406
(FORMERLY CONTRACT ET-77-C-01-2582)

TECHNICAL SUBCOMMITTEE RECOMMENDATIONS

This document is Volume I of a two volume program for Task IX, Technical Support. We, as members of the Technical Subcommittee, participated in the development of the technical objectives and concepts shown in Volume I. We find these objectives, concepts, and plans to be reasonable and are focused on achieving specific milestones recognized by the Committee. We recommend DOE approval of this program.

The implementation and management of this program, including cost, is not within the scope of the Committee's activities.

D. Aubrecht 8/24/78
D. Aubrecht, Chairman

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P. Thakkar, MLGW

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EXECUTIVE SUMMARY

The Industrial Fuel Gas Demonstration Plant Program (MLGW/DOE), Contract ET-77-C-01-2582, has been slowed due to lack of an adequate data base for demonstration plant design. This design data base is to be developed by Institute of Gas Technology (IGT) at their U-GAS pilot plant. While initial data and operating results from the pilot plant have been encouraging, ash-balanced operation with coal using the technique of ash agglomeration has proven to be more difficult than originally envisioned.

Ash must be removed from the gasifier at the same rate as it is being fed to achieve overall ash balance. Adequate ash balance has been achieved by bed withdrawal, but in order to attain high levels of carbon utilization, preferential removal of high-ash material from the gasifier will be required. It is the conclusion of all parties involved that the operating parameters necessary to achieve ash balance and high carbon utilization must be demonstrated at the pilot plant level before a full scale demonstration plant design effort is started.

IGT, with guidance from the program Steering Committee and assistance from the Technical Sub-Committee has re-evaluated its efforts under Task IX, Technical Support. With a critical assessment of data generated to date and an analysis of demonstration plant design data need formulated by Foster-Wheeler Energy Corporation, IGT has developed the attached program to meet the demonstration plant design data requirements. The program reflects innovations in support studies (Bench scale reactor and cold flow model), new procedures in formulation of test objectives, test monitoring, and increased emphasis on overall project management using an altered organizational structure.

The time required for execution of this revised program is seven (7) months. The cost of completing the program is \$1,100,000 over and above that originally budgeted for Task IX. The success of the IFG Demonstration Plant Program depends upon results achieved under this seven month program. We strongly recommend that this program be approved and work started as soon as possible.

DISCUSSION

In tests to date, the U-GAS pilot plant has been able to produce ash agglomerates with both coke and coal, though it has not yet been able to attain full ash balance when operating with coal. A broad range of ash-balanced operating conditions has been achieved with coke. We believe that the mechanism for forming ash agglomerates is similar for both of these materials. However, it appears that the operating range for coal is narrower than that for coke. This has made it more difficult to attain ash-balanced operation with coal in pilot plant operations. Such an operation must be attained before proceeding with the design of the demonstration plant.

At steady state conditions, the amount of ash fed to the gasifier has to be equal to the amount of ash removed as agglomerates. The feed rate of ash is directly proportional to the rate of gasification of coal; this in turn is a function of temperature, bed volume, steam and oxygen feed rates. Mathematical equations are available to determine the rate of gasification.

The removal of ash from the gasifier is proportional to the rate of ash agglomeration. Exact mathematical relationships are not yet known for estimating this rate. However, based on analysis of data obtained during coke tests, the main independent variables that affect ash agglomeration are temperature, bed ash content, particle size, gas velocity and bed height. The effects of these variables on the agglomeration of coal ash are expected to be very similar to that for the agglomeration of coke ash and will be verified in bench scale studies and pilot plant operations.

Further, analysis of latest data from our cold flow model indicates that the rate of agglomerate discharge is proportional to venturi diameter and that the present 3-inch-diameter venturi may be inhibiting agglomerate discharge in the pilot plant.

The above considerations have led to the formulation of this overall program plan. The main objective of the plan is to obtain operating and process data for the design of the demonstration plant. Prior to achieving this main objective (Milestone 7 and 8 in Figure 1), the plan has four preliminary goals on which initial efforts will be concentrated:

- First, to establish the effect of the major variables on the rates of coke and coal agglomeration in the bench scale tests. (Milestone 2)
- Second, to determine the optimum venturi configuration for future pilot plant operations by cold flow model studies. (Milestone 3)
- Third, to confirm the operating range for coke in the pilot plant. (Milestone 5)
- Fourth, using the above information as baseline, to operate the pilot plant to determine the operating range for coal. (Milestone 6)

The program plan has been formulated with the assistance of the Technical Subcommittee which has members from all the parties involved in the Industrial Fuel Gas Demonstration Plant Program, namely, Memphis Light, Gas and Water Division, Department of Energy, Foster-Wheeler Energy Corporation, Delta Refining Company, Institute of Gas Technology and Monsanto Research Corporation.

The overall program plan is presented in two volumes. Volume I - Plan, Schedule and Organization discusses the three major sub-tasks of the program: 1) Bench-Scale Tests, 2) Cold Flow Model Studies, and 3) Pilot Plant Operations. In addition, the schedule and organization to implement the plan are presented.

Volume II - Pilot Plant Tests, the other volume of the overall program plan, is a detailed presentation of test objectives and procedures. It consists of specific test objectives, outlines the approval procedure for test plan, discusses the monitoring of test operations, and presents the cost estimate for the plan. Volume II is presented as a separate document.

PROGRAM PLAN AND SCHEDULE

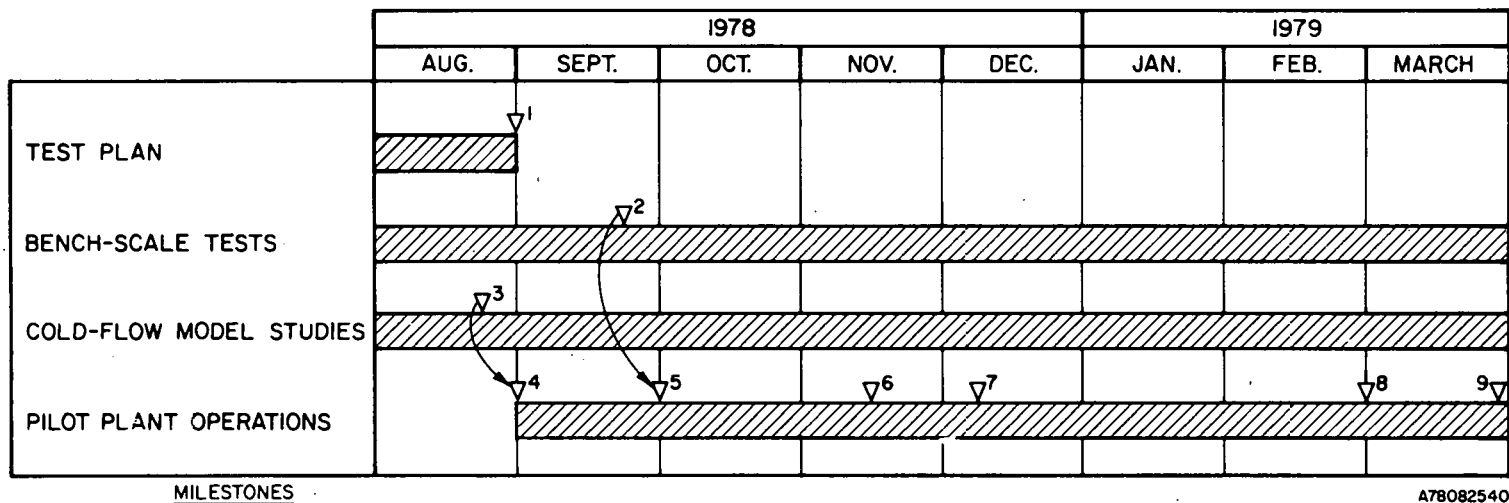
The overall program plan has been divided into three major subtasks which include bench scale tests, cold flow model studies and pilot plant operations. These subtasks will be carried out in a parallel path program as shown in the attached schedule (Figure 1). In this manner a timely execution of the overall plan will be assured. The overall plan will require a period of about seven months to achieve the major program goal of obtaining a demonstration plant design data base.

