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William B. Clark, Rodney P. Bowser, James F. Griffin, Wayne E. Kesling, Thomas J. Kissner, Fredrick G. Krach, Lane W. Metcalf, Woo K. Park and Robert P. Wurstner

December 14, 1979

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MOUND FACILITY
Miamisburg, Ohio 45342

operated by
MONSANTO RESEARCH CORPORATION
a subsidiary of Monsanto Company

Monsanto

for the
U. S. DEPARTMENT OF ENERGY

Contract No. DE-AC04-76-DP00053

MASTER

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1. Introduction

Morgantown Energy Technology Center (METC) is planning to expand its in-house coal gasification R&D capabilities by installing a research facility that can address a number of concepts including entrained, fluid bed, and catalytic gasification and flash pyrolysis. This Advanced Gasification Concepts (AGC) facility is, in addition, intended to have sufficient flexibility to allow its use beyond the stated objectives that formed the basis for its design. The design, as it currently stands, includes piping and instrumentation diagrams, vessel drawings and specifications, instrumentation lists and specifications, and equipment layout and isometric drawings. Before the design is finalized, a critique is needed to ensure that the intended flexibility and objectives can be met.

This Technical Review of the Flud Bed Design Report was prepared by Monsanto Research Corporation (MRC) to satisfy the requirements of the U. S. Department of Energy Field Task Proposal/Agreement bearing Contractor Number P79-8-249. The overall objective was to provide Morgantown Energy Technology Center (METC) with a critique of the design report entitled "Design and Specification of a Coal/Char Gasification Fluid-Bed Bench Scale Facility," Revision 2, dated June, 1979, prepared by Science Applications, Inc. (SAI).

The design approach was evaluated to determine whether the present design will meet the research objectives, including the need for flexibility.

Heat and material balances, critical velocity requirements, vessel arrangements, potential operational problems, and instrumentation were reviewed.

The mechanical design review included a critique of the drawings and specifications, adherence to standards and codes, materials of construction, vessels, piping, valves, heaters, and fittings. In addition, utilities requirements, heat transfer and particulate removal calculations, and pumping and heat exchanger requirements were checked.

An evaluation of the equipment cost includes a critique of the reliability of the equipment cost breakdown, the areas of cost uncertainty, and the areas for potential cost savings.

A safety analysis is provided that identifies highly probable and highly serious potential safety hazards and includes appropriate recommendations.

2. Summary of conclusions and recommendations

This section is a concise comprehensive summary of the significant conclusions and recommendations pertaining to the functional capabilities, cost, and safety of the system. It does not include the suggestions regarding minor clarifications. Additional discussions regarding the conclusions and recommendations are presented in the subsequent sections of the report.

2.1. Several statements in the report require updating and clarification. It is recommended that the report be updated.

2.2. The SAI report optimistically states that design is sufficiently complete to initiate procurement, whereas the experiments to be performed with the system have not yet been clearly defined. It is recommended that a specific test plan be generated, including accuracy requirements, and the conceptual design be thoroughly reviewed before proceeding further with the detailed design. Procurement should not be initiated yet.

2.3. The fluid bed cannot be operated properly over such a wide range of particle sizes as 5 to 300 μ. With such a wide range, it is difficult to provide sufficient gas velocity to fluidize the larger particles without significant carryover of the smaller particles. It is recommended that a small particle size range be selected at the upper end of the 5 to 300 μ range.

2.4. No provisions for solids sampling and/or monitoring solids flow in the system during an experimental run were reported. It is recommended that consideration be given to the benefits of sampling and of verifying the solids flow.

2.5. Insufficient heat is provided to the gas streams to prevent condensation of the steam when the steam and noncondensible gas streams are mixed. It is recommended that an additional gas preheater be provided.

2.6. The present reactor design of Hastelloy X can be operated only to 1650°F based on ASME code requirements. It may be possible to obtain approval to use Hastelloy X at higher temperatures, such as 1800°F, from ASME as a special case. The heaters could then be oversized to provide for the higher temperature option. If a special case approval cannot be obtained for Hastelloy X, then it is recommended that consideration be given to alternate materials and designs.

2.7. The present reactor heater design requires long heat-up times to reach steady state conditions and could limit the flexibility of the system. It is recommended that the reactor heater duty be increased in size to obtain the desired heat-up time and to cover expected worst case endothermic operating conditions when defined.

2.8. It was concluded that the proposed rotary star feeder, coupled with modifications based on METC's experience, is the best approach.

2.9. The reactor and reactor heater designs as provided will be difficult to dismantle and clean. A reactor and reactor heater design of removable sections would allow

for greater flexibility of bed height and ease of cleaning and inspection.

2.10. The 2-in. inlet should be significantly larger for ease of adding coal to the hopper.

2.11. The cyclone separator is designed to handle the total solids feed rate to the reactor of 1 to 2 lb/hr. It is recommended that the design be based on the actual expected entrainment rates and expected particle size distribution. The particle size distribution to the unit should be confirmed after the test program is defined.

2.12. The liquid cooling system is adequately sized for the present system. This is an inexpensive area to add extra capacity for future flexibility, and it is recommended that this be done.

2.13. The flexibility of the instrumentation for this project could be increased by the use of dual thermocouples to eliminate unnecessary shutdowns, and the use of data loggers to provide a programmable capability.

2.14. The material and energy balance summaries and computer simulation appear to be numerically correct; however, they do not include separate cases for all the parameters that will be investigated. The material and energy balances should be reviewed when the test program is defined and should include cases for the planned endothermic conditions with catalized and noncatalized coals.

2.15. The cost estimate is incomplete and confusing, making it difficult to evaluate. The total project cost was not included. It is recommended that the estimate be updated to represent the current plans.

2.15.1. The estimate did not include engineering costs to complete the design which will be a significant cost.

2.15.2. Most of the material costs assigned to individual items seemed reasonable.

2.15.3. The allowance for contingency is low for this early in the life of the project.

2.15.4. An escalation factor should have been added to allow for the rise in costs due to inflation.

2.16. The safety requirements of the system and facility and their relationships are not clearly defined in the design report or the operating and safety manual. It is recommended that the planned SAR be completed and that the Operating and Safety Manual be updated. The following specific safety recommendations are made:

2.16.1. It is recommended that nitrogen be used to pressurize the feed hopper instead of the flammable gases to avoid unnecessary safety concerns.

2.16.2. It is recommended that the flammable gas feed systems include flame arrestors.

2.16.3. The system should be instrumented for remote operation to eliminate the need for personnel to enter the pressure cell while the system is operating.

2.16.4. The relief valves provided on pressure vessels are shown relieving to the atmosphere. These relief valves should go to the flare. If the proposed carbon steel relief valves are used, they should be located away from the hot equipment. Also, it would be safer to have some system to alert personnel when relief valves are activated. Pressure sensing and venting devices should be incorporated at all points where pressures may be isolated.

2.16.5. An explosion suppression system, available from Fenwall, should be investigated. A fire protection system, preferably Halon, should be provided for the electronic equipment.

2.16.6. It is recommended that only blow-out walls be used rather than blow-out walls and a blow-out roof because of the problems associated with snow and ice loading and the problems of containment of the blow-out portion of the roof.

2.16.7. It is recommended that action and alarm levels for toxic and flammable gases be defined to ensure personnel safety.

2.16.8. It is recommended that a two-speed ventilation system be provided for the cell. The high-speed ventilation should prevent buildup of toxic or flammable gases and the low-speed should maximize the sensitivity of gas detection monitors.

2.16.9. The design of the information/alarm systems should consider "human factors" to ensure proper reaction from operators to the system deviations.

2.16.10. It is recommended that emergency power be provided to all systems necessary to monitor and shut down the process, including such things as air supply to the air-operated valves.

2.17. Since quality control is not mentioned in the documentation provided, it is recommended that consideration be given to the implementation of appropriate quality control measures. For example, it should be required that the Hastelloy X welds be radiographed.

3. General review of design report

Section 3 includes general discussions of topics applicable to most of SAI's design report, but not specifically applicable to any single page or few pages of the design report. It complements the discussions in Section 4, which address topics page by page.

3.1. Test Program

The overall objective of the report is to design a bench scale fluid bed reactor to study catalized and noncatalized coal reactions and to evaluate ways to reduce catalyst costs and/or improve reactivity. This system needs to operate independently of the entrained system and have the flexibility to operate at numerous conditions. Studies with this system are expected to last for approximately five years. Specific test plans for the system will be defined when METC reviews the conceptual design provided by SAI. When the test program has been specified, the equipment specifications will have to be reviewed.