The plan includes several milestones to assess the progress of the program during the course of the work. The most important of these occurs after about three months when a 5-day pilot plant test with coal is scheduled (Milestone 7). The objective of this test will be to achieve ash-balanced operation with coal under agglomerating conditions. The data from this test will guide development of objectives for subsequent ash agglomerating tests with coal. Another important milestone (Milestone 8) occurs six months after the start of the program when tests at pressure will be completed. The data from these tests will be the basis for detailed design of the demonstration plant. Each of the three sub-tasks are described briefly below.

Bench-Scale Tests

The objective of this subtask will be to establish a sound basis for comparing the ash agglomerating properties of coke and coal. Tests will be made in existing laboratory equipment to measure the effects of the major variables on ash agglomeration. Additional petrographic studies and tests will be conducted with coke and coal to delineate the effects of ash chemistry on agglomeration.

A separate in-house task force of IGT scientists has been formed to aid in the direction of this work. Outside consultants will also be used for this purpose. The relationship of the task force to the program is further discussed under Program Organization Section.



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Figure 1. OVERALL PROGRAM SCHEDULE

The details of this subtask and related scheduling of the various work areas is discussed in Appendix A.

Cold Flow Model Studies

The objective of this subtask is to determine the best configuration for the ash agglomerate discharge venturi for subsequent verification in the pilot plant and scale-up to the demonstration plant. Current information indicates that a larger venturi should be used in the pilot plant, and that the design should be modified to separate the two main functions of the venturi, namely, to feed steam and oxygen to the bed and to control agglomerate discharge. Tests are planned to study a range of venturi diameters and grid designs and their related effects on bed mixing and agglomerate discharge.

A separate in-house task force of IGT senior staff and management has been formed also to aid in the direction of this work. This is further discussed under the Program Organization Section.

Details of this subtask and the scheduling of the various work areas within this subtask are further discussed in Appendix B.

Pilot Plant Operations

The objective of this subtask is to establish the operating conditions necessary to achieve ash agglomeration with coal. After this has been achieved, additional tests at pressure will be conducted to develop demonstration plant design data base.

Before these objectives can be realized, it will be necessary to modify the discharge venturi in the pilot plant. The coal feed section is also being modified to allow mixed coke/coal feeding. These modifications will allow more flexibility in operations and a smoother transition from coke to coal during run start up.

Once these modifications are completed, it will be necessary to conduct a shakedown test with coke to verify the modified venturi design. This shakedown test will also provide data on the effect of major variables on the agglomeration of coke ash.

After shakedown, tests will be conducted with coal to determine the extent of ash agglomeration possible. Operating conditions for these tests will be based on data and information obtained in the preceding pilot plant test with coke and on the relative behavior of coke and coal as established in the bench-scale tests.

This will be followed by about a 5-day test with coal to achieve ash-balanced operation under agglomerating conditions. Next, a series of tests will be conducted at pressure to develop the demonstration plant design data base.

A special pilot plant test organization that has one senior IGT operating person on every shift, besides a shift engineer, has been established. The test organization will assure that approved test plans are followed and senior personnel are available to advise on any necessary deviations. This is further discussed under Program Organization section.

Details of this subtask and related scheduling are discussed in Appendix C.

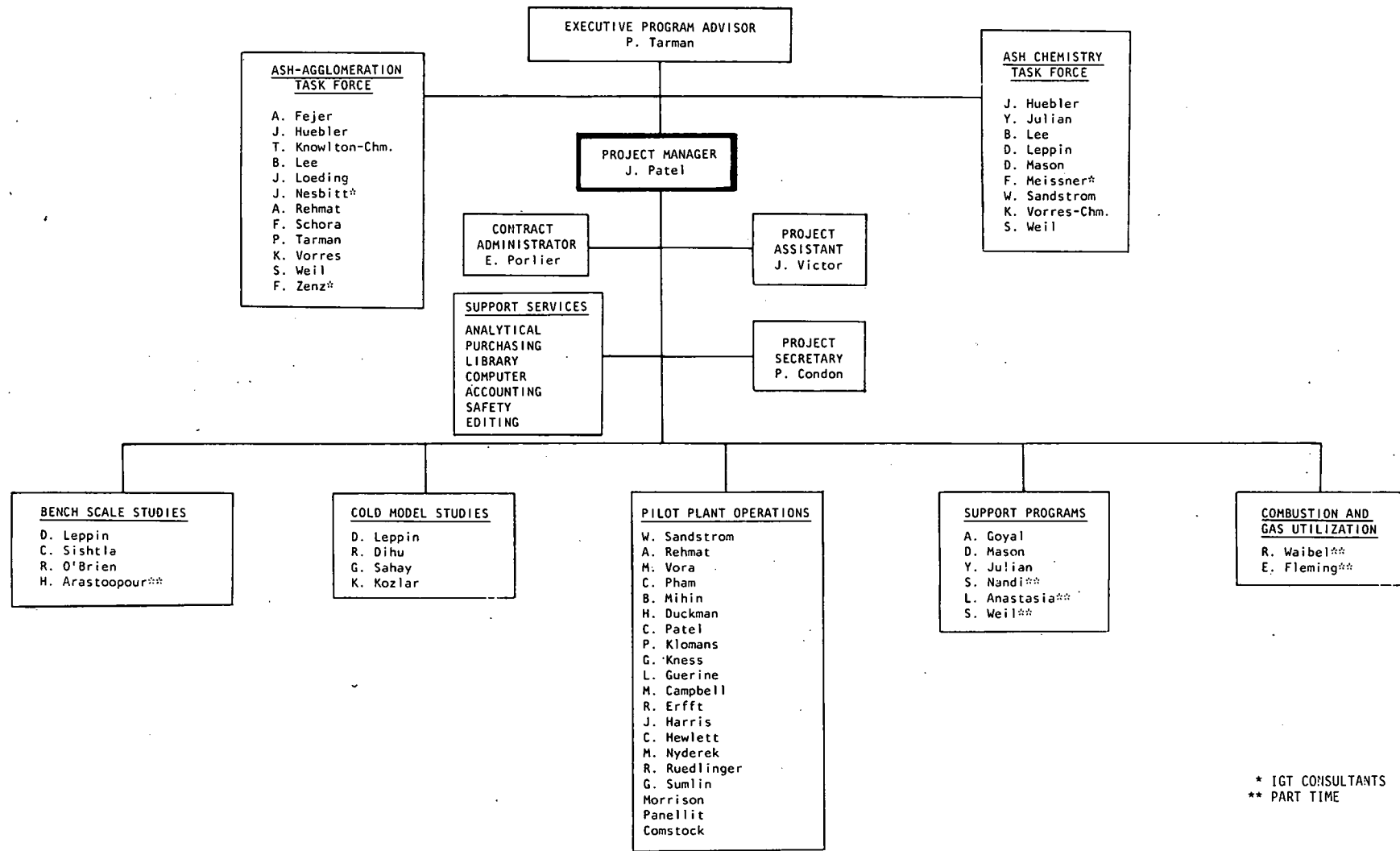
PROGRAM ORGANIZATION

The IGT organization for the execution of the program is shown in Figure 2. The program has a line-and-staff organizational structure. IGT management is fully committed to this program as a major project whose aims parallel corporate goals of IGT. The management has assigned an Executive Program Advisor to assure that all required IGT resources are made available for the execution of the program in a timely fashion.

The IGT Project Manager has the primary responsibility for the technical and administrative performance of all work under the program. The Project Manager has full access to IGT management and senior staff and draws upon their services as required. In fact, during the last six months several meetings of senior staff and management personnel have been convened to discuss various aspects of the program. In addition, informal discussions are continually held with management personnel to keep them aware of the program status. To formalize this relationship, two task forces have been set up to fully utilize all available IGT resources. The two task forces are: 1) Ash Chemistry Task Force and 2) Ash Agglomeration Task Force. A brief background of personnel associated with the program is presented in Appendix D.

The Ash Chemistry Task Force consists of IGT scientists and consultants with Dr. K. Vorres as its chairman. The main goal of the task force will be to determine differences between coke and coal ash and the influence of ash properties on agglomeration. The task force will also aid in directing the bench scale tests and the petrographic work. The chairman will use outside consultants as required. The task force will hold regular meetings at least once every other week. The recommendations of the task force will be presented in a report to the Project Manager who will be responsible for its implementation.

The Ash Agglomeration Task Force will concentrate their efforts on the influence of fluidization, venturi design, and grid design on ash agglomeration in the pilot plant. The task force will also aid in directing cold-flow model studies and pilot plant operations. The task force will function along similar lines as the Ash Chemistry Task Force above. Dr. T. Knowlton will chair this task force which will consist of senior staff and management personnel. These members, besides having vast experience in process development and being involved in other major projects at IGT, will be able to draw upon other pertinent resources as the need arises.



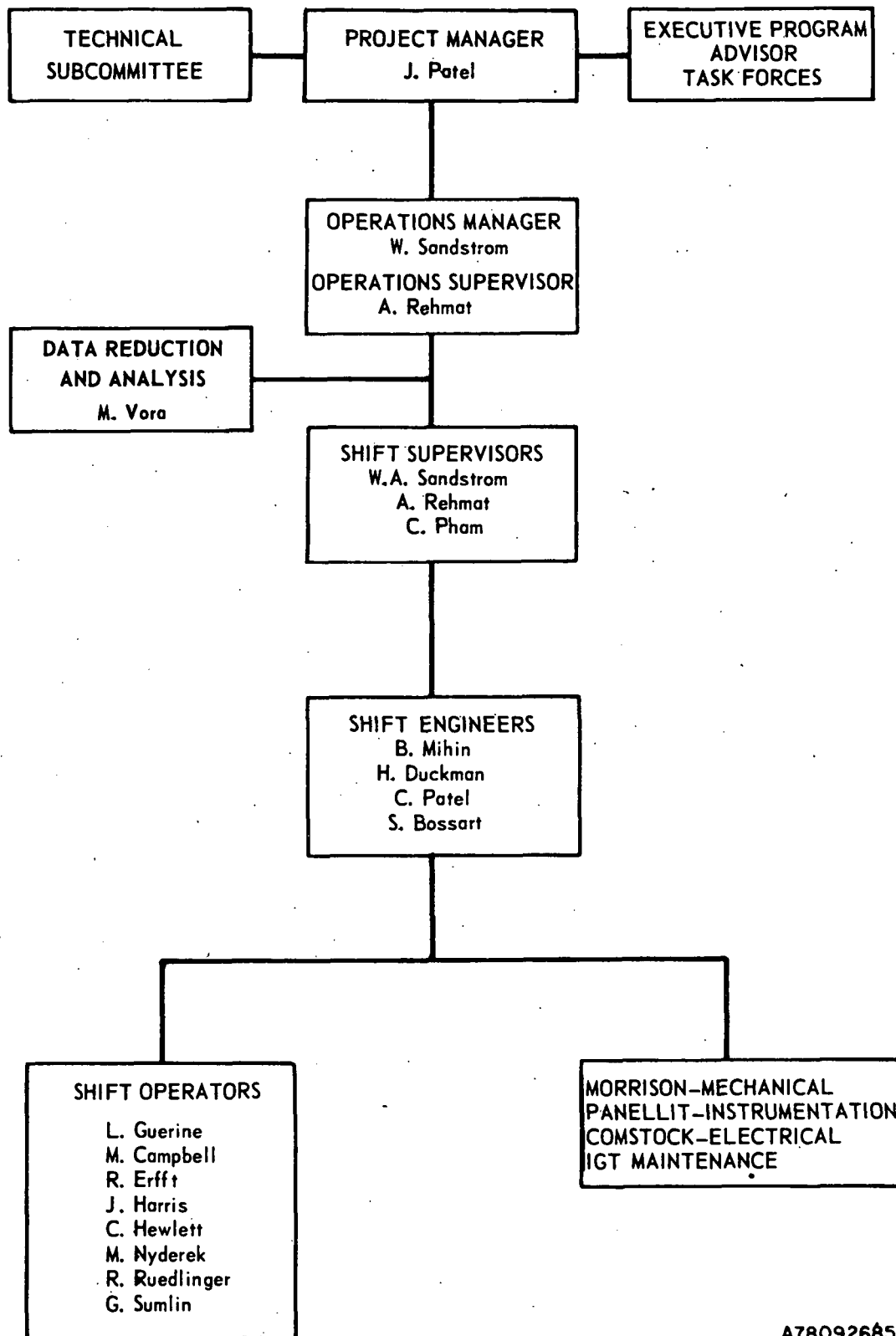
* IGT CONSULTANTS
** PART TIME

Figure 2. PROGRAM ORGANIZATION

Different staff groups provide support services required by the program. These services are provided both at regular intervals and on an "as needed" basis. To assure responsiveness to the needs of the program, the Executive Program Advisor appraises the cognizant IGT vice-president under whose direction all services are combined. Contract administration is provided by a full-time contract administrator who has this program as one of his main responsibilities.