3.2. Materials of Construction

The specified material of construction for most of the system is Hastelloy X. Since this material is ASME code rated to 1650°F, a special case may have to be presented to ASME for use above this temperature. With the heater element and preheater tube outside wall limited to 1650°F, the preheated gas could not be heated to the specified 1750°F, thus limiting the amount of sensible heat available. It should be noted than another preheater is required before the steam is mixed with the other gas streams to avoid condensation. The reactor operating temperature would also be limited to 1650°F at the outside surface of the reactor wall. If these temperature limitations are too great, alternate designs could be considered.

3.3. Instrumentation

The flexibility of the instrumentation for this project could be increased by the use of dual thermocouples eliminating unnecessary shutdowns and by the use of data loggers. A digital data logger which can be programmed for increased flexibility has the capacity to easily monitor 100 temperature points and could replace many three-pen recorders for a cost savings.

The P&I diagrams provide sufficient conceptual information as to what kinds of instrumentation are being proposed and where they are located in the process flow. The two major areas of concern on instrumentation are the need to further define the safety interlocking system and the need to define what valves require remote operation to eliminate the need for personnel to enter the pressure cell during operation.

In some cases the instrumentation specifications are too specific: They appear to be rigid specifications from a particular manufacturer, e.g., multipoint recorders. In other cases the specifications are too general. The instrumentation specifications should be reviewed in greater detail after the process accuracy requirements are defined and completion of the P&I diagram.

3.4. Quality Control

Quality control is not mentioned in any of the documentation provided. The system involves unique designs, hazardous materials, and considerable complexity. As the end result must be meaningful experimental data, it is recommended that consideration be given to the implementation of appropriate quality control measures that meet the intent of a formal program such as DOE AL Appendix 08XA.

4. Detailed review of design report

Section 4 includes discussions which are specifically applicable to a single page or a few pages of SAI's design report. Some topics, of a more general nature, were previously discussed in Section 3, which complements Section 4.

Page 1-1

The operating parameters, such as the gas fluidization velocity, and the degree of flexibility will change between coal, char, and coal history primarily as a result of the large differences in density. Definition of specific test plans will enable better definition of these parameters.

The SAI report states that the "level of material contained in this report should enable the contracting agency to proceed directly with the equipment selection, vendor fabrication, and construction with minimal additional engineering effort." The design concept is reasonable; however, a large engineering effort will be required to finalize the detailed design.

Page 2-1

The fluid bed system and entrained system are intended to be operable simultaneously and independently. This is not clearly stated in the report and should be clarified.

Page 2-2

Plant air is listed as a utility; however, what it will be used for is not discussed. The reactor heater does not have the capacity to supply all the necessary heat required for possible endothermic reactions. The sensible heat and the heat available from possible exothermic reactions should be considered only as a safety factor for future flexibility. It is recommended that the reactor heater be designed in sections matching the anticipated bed height. The heaters could be oversized for later flexibility up to 1800°F, as discussed with METC, provided that ASME would approve the use of Hastelloy X as a special case for this temperature. Heat losses above the bed height are expected to be high, eliminating the need for cooling.

The definition of the term "adiabatic" is not clear. METC's intent is to match the temperature of the reactants with the temperature of the reactor inside wall. The report should be updated to clearly state this intent.

Page 3-1

No specific tests have been defined to investigate significant improvements in the overall catalytic gasification process and thus improve the economics. Ways to improve economics include reduced catalyst loading, reduced catalyst cost, improved reactivity of the catalyst, and operation at lower temperature. The report should be updated to include the specific test plan to study these variables.

Page 4-1

Actual pressure cell dimensions are not clear. The report uses a maximum height restriction of 20 to 25 ft. The preliminary equipment layout drawing shows the

equipment height of 22 ft and a cell height of 26 ft. The budgetary estimate includes a pressure cell with dimensions of 20 x 50 x 20 ft. The report should be updated to reflect the actual cell dimensions which are understood to be 20 x 15 x 36 ft with a height restriction of 27 ft to the crane hook.

The report does not include provisions for feed preparation, such as coal grinding, screening, catalyst impregnation, and drying. Feed preparation will affect the properties of the coal and char and will ease solids handling problems like agglomeration. Information on planned feed preparation should be included in the design report.

Page 4-2

The safety requirements of the system and facility and their relationships are not clearly defined in the report. It is recommended that the planned SAR be completed.

The interface between the instrumentation and the automatic data acquisition system is unclear.

Page 5-1

The report says "to preheat the gas to 250°F above the reactor temperature" and needs to be clarified to show this gas outlet temperature is 1750°F.

It should be made clear how the feed temperature of the gas going to the preheater is heated to 200°F.

The present gas preheating system mixes saturated steam at 365°F with the other gas stream at 200°F making condensation an area of concern on the fluid bed system. A "Dowtherm" jacket will be used on the entrained system to superheat the other gases to 600°F before they are mixed with the steam from the steam generator. It is recommended that a similar system be used for the fluid bed system.

Page 5-2

The report should define under what conditions the reverse Boudard reaction could exist. A problem could exist if a large amount of carbon monoxide is bypassed around the preheater, since this would substantially cool the preheated gas entering the reactor. This should be reviewed after the test plans are defined.

Page 5-3

The report specified a particle size distribution of 5 to 300 μ which is smaller than is normally used on larger scale experimental fluidization units, 8 to 100 mesh (149 μ to 2380 μ). METC does not plan to operate the fluid bed system with this 70% through 200 mesh (5 to 300 μ) coal. The report should be clarified. It is recommended that a small particle size distribution range be picked at the upper end of the 5 to 300 μ specified range to give greater flexibility to the operating parameters and make it easier to achieve steady state conditions.

Page 5-5

The superficial gas velocities should be adjusted for an actual gas residence time in the bed of approximately 1 to 5 sec. The velocity needs to be high enough to eliminate agglomeration; however, excess velocity may carry over fines and not allow enough time for tar cracking. The

planned feed preparation and catalysts will help minimize these solids handling problems. The listed velocities of 0.1 to 20 cm/sec will have to be updated based on the actual coal particle sizes.

The molar ratios of H_2O/CO and H_2/CO are specified as zero and the molar ratio of steam/base carbon is specified as 1 to 2. These numbers should be consistent: METC does plan to make some runs with no steam.

Page 5-6

The specifications and the P&I diagram do not include the external heating on the coal hopper to prevent condensation of vapors as mentioned in the report. Inert gas would be better to use for pressurizing the feed hopper instead of the flammable gases and steam mixture and would minimize condensation problems provided that this would not upset the material balance.

The current conceptual design provided by SAI included few provisions to easily measure the material balance. The three char receivers and an additional char receiver, located below the reactor, should be easier to empty and weigh. A rotary valve at the bottom of these vessels could feed the solids to containers on scales if this is economical based on the system desired accuracy. This would allow continuous monitoring of solids flow and could also be used to calibrate the coal feed system. Other methods of verifying the solids flow should be considered. The liquid cooling system could include flow totalizers or scales to measure the initial and final contents of the system if the desired accuracy cannot be achieved with the level gages provided.

Page 5-7

It might be possible to eliminate the cyclone separator and use just the venturi scrubber. If this alternative is used, the solid fines and liquid byproducts could not be kept separate which would be a disadvantage.

The two differential pressure level controls should be adequate eliminating the radioactive probe alternative. METC is in agreement that this alternative is not necessary.

Page 5-8

The gas preheater is not capable of adding much of the heat required for the endothermic reaction because the maximum code temperature of Hastelloy X is 1650°F. Since the reactor design temperature is 1500°F, the gas can be heated only an additional 150°F. Carbon monoxide, bypassed to reduce carbon deposition, and other process gases, bypassed around the gas preheater to maintain temperature control, further reduce the heat which can be added to the system. Thus the reactor heater must be sized to supply essentially all the heat required for the planned endothermic operating conditions.

Operating at twice the minimum fluidization velocity may cause high entrainment if a large particle size distribution

spread is used. A typical ratio range of largest particle size/smallest particle size to get good mixing would be 8 to 10.

Page 6-2

Inert gas is shown on the P&I diagram, but not shown on the process flow diagram.

Page 6-3B

The normally closed relay shown on the electrical power to the gas preheater should fail open. It is expected that METC's plan to use solid state controllers instead of relays will be shown on the revised P&I diagram.