The line organization is divided along task lines. The bench scale tests and cold-flow model studies are under the supervision of one person for better coordination. The Support Programs are under direct supervision of the Project Manager. This subtask includes pilot plant data correlation and mathematical modelling, coal kinetic reactivity measurements and petrographic studies.

The Pilot Plant Operations are under the direction of an Operations Manager who is responsible for day-to-day operation of the pilot plant. He is aided by an operations supervisor, five shift engineers, and nine operators. The organization utilized during performance of pilot plant tests is shown in Figure 3. Detailed test plans and objectives will be formulated in consultation with the Technical Subcommittee and the two task forces. During a test, there will be a shift test supervisor and a shift engineer on every shift. The test supervisor will assure that the approved test plan is followed and will be the person responsible for communicating with on-site monitors. The shift engineer, along with two operators, will be responsible for the operation of the pilot plant during the test. Any required deviations from the approved test plan will be decided upon by the test supervisor and will be acted upon after the Project Manager obtains the necessary approvals. Mechanical, instrumentation, and electrical services are provided by IGT subcontractors.



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Figure 3. PILOT PLANT TEST ORGANIZATION

APPENDIX A

BENCH-SCALE TESTS

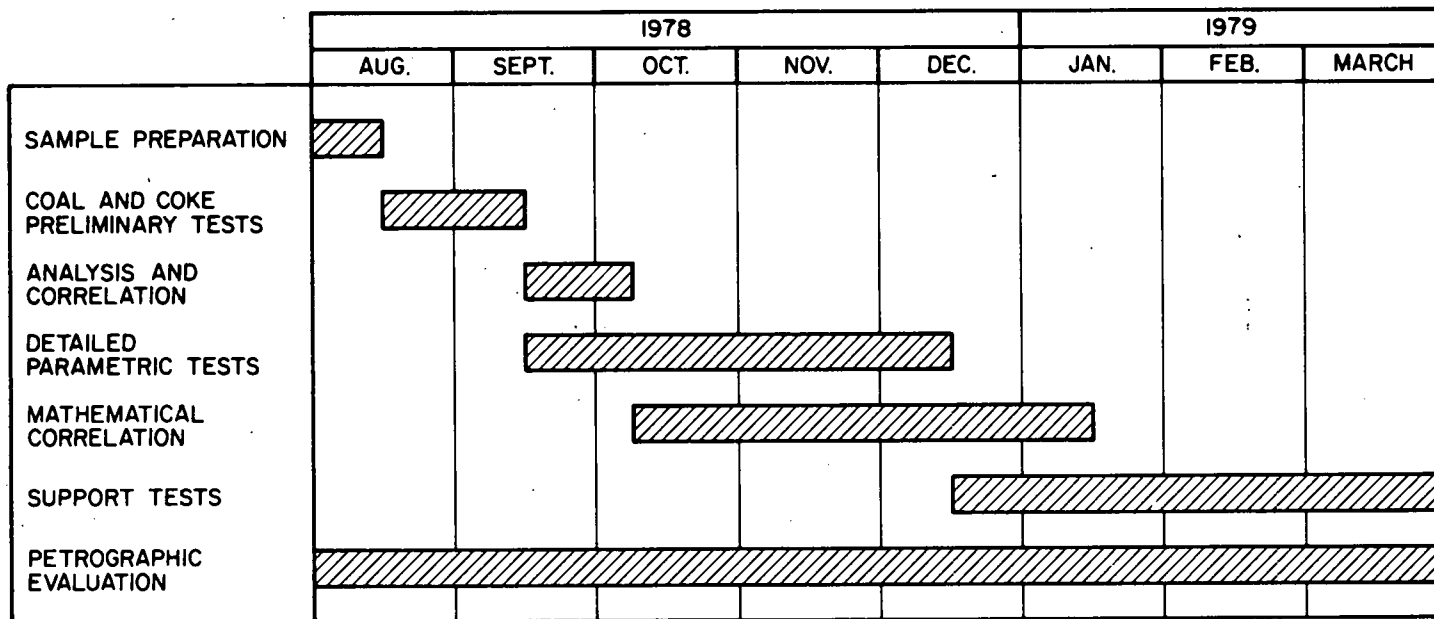
APPENDIX A
BENCH-SCALE TESTS

The objective of the 2-inch diameter high temperature reactor tests is to determine the effect of the five major variables on the rate of ash agglomeration of both coke and coal. (For details about the equipment refer to the Appendix of the June Monthly Report.) Tests will be conducted to determine the relationship between the behavior of coke and coal in the 2-inch unit. With the operating range for coke established in the pilot plant, and the relationship between coke and coal established in the 2-inch unit, we should be able to postulate the operating ranges for coal in the pilot plant. This information will be used in arriving at definitive test plans for pilot plant operations with coal. The schedule for bench scale tests is shown in Figure A-1.

We can determine the variables which affect the agglomeration process in a batch system; and get quantitative information on the sensitivity of the agglomeration process to these variables. The variables and their ranges of interest are listed below:

<u>Variable</u>	<u>Coal</u>	<u>Coke</u>
T, Temperature	1800°F - 2100°F	1800°F - 2100°F
C _A , Ash Content of Material	40 wt% - 80 wt%	15 wt% - 40 wt%
D _p Average Particle Size	-1/4 inch to 400 mesh	-1/4 inch to 400 mesh
V, Superficial Velocity	2 ft/sec to 6 ft/sec	2 ft/sec to 4 ft/sec
H, Bed Height or L/D ratio	1 to 4	1 to 4

The dependent variables of interest are the degree and rate of agglomeration resulting from the above conditions. The screen analysis of particle size distribution of the residue can be used to determine the degree of ash agglomeration. The rate of agglomeration per unit charge of material to the reactor will be determined by making tests for a fixed period of time -- most likely one hour.



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Figure A-1. BENCH SCALE TESTS SCHEDULE

An initial series of tests will be performed with both coke and coal in which the number of tests will be kept to a minimum yet sufficient to obtain the necessary information on the effect of the variables. Approximately 13 tests will be required to accomplish this as shown in the following table. If extensive sintering occurs at a particular condition, this information will still be useful in operation of the pilot plant. In addition materials which have agglomerated will be available for petrographic and microscopic examination.

Later, another detailed series of tests will be performed to obtain data under controlled conditions to formulate a mathematical model for the growth of particles and rates or kinetics of ash agglomeration.