Flow transmitters on the feed gas streams numbered 202, 203, and 204 should be numbered 203, 205, and 207 respectively to be consistent with the flow instrument process data sheet on SAI's page 9-68.

Page 6-3A

The (s) symbol used to tie the reactor thermocouples to the gas preheater is not defined.

The relief valves provided on the pressure vessels are shown relieving to the atmosphere. These relief valves should go to the flare.

Solids could plug the line to the flare if the venturi scrubber is bypassed.

The reactor heater control and safety interlock system is not defined on the P&I diagram.

Page 7-1

Typographical error, "(TRC 202-208)" should say "(FRC 202-208)." The flammable gas feed systems should include flame arrestors. The process safety system is not well defined at this time. It is unclear what "hand control valve" means. METC plans to use pneumatic valves to avoid penetration to the pressure cell. These changes should be included in the report and P&I diagram.

Page 7-2

It is recommended that a pressure vessel, similar to the char pots, be located below the reactor to catch large particles and aid in the coal feeder calibration. The system instrumentation will have to be adjusted for each particle size distribution which will be used.

Page 7-4

The gas grab sampling system is shown on the P&I diagram, but there are no equipment specifications. This system should be instrumented for remote operation to eliminate the need for personnel to enter the pressure cell while the system is operating.

Page 8-3

If hydrogen is used to pressurize the feed hopper, as proposed by SAI, to avoid condensation, then provisions should be included in the safety system.

Page 8-7

An emergency shutdown which dumps inert gas to the system will be a thermal

shock. There might be a safe way to shut down on emergency conditions which would minimize thermal shocks.

Page 9-3, Reactor Specifications

The effects of cycling temperatures up to 1650°F on the Hastelloy X reactor and other equipment are uncertain.

It is recommended that the reactor be fabricated in sections using "Grayloc" flanges for flexibility and ease in cleaning and inspection. Since the Hastelloy X flanges will be expensive, a cost evaluation should be used to determine the economic number of sections.

A well qualified vendor should be selected to build the reactor to ensure high quality control. Welding of the Hastelloy X will be important and procedures should require radiography and possibly post-weld heat treatment.

The calculations for the reactor should include thermal expansion considerations.

Page 9-7, Recycle Liquid Cooler Specifications

The parameters for cooling water should be defined for proper economic selection of the recycle liquid cooler.

The capacity of the liquid cooler looks adequate, but the reasons for the design basis are unclear.

Page 9-10, Char Receivers Specifications

A nozzle for a pressure relief valve is mentioned on the equipment requisition sheet but no nozzle is provided for it on the specification or the drawing. It would be advisable to have the relief valve on the vessel instead of on the inlet piping.

Few provisions were made for ease of solids removal and weighing.

Page 9-13, Fines Receiver Specifications

A nozzle for a pressure relief valve is mentioned on the equipment requisition sheet but no nozzle is provided for it on the specification or the drawing. It would be advisable to have the relief valve on the vessel instead of the inlet piping.

Few provisions were made for ease of solids removal and weighing.

Page 9-16, Product Liquid Receiver Specifications

A hold-up time of one hour could be inadequate. The actual internal volume and average hold-up time are not specified.

The design pressure should be 165 psig as stated, but it may be possible to operate at atmospheric pressure instead of 150 psig, thus eliminating one pressure vessel potential hazard.

Page 9-20, Char/Coal Feed Hopper Specifications

Typographical error, double cone assembly called "cove" assembly on the equipment drawing. The report does not state whether the vessel capacity of 2.4 ft^3 is with or without the cone assembly installed.

The 2-in. inlet should be larger for ease of adding coal to the hopper.

The report does not specify how the cone assembly is attached to the hopper internals.

Page 9-24, Char/Coal Feeder Specifications

It is not clear what will be done to calibrate the char/coal feeder. An additional char receiver mounted below the reactor as discussed earlier in section 4 for SAI page 5-6 could also be used for feed calibration.