PRELIMINARY TESTS FOR COAL AND COKE

<u>Run No.</u>	<u>Temp. °F</u>	<u>Ash Concentration, wt%</u>	<u>Superficial Velocity, fps</u>	<u>Particle Size</u>
1	1900	40	4	-1/4 to 400 mesh
2	2000	40	4	-1/4 to 400 mesh
3	2100	40	4	-1/4 to 400 mesh
4	1900	50	4	-1/4 to 400 mesh
5	2000	50	4	-1/4 to 400 mesh
6	2100	50	4	-1/4 to 400 mesh
7	1900	70	4	-1/4 to 400 mesh
8	2000	70	4	-1/4 to 400 mesh
9	2100	70	4	-1/4 to 400 mesh
10	2000	50	2	-1/4 to 400 mesh
11	2000	50	6	-1/4 to 400 mesh
12	2000	50	4	-1/4 to 14 mesh
13	2000	50	4	-20 mesh to 40 mesh

Petrographic Studies

The main thrust of petrographic studies will be to elucidate the differences in the ash characteristics of coke and coal and their effects on ash agglomerate formation. The petrographic studies will also be performed to better understand results obtained from the 2-inch diameter hot bench-scale unit and the pilot plant tests. The following is a list of items for petrographic studies:

1. a. Obtain additional proof that ferrous aluminum silicate is present in the coke feed.
b. How does particle size of coke ash compare with coal ash?
2. How much agglomeration occurred in Run 124 with a bed temperature of 1900°F
3. How does FeS participate in agglomeration?
 - a. Does it exude to the surface of the coal particle? Get SEM on un-sectioned coal particles heated to 1900°F.
 - b. Does FeS spread on ash particles?
4. How much iron is occluded as FeS and thus is unavailable for fluxing?
5. Is the variation of ash (in color and composition) from one particle to another, the same for float and sink samples?

(An electron probe apparatus may be required for greater precision in elemental analysis.)
6. Is there a better coal for agglomeration?

APPENDIX B

COLD FLOW MODEL STUDIES

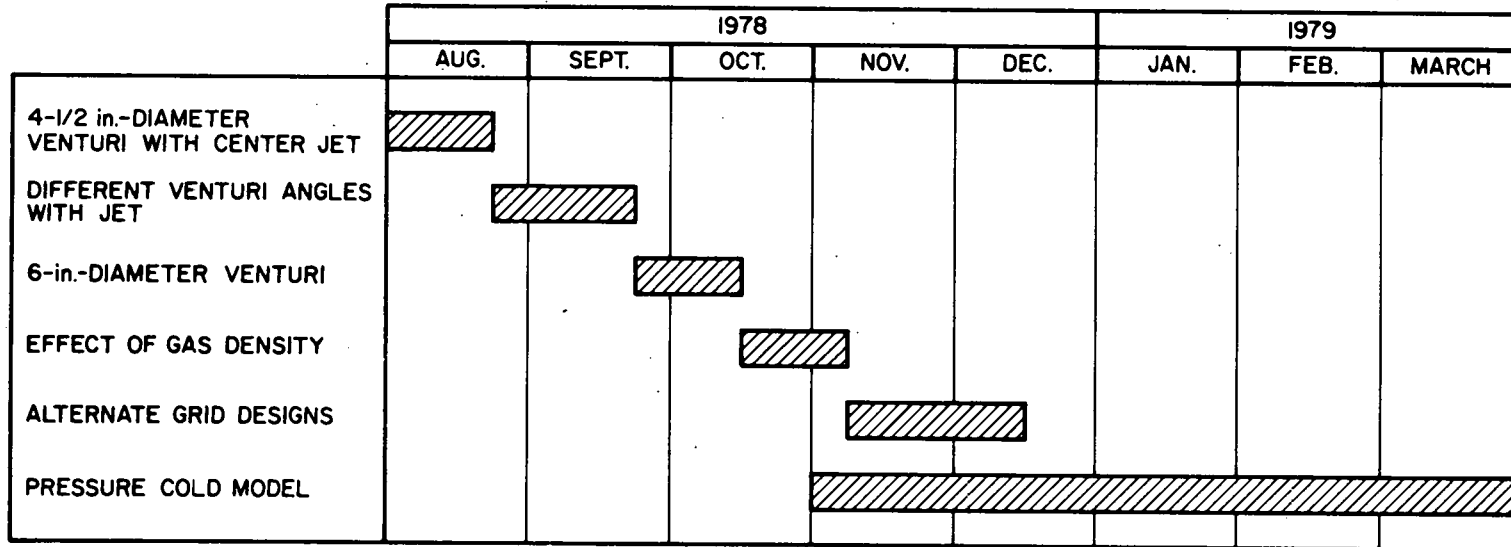
APPENDIX B
COLD FLOW MODEL STUDIES

The objective of cold model studies is to systematically obtain information on the fluidization characteristics and aerodynamic behavior of the gasifier, and to define the configuration of the grid and the venturi section suitable for the Demonstration Plant. The cold model is also utilized to study any modifications of the grid or venturi section before they are implemented in the pilot plant. The schedule for cold model studies is shown in Figure B-1.

The configuration of the atmospheric pressure, semi-cylindrical cold model of dimensions similar to the AAG Pilot Plant Reactor has been discussed previously. Experimental data for several preliminary and trial runs at various conditions and with various types of materials have been presented in these previous studies.

Under this project we have initiated the construction of a fully round 4-ft. diameter pressurized cold model. The configuration to be employed for this unit and a brief outline of an experimental test plan have been presented in "Cold Flow Model Test Plan," published in June 1978.

We have conducted extensive additional experimental tests on the atmospheric cold model geared towards determining the effect of venturi diameter, venturi throat length and agglomerate concentration on discharge of agglomerates from the venturi. It has been determined that the solid discharge rate through a venturi is directly proportional to diameter and inversely proportional to the square of venturi velocity. This indicates that the discharge rate is dependent on the perimeter and not the area of the venturi and on the kinetic energy of the gases flowing through the venturi. The effect of agglomerates concentration on discharge and on defluidization above the venturi has also been studied in these tests but a preliminary investigation of the feasibility of using CO₂ instead of air to determine gas density is underway. The work to date is summarized in the following two tables.



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Figure B-1. COLD-FLOW MODEL STUDIES SCHEDULE

PROPERTIES OF BED PARTICLES AND AGGLOMERATES
USED IN COLD FLOW MODEL TESTS

<u>Material</u>	<u>Average Diameter inch</u>	<u>Particle Density lb/ft³</u>	<u>Terminal Velocity in air ft/s</u>	<u>Bulk Density lb/ft³</u>
<u>Bed Particles</u>				
Acrylic	0.0254	72.0	7.91	36.0
Char from bed of AAG	0.0254	118.7	10.2	55.9
Husky Lignite Char	0.0421	95.6	11.7	51.8
<u>Agglomerates</u>				
Alumina	0.152	157.2	52.9	
Alumina	0.172	149.6	54.9	
Alumina	0.182	149.6	56.4	
Alumina	0.253	149.6	66.5	
Alumina	0.259	149.6	67.3	
Alumina	0.285	149.6	70.6	
Alumina	0.289	149.6	71.1	
Actual Agglomerates, screened, Run 39	0.167	127.0	49.8	
Actual Agglomerates, screened, Run 102	0.182	92.9	44.5	
Polystyrene Spheres	0.394	68.9	56.3	
Glass Beads	0.188	165.0	60.2	
Glass Beads	0.252	165.0	69.8	

VENTURI CONFIGURATIONS USED
L/D Ratio, Inches

2 X 2
3 X 2
3 X 3
4-1/2 X 2
6 X 42

We plan to investigate the proposed 4-1/2 in. venturi with a center jet before installing it in the pilot plant (see section on Pilot Plant Operations). In addition, venturi divergent angles will be varied. In these tests, we will determine the effect of the above changes on agglomerate discharge rate at venturi diameters of 4.5 and 6 inches. Additional tests will be conducted to determine the effects of concentration on defluidization.

In order to complete our knowledge of the behavior of the venturi we will conduct the following tests using a 6-inch diameter venturi.

- Discharge rate and agglomerate concentration tests at standard values of the other variables but with varying venturi velocity. (See June Monthly Report, Page 55, for these conditions.)
- Throat length will be varied from 2 to 42 inches in these tests, and the effects of concentration on defluidization will be determined.

Changes in grid and venturi design will be tested in the cold-flow model to determine their effect on solid mixing and discharge rates. A 60° angle grid and different grid hole design will be tested. Additional tests will be performed to investigate the effect of gas density if it is feasible to use CO₂.

At the end of the above series of tests, predictions of the sizes of venturi required for the Demonstration Plant can be made. The effect of venturi diameter and agglomerate concentration will have been estimated from the experiments, and if CO₂ can be used, an estimate of gas density will also have been made. At this point, the configuration deemed most suitable for the Demonstration Plant will be selected and further studied. The effect of bed height and superficial velocity on the behavior of this configuration will have been suggested by the influence of throat diameter and diverger on discharge behavior, in which case such alternate configuration will be tested preliminarily.

In the meanwhile, the pressurized cold model tests will be started to verify the effect of pressure. A venturi configuration as suggested by the atmospheric cold model test work will be employed.

APPENDIX C

PILOT PLANT OPERATIONS

APPENDIX C

PILOT PLANT OPERATIONS

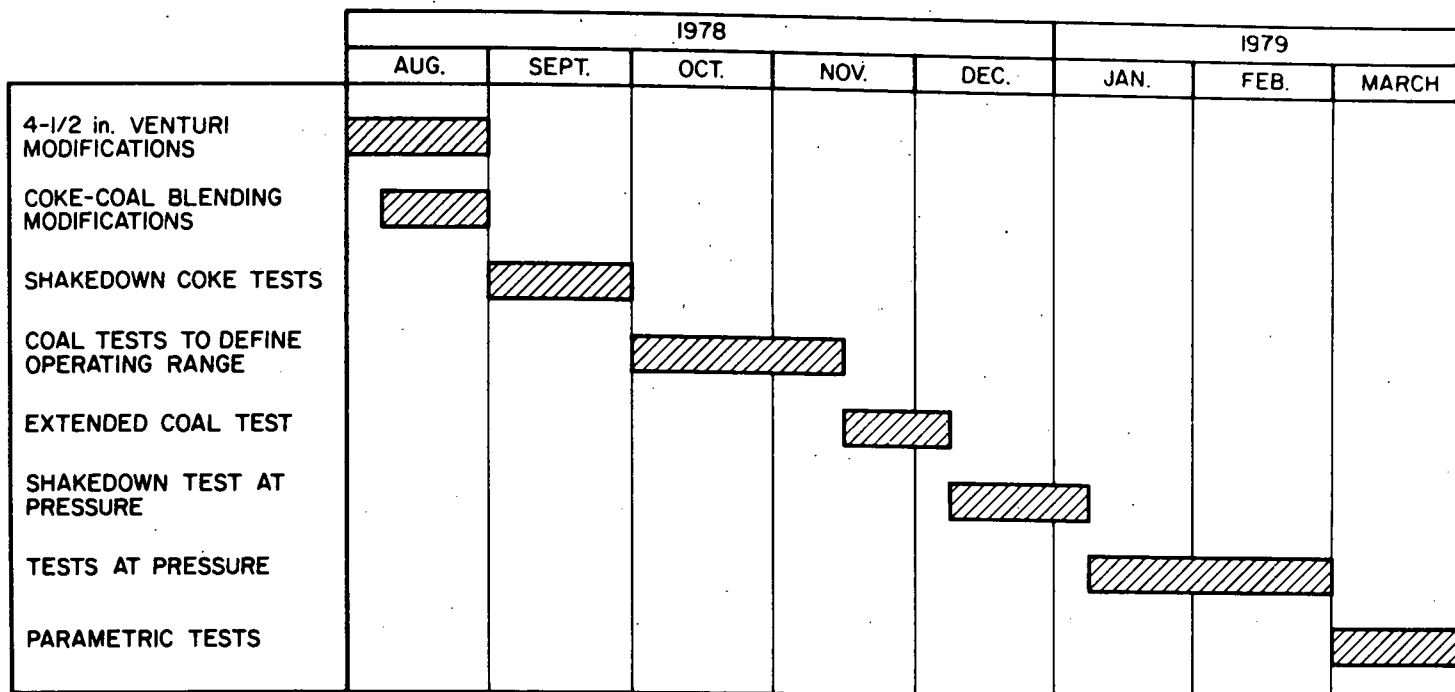
The main objective of the pilot plant operations is to provide process and operating data for the design of the gasification and related sections of the demonstration plant. Before this objective can be achieved, it will be necessary to attain ash-balanced operation with coal in the pilot plant. Specifically the operation of the pilot plant is planned to provide information on the following:

1. Carbon conversion efficiency with low carbon-content residue discharge.
2. Operation of gasifier at pressure of about 3 atmospheres.
3. Product gas quality and yield.
4. Utility requirements.
5. Range of operating parameters.
6. Start-up and shutdown procedures.
7. Turndown capability.
8. Peripheral equipment design.

The schedule for pilot plant operations is shown in Figure C-1.

Modifications

All necessary modification to the pilot plant for operations at higher pressure have been completed. The recommendations made related to pressure operation in "AAG Pilot Plant - Design Analysis, Risk Analysis, and Configuration Control," May 1978 have been complied with. In addition two modifications approved by the Technical Subcommittee are being made and should be completed by the end of August. The 3 inch by 3 inch venturi will be replaced with 4-1/2 inch by 2 inch venturi. Also the size of the oxygen enriching jet in the center of the venturi will be increased so that it has the capability to supply all the oxygen that is normally introduced through the venturi. This modification will allow a larger discharge rate through the venturi and also allow discharge of a material of wider size and density. The other change will be to



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Figure C-1. PILOT PLANT OPERATIONS SCHEDULE

install variable speed drives on both coke and coal silo screw feeder motors. This will provide capability of gradually feeding coal and simultaneously reducing coke feed to the gasifier and avoid sudden switching of feed material.

Modifications to use pretreated coal in the gasifier are not planned at present. The Technical Subcommittee has agreed that pilot plant tests have proved that the caking coal can be fed directly into the gasifier. The effect of pretreatment versus no pretreatment on ash agglomeration will be determined by laboratory tests. If these tests show pretreatment will be necessary to attain ash agglomeration, arrangements will be made to obtain pretreated coal for pilot plant tests.