The proposed rotary star feeder and other potential feed mechanisms were evaluated for this application. Vibrating feeders, fluid bed feeders, and screw feeders were considered. The design may require several interchangeable star wheels to minimize pulse feeding at low feed rates. A vibrating system on the feed hopper and feeder may be helpful. A fluid-bed coal feeder would not have a wide feedrate range and the carrier gas could interfere with operation of the reactor. A screw type coal feeder may be acceptable; however, pressure fluctuations between the reactor and the pressurized feed hopper may cause problems since the screw feeder does not provide positive pressure isolation. Calibration provisions are unclear. It was concluded that the proposed rotary star feeder, coupled with modifications based on METC's experience, is the best approach.

Page 9-26, Gas Preheater Specifications

The specified "gas side" design temperature of 2600°F is above the melting point (2300 to 2470°F) for Hastelloy X. The outlet gas temperature of 1750°F is also above the maximum code temperature of 1650°F. If the code temperature is used as the maximum allowable temperature at the heater tube outside wall, this will then limit the flexibility of the system. Alternate designs could be considered for higher temperatures and greater flexibility.

It is not clear what the Inconel 600 alloy "High Temperature Atmosphere Retort" specification refers to.

Page 9-29, Reactor Heater Specifications

The temperature limit of the heater would be 1650°F at the reactor outside wall if the maximum code temperature for Hastelloy X is used as the design basis.

Greater flexibility would be achieved if the reactor and reactor heater were designed in removable sections. The reactor could then be dismantled for inspection and cleaning. The reactor heater sections could be oversized for flexibility with section heights equal to the minimum expected fluid bed height. Based on these criteria, each reactor heater section would be capable of supplying all the heat required for the carbon steam reaction with 2 lb/hr char feed at a minimum bed height of 1 ft, 16,300 BTU/hr. The sensible heat and the heat recovered

from the exothermic reactions would then add to the system flexibility. A reactor heater sized for 16,300 BTU/hr with a heated nitrogen purge of 10 lb/hr from the gas preheater would require a minimum of 3 hr to heat the reactor to 1500°F.

It is not clear what the Inconel 600 alloy "High Temperature Atmospheric Retort" specification refers to.

The reactor heater will need to be a clam shell type that can wrap around the thermocouple nozzles. This may cause uneven heating and inaccurate temperature measurements.

Page 9-31, Cyclone Separator Specifications

The cyclone separator is designed to handle 1 to 2 lb/hr, which is the feed rate of the reactor. This design basis seems too conservative and may not be the optimum design for efficiency and cost. The design should be based on the actual expected entrainment rates and expected particle size distribution. The particle size distribution to the unit should be confirmed after the test program is defined.

Page 9-34, Product Gas Scrubber - Quencher Specifications

The design of this equipment should be reviewed after consulting with a vendor of cyclone separators to determine the actual solids flow rate to the quencher.

Page 9-38, Recycle Liquid Pump Specifications

The pump head of 25 psi does not agree with the suction and discharge ΔP of 15 psi. This pump design should be reviewed after the piping layout is completed.

The liquid cooling system is an inexpensive area to add extra capacity for future flexibility.

Page 9-42, Product Gas Meter Specifications

The design flow rate for the product meter of 5 lb/hr will not be adequate if tests are run with noncondensable gases. This design should be verified after the specific test plan has been determined.

Page 9-43, Recycle Liquid Filters Specifications

There should be a disposable filter element available in suitable materials other than stainless steel at a lower cost, such as polypropylene or cotton. The design basis should be reviewed after the cyclone is reviewed by a vendor to determine actual solids loading which will probably be less than 0.002 lb/hr.

Page 9-49

The report mentions averaging or differential thermocouples but does not tell where they would be required. This could be related to the (s) symbol on the P&I diagram.

The materials of construction for Bourdon tubes and strain gages will be important because of corrosion where high temperatures and pressures exist. Isolation membranes may be required if gages are not available in the desired materials.

Page 9-56

It is unclear what instruments require the one-year guarantee mentioned in the blanket instrumentation specification.

The purchase of charts and tapes for recording instruments should be defined based on the needs rather than "three months' supply."

Page 9-61

"Polyflo" or other plastic tubing would be much easier and cheaper to use, where applicable, than rigid tube; however, plastic tube should not be used in areas with high temperatures.

The report should state that the plant instrument air is available at 50 psig and that METC plans to reduce the pressure to 3-15 psi.

Page 9-81

If carbon steel relief valves are used, they should be located away from the hot equipment.