Shakedown Tests

To familiarize the operating personnel and check out the new venturi a shakedown test will be conducted with coke. The shakedown test will be completed after a 2-3 day steady-state operation with coke. Following the shakedown, a test will be conducted to confirm the operating range with coke in the modified pilot plant. The following is a summary of operating conditions for this test:

Temperature - 1850° to 1950°F

Ash Content - 20 to 40 wt %

Bed Height - 2 to 4 feet

Superficial Velocity - 2 to 4 ft/sec

Particle Size - Internal Cyclone On and Off

External Fines Recycle On and Off

Coal Tests to Define Operating Range

The 2-inch diameter bench-scale studies will have indicated suitable conditions for the operating variables for coal (see section of Bench Scale Tests). Next series of tests will be conducted using this information to determine the rate of agglomeration at operable conditions in the pilot plant and thus allow a logical approach to ash-balanced operation with coal. For a discussion of variables affecting ash agglomeration and requirements of ash-balanced operation refer to Appendix E. The following are the tentative operating conditions for the above tests:

Temperature - 1850° to 1900°F
Ash Content - 50 to 70 wt %
Bed Height - 2 to 4 feet
Superficial Velocity - 3 to 5 ft/sec
Particle Size - Internal Cyclone On and Off
External Fines Recycle On and Off
Mode of Gasification - Steam/Oxygen

At present, the coal being used for pilot plant tests is an unwashed Western Kentucky No. 9 coal. The unwashed coal has a relatively high ash content of about 18 wt%. The ash includes clay and shale from the roof and floor material scraped during the mining operation. Due to the high ash content of coal, the pilot plant has to produce and discharge agglomerates at almost double the rate for coke. To determine the effect of the high ash content on the operation of the pilot plant, we are obtaining a 100 ton batch of washed Western Kentucky No. 9 coal from the same mine as the unwashed coal and conduct tests with it on the pilot plant. The timing of these tests will depend on delivery of the coal to pilot plant site. The operating conditions for the tests will depend on results of the previous tests. However, the conditions will be similar to those that yielded some agglomeration with the unwashed coal.

Extended Coal Test

The extended coal test will be conducted about three months after starting pilot plant test and will serve as a basis for programmatic decisions.

Tests to date will allow us to determine the rate of agglomeration at stable operating conditions. Based on the pilot plant test information and the 2-inch bench scale studies, a logical approach to ash-balanced operation with coal could be predicted. Based on the operating variables selected, the extent of ash agglomeration and the product gas quality and yield will be estimated. The extended test will be conducted to

verify the estimated performance of the pilot plant. The test duration will be about 5 days at stable operating conditions with a determined degree of ash agglomeration. The test may also include fines recycle and will include steam-oxygen mode of operation. Exact operating conditions for the test will depend on results of tests conducted to that date.

Tests at Pressure

The objective of tests at higher pressure is to provide a basis for pressure scale up of pilot plant results to the pressure level of the demonstration plant. The atmospheric tests would have established the optimum operating conditions for the pilot plant for coal. The pressure tests would essentially be performed at these optimum operating conditions, unless there are indications that they change with higher operating pressure. These tests will indicate the effect of pressure on agglomeration, carbon conversion efficiency, fines recycle, product gas yield and composition. Two and a half months are allowed for the operation of pilot plant at pressure. At present, it is believed that operation at only one pressure level -- 60 psi -- will be sufficient to provide pressure scale-up information but tests at an intermediate pressure -- 40 psi -- may be necessary. A decision on this will be made after the first few tests at pressure. The exact operating conditions for pressure tests cannot be established at this time.

Parametric Tests

A series of parametric tests will be performed to determine the operating characteristics. These tests will investigate and verify the range of operability without sintering and defluidization. Tests will also be performed specifically to obtain information on the turndown capability of the gasifier, the response time of the gasifier and the load following characteristics of the gasifier. The tests will provide information on gasification efficiency, gas yields and gas quality when operating at other than design conditions.

APPENDIX D

PROGRAM PERSONNEL BRIEFS

APPENDIX D

PROGRAM PERSONNEL BRIEFS

- ANASTASIA, L. -- Manager, Environmental Engineering. Responsible for environmental data on the U-GAS program.
- ARASTOPOUR, H. (Dr.) -- Chemical Engineer. Mathematical modeling of agglomeration.
- CAMPBELL, M. -- Pilot Plant Operator.
- CONDON, P. -- Secretary. Project secretary.
- DIHU, R. -- Associate Chemical Engineer. Working on pressurized cold model.
- DUCKMAN, H. -- Pilot Plant Shift Engineer.
- ERFFT, R. -- Pilot Plant Operator.
- FEJER, A. (Dr.) -- IGT Senior Consultant. Former Chairman of Mechanical and Aerospace Engineering at IIT. Background in aerodynamics and fluid flow.
- FLEMING, E. -- Chemical Engineer. Involved in combustion studies on the program.
- GOYAL, A. -- Chemical Engineer. Responsible for data analysis and pilot plant modelling.
- GUERINE, L. -- Pilot Plant Operator.
- HARRIS, J. -- Pilot Plant Operator.
- HEWLETT, C. -- Pilot Plant Operator.
- HUEBLER, J. -- IGT Senior Vice President. Over thirty years of industrial research experience. Background in combustion and heat transfer.
- JULIAN, Y. -- Chemist. Involved in petrographic work on coal and coke ash.
- KLOMANS, P. -- Chief Technician, Pilot Plant Operations.
- KNESS, G. -- Pilot Plant Draftsman.
- KNOWLTON, T. (Dr.) -- Manager of Fluidization Research. Chairman of Ash Agglomeration Task Force. Background in fluidization related to coal conversion processes.
- KOZLAR, K. -- Technician. Involved in atmospheric cold model.
- LEE, B. (Dr.) -- IGT President. More than fifteen years of experience in process development. Background in fluidization and coal conversion processes.

LEPPIN, D. -- Chemical Engineer. Responsible for bench scale tests and cold model studies.

LOEDING, J. -- Associate Director, New Processes. Formerly involved in the U-GAS development work.

MASON, D. -- IGT Senior Consultant. Over thirty years of experience in chemistry and petrographic work on coal.

MEISSNER, F. (Dr.) -- Private consultant to IGT. Former professor at MIT.

MIHIN, B. -- Pilot Plant Shift Engineer.

NANDI, S. -- Chemical Engineer. Responsible for kinetic reactivity measurement of coals.

NESBITT, J. -- Private consultant to IGT. Over thirty years of industrial research experience. Background in coal fines combustion.

NYDEREK, M. -- Pilot Plant Operator.

O'BRIEN, R. -- Technical Assistant. Involved in bench scale tests.

PATEL, C. -- Pilot Plant Shift Engineer.

PATEL, J. -- Assistant Director, Utility Gas Development. Project Manager for the U-GAS process.

PHAM, C. -- Pilot Plant Shift Engineer.

PORLIER, E. -- Contract Specialist. Responsible for contract administration on the program.

REHMAT, A. -- Pilot Plant Operations Supervisor. Involved in development work on the U-GAS process. Background in operations.

RUEDLINGER, R. -- Pilot Plant Operator.

SAHAY, G. -- Chemical Engineer. Working on atmospheric cold model.

SANDSTROM, W. -- Pilot Plant Operations Manager. Extensive background in fluidized bed operations. Responsible for pilot plant operations.

SCHORA, F. -- IGT Senior Vice President. Over twenty years of process development experience. Responsible for initiation of U-GAS program at IGT.

SISHTLA, C. -- Chemical Engineer. Day-to-day bench scale studies.

SUMLIN, G. -- Pilot Plant Operator.

TARMAN, P. -- IGT Vice President, Process Research. Over twenty years of experience in process development. Executive Program Advisor

VICTOR, J. -- Chemical Engineer. Project assistant.

VORA, M. -- Chemical Engineer. Pilot plant data reduction and analysis.

VORRES, K. (Dr.) -- Associate Director, Process Program Development. A well-known expert on coal ash chemistry with over twenty years of experience in basic industrial research.

WAIBEL, R. (Dr.) -- Manager, Combustion Research. Responsible for combustion studies on the program.

WEIL, S. (Dr.) -- Senior Scientist. Over thirty years of research experience at IGT with spacial background in fundamentals of coal conversion processes.

ZENZ, F. (Dr.) -- Private consultant to IGT. A well-known industrial consultant in fluidization.

APPENDIX E

VARIABLES AFFECTING ASH AGGLOMERATION

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VARIABLES AFFECTING ASH AGGLOMERATION

At steady state conditions the amount of ash as coal fed to the gasifier has to be equal to the amount of ash removed as agglomerates. The feed rate of ash is directly proportional to the rate of gasification of coal; this in turn is a function of temperature, bed volume, steam and oxygen feed rates. Mathematical equations are available to determine the rate of gasification. The removal of ash from the gasifier is proportional to the rate of ash agglomeration. Exact mathematical relationships are not yet known for estimating this rate. However, based on analysis of data obtained during coke tests, the main independent variables that affect ash agglomeration are:

1. T Fluidized bed temperature
2. C_A Ash concentration in bed
3. D_p Average particle size in bed
4. V Overall superficial velocity
5. H Bed height or equivalent

The effect of each variable is discussed below:

Temperature

The average bed temperature has a marked effect on agglomeration. There is a minimum temperature of about 1860-1880°F below which coke ash agglomerates do not form agglomerates at an appreciable rate. On the other hand, operating at too high a temperature results in clinkering and defluidization. The temperature required to form ash agglomerates is strongly influenced by solid particle size and superficial velocity (discussed further in the text). It is postulated that a higher temperature zone exists in the vicinity of the grid and the venturi; however, the average bed temperature is only an indication of the temperature of the hot zone. The 2 in.-diameter bench scale studies also indicate that a hot zone temperature of 2000°F is required to make agglomerates with coal.

Ash Concentration in Bed

The concentration of ash in the bed affects the rate of ash agglomeration because it determines the sticky surface area that is available for captivation and growth of ash particles.

With coke, a bed ash content in the range of 20 to 30 wt % is required before a noticeable rate of ash agglomeration is achieved. A high ash concentration or absence of simultaneous ash agglomeration also leads to sintering and bed defluidization as indicated in Table 1 below. Also higher ash concentrations lead to higher ash agglomeration rates as shown in Table 2.

Table 1

<u>Run No</u>	<u>Feed Material</u>	<u>Feed Size</u>	<u>Bed T °F</u>	<u>% Ash in Bed</u>	<u>Comments</u>
39	coke	-6 mesh	1912	25-30	Agglomeration
44	coke	-6 mesh	1900	35	Sintering

Table 2

<u>Run No</u>	<u>Feed Material</u>	<u>Bed T °F</u>	<u>% Ash in Bed</u>	<u>Aggl. Rate lb/hr</u>
50	coke	1940	29	62
52	coke	1937	23	49

Average Particle Size in Bed

Particle size affects the rate of ash agglomeration because it directly relates to the number of inter-particle collisions required to produce one ash agglomerate. Also smaller size particles gasify at a faster rate, requiring a higher rate of ash agglomeration. Table 3 shows that as the particle size in the bed decreases, a higher temperature, hence higher ash agglomeration rate is required to keep up with the increased gasification rate.

Table 3

<u>Run No.</u>	<u>Feed Material</u>	<u>Feed Size</u>	<u>Fines</u>	<u>Bed T °F</u>
31	Coke	1/4 X 0	All Fines Removed	1880
31	Coke	-6 mesh	All Fines Removed	1900
48	Coke	-6 mesh	Int. Cyclone	1928
50-53	Coke	-6 mesh	Total Fines Recycle	1950

Superficial Gas Velocity

The gas velocity determines the circulation pattern of solids in the fluidized bed. Though not a first order effect on the rate of ash agglomeration, increasing the gas velocity increases the kinetic energy of the particles and therefore reduces their tendency to adhere during a collision. Higher velocity

also increases solids circulation and decreases the temperature of the hot zone. In contrast higher circulation results in a higher number of collisions which favors agglomeration. On the other hand higher velocity very strongly reduces clinker formation and defluidization; allowing operation at relatively higher temperatures. Table 4 shows data supporting the above facts.

Table 4

Run No	Feed	Size	Vel ft/sec	Fines	Temp °F	Comments
48	Coke	-6 Mesh	2.1	Int. Cyclone	1928	Aggl.
125	Coke	1/4 X 0	4.5	Int. Cyclone	1950-1960	Aggl.
113	Ill. Coal	1/4 X 0	2.4	Int. Cyclone	1850	Sinter
116	Ill. Coal	1/4 X 0	2.4	Int. Cyclone	1830	Sinter
118	Kent. Coal	1/4 X 0	3.6	Int. Cyclone	1850	No Sinter
122	Kent. Coal	1/4 X 0	3.2	No Int. Cyclone	1820-1840	No Sinter

Bed Height

The bed height has not been varied sufficiently during tests with coke to provide data as to its effect on the rate of ash agglomeration. It is known that deeper beds will increase the rate of gasification, hence ash formation; and a higher rate of ash agglomeration is required to maintain ash balance. However, since agglomeration does not occur throughout the bed, its rate does not increase with bed depths. Therefore, deeper beds require higher ash contents, hence operation closer to the sintering point, than shallow beds. That is, at otherwise similar operating conditions, shallow beds will be more easily operated.

The above data analysis show that the rate of ash agglomeration, R_A , increases with temperature, ash concentration, and particle size, and decreases with gas velocity. No effect of bed height is expected. We also know that the rate of ash formation (gasification), R_G , increases with temperature and bed height (volume) but decreases with ash concentration and particle size. No effect of velocity, per se, is expected.

In order to avoid excessive ash buildup and possible sintering, it will be necessary to increase R_A relative to R_G , i.e., reduce R_G until it equals R_A . The most important variables to accomplish this are those that have opposite effects.

Thus, increasing C_A can bring an imbalanced system into ash balance. Increasing average particle size would have a similar effect. Also,

decreasing bed height, since it decreases R_G but has only small effects on R_A , can also bring a system into balance. Since the effect of temperature on R_A is not known precisely, changes in this variable could have different effects. For instance, if R_A increases faster than R_G with increases in temperature, then raising bed temperature would tend to bring a system into ash balance. This behavior has been observed in many coke runs.

The above analysis shows that the most important operating variables for bringing the system into ash balance are ash concentration, temperature and bed height.