It would be helpful to have some system to to alert personnel when relief valves are activated.

Page 9-94 Insulation Specifications

The blanket specification does not define what is insulated for energy conservation versus personnel protection. It would be better to specify insulation for each piece of equipment based on the equipment fabricator's preference.

Page 11-1

Some methods for calculating superficial fluidization velocities give higher than actual values, by up to an order of magnitude. The use of appropriate experimental data is preferred.

Page 11-24, Material and Energy Balance

The information provided by SAI was confusing since extremely high feed rates such as 20,000 lb/hr char/coal were used instead of the desired 2 lb/hr. This should be corrected in the report.

The material and energy balances should be reviewed after the specific test plan is defined. The planned change to use larger particles than the 50 μ average size discussed in the report may increase the size of the equipment and/or increase the gas flow rate requirements.

SAI used the basis that complete equilibrium will exist for the exothermic water-gas shift reaction and the methanation reaction. This is a good assumption for cases where catalysts are used with sufficient gas residence time in the fluidized coal bed. The outlet gas compositions did meet these equilibrium conditions for the simulation summaries that were provided. This equilibrium assumption may not be correct for cases at low temperatures without catalysts where extremes are used in the feed gas molar ratios; however, this should not cause any problems if the reactor heater is adequately sized.

The basis for percent carbon conversion with the carbon steam reaction needs to be clarified. This basis is dependent upon the residence time and temperature. The values of 84% to 98% used in most of the simulation summaries are reasonable for most typical runs. Simulation cases CH-6 and CH-7 are below the saturation temperature and pressure of the steam supply system and would cause condensation and difficulty in maintaining the system control. The carbon conversions for these two cases were given as 10% for case CH-6 and 36.7% for case CH-7: these low conversions were the result of the low temperature and the lack of energy available for the carbon steam reaction. It is not clear why cases at these extremely low temperatures were included in the report.

The apparent basis for the energy balance was that the operation of the system will be under conditions where no heat is supplied to the reactants by the reactor heater, with heat losses assumed to be zero. The only energy balance that was provided in the computer simulation was reviewed. Detailed calculations were not provided to accurately check the simulation; however, the final values used seem to be reasonable. If the assumption is used, that heat will not be added by the reactor heater, this will limit the flexibility of the system to low carbon conversion rates when noncatalized coal is used with non-ideal operating parameters.

The final design of the reactor heater should be made conservative to ensure future flexibility and minimize the time required to heat the reactor up to operating temperature. The SAI design of the reactor heater with a duty of 10,000 BTU/hr and with the preheated gas flow of 10 lb/hr would require a minimum of 5 hr to heat the reactor up to 1500°F. This heat-up time of 5 hr is probably longer than desired. A conservative approach would be to design the reactor heater to supply all the heat of reaction for the carbon steam reaction not including sensible heat or heat recovered from possible exothermic reactions. If the maximum feedrate is 2 lb/hr char, there will be 1.7 lb/hr carbon available for the carbon steam reaction with a heat requirement of 16,300 BTU/hr. The reactor will weigh approximately 370 lb and will, therefore, take a minimum of 3 hr to heat up to 1500°F with a reactor heater of 16,300 BTU/hr and a 10 lb/hr nitrogen purge from the gas preheater at 1500°F. If this heat-up time is longer than desired, the reactor heater should be further increased in size.

In conclusion, the material and energy balance summaries and computer simulation appear to be numerically correct; however, they do not include separate cases for all the parameters which will be investigated. The material and energy balances should be reviewed when the test program is defined and should include cases for the planned endothermic conditions with catalized and noncatalized coals.

5. Review of cost estimate

Section 5 contains a review of SAI's cost estimate that was provided as an informal supplement to the design report. It was reviewed for reliability of the equipment cost breakdown, the areas of cost uncertainty, and the areas for potential cost savings.

In general the cost estimate is incomplete and confusing, making it difficult to evaluate. The total project cost was not totalized and escalation and contingency factors were not included. It is recommended that the estimate be updated to represent the current plans.

It is confusing as to what labor charges are included for the instrumentation versus the other equipment installation. There were no engineering charges included in the estimate to complete the design which will be a significant cost.

The estimate included two "wrap around heaters" and did not define whether both were for the reactor or whether one was for the gas preheater.

The verbal quote on the reactor appears to be reasonable; however, costs will increase if the reactor is made in removable sections. There may be interface problems between fabricators of the reactor and the reactor heater which could increase costs.

The verbal quote for the char receivers looks high in comparison to the other Hastelloy X equipment.

The verbal quote for the cyclone separator does not include drawings or dimensions to evaluate. The cyclone may be made smaller and less expensive if the feed rate is reduced from 2 lb/hr to the actual flow of entrained solids.

The engineering estimate for the liquid filter does not state the quantity of filters.

The verbal quote for the coal feeder is higher than the one which was quoted on the entrained gasification system which had higher pressure and flow requirements.

Incorrect dimensions, 20 ft x 50 ft x 20 ft, were used to estimate the pressure cell cost. Also, it was not part of the design.

In general, the other equipment and the instrumentation verbal quotes appear to be reasonable.

Major changes to the P&I diagrams, from the estimated criteria, like replacing manual hand control values, "HCV," with automatic valves for remote operation will increase costs for that part of the system. Data loggers which can be programmed for flexibility could be used to reduce the cost of the temperature recording system. It appears that costs were not included for the safety interlock system or the electrical interface with the facility.

Potential major equipment changes to the system, since the estimate, include the additional dump tank below the reactor, an additional gas preheater to eliminate steam condensation when the gases are mixed, and utility interface equipment. A system to verify solids flow and/or monitor the material balance will also increase costs if used.

6. MRC safety analysis

The purpose of this safety assessment is to provide a third party review to assist in maximizing the safety and property protection features. This analysis identifies the highly probable and highly serious potential safety hazards and includes appropriate recommendations.

This safety review is concerned with the process concept and generic safety features of the conceptual facility design. Specific design features are considered when identified in the Operation and Safety Manual, indicated on process flow sheets, or verbally communicated to MRC personnel; however, a comprehensive safety analysis of the design was not possible because of a lack of a definitive design. We have attempted to identify potential hazards in the process, facility, monitoring systems, and procedures from information available and to suggest corrective or mitigating changes.

The "Operating and Safety Manual" was very general because of a lack of definitive design. Therefore, we strongly agree with the SAI recommendation contained therein;"... that the operating and safety manual be continuously updated during the entire project life."

The general method of analysis used was based upon the ERDA developed "Occupancy-Use Readiness Manual - Safety Considerations" ERDA-76-45-1. This method provides an overall review of the safety concerns of the project but does not provide a systems analysis on the component and component interaction level as does fault-tree analysis. This technique involves the DOE's management oversight and risk tree (MORT) concepts.

The major areas considered in the analysis were: the structures, services, process and hardware design, management control systems, monitoring systems, and personnel readiness. Each of these areas is discussed in greater detail and suggestions to improve or ensure safety and property protection in each area are offered.

6.1. Building and Grounds

It is important to be assured that no one is in the cell, or endangered by the relief mechanisms, while the process equipment is energized. This involves:

- Assurance by the operator that the cell is unoccupied prior to system activation.
- Methods of preventing entry into the cell - possibly system interlocks.
- Methods of locking and assuring that the perimeter fence around the test cells is secured. The fenced area should allow for safe "blow-out" of the cell without endangering personnel.

If the blow-out design of the roof is considered, the effect of snow loading on the degree of blow-out protection needs to be evaluated. A preferred cell relief mechanism may be to blow the rear walls into bunkers. The blown-out panels should be designed not to shear any utilities.

Employe evacuation routes into the proposed fenced enclosure or near any endangering utilities (high pressure lines, etc.) must be avoided. Thus, to meet Life Safety Codes, two or more exits in the direction opposite the cell are recommended.

The layout of the total system (control room, cells, gas supplies, etc.) should consider all energy sources with the potential for causing accidents. Ground space permitting, all such energy sources should be separated so that they will not impinge on each other. This will probably exclude all gas storage, etc. from the proposed fenced area. Also, supply lines should not be endangered by the cell relief mechanism, See Figure 6-1.

It is recommended that the Control Room and test cells be physically isolated from each other as far as practical. This is recommended because:

- Design analysis of the cells cannot anticipate consequences of all possible system failures.
- Noise created by an explosion may be harmful to control room occupants and it will be difficult to analyze these effects as part of the cell safety analysis.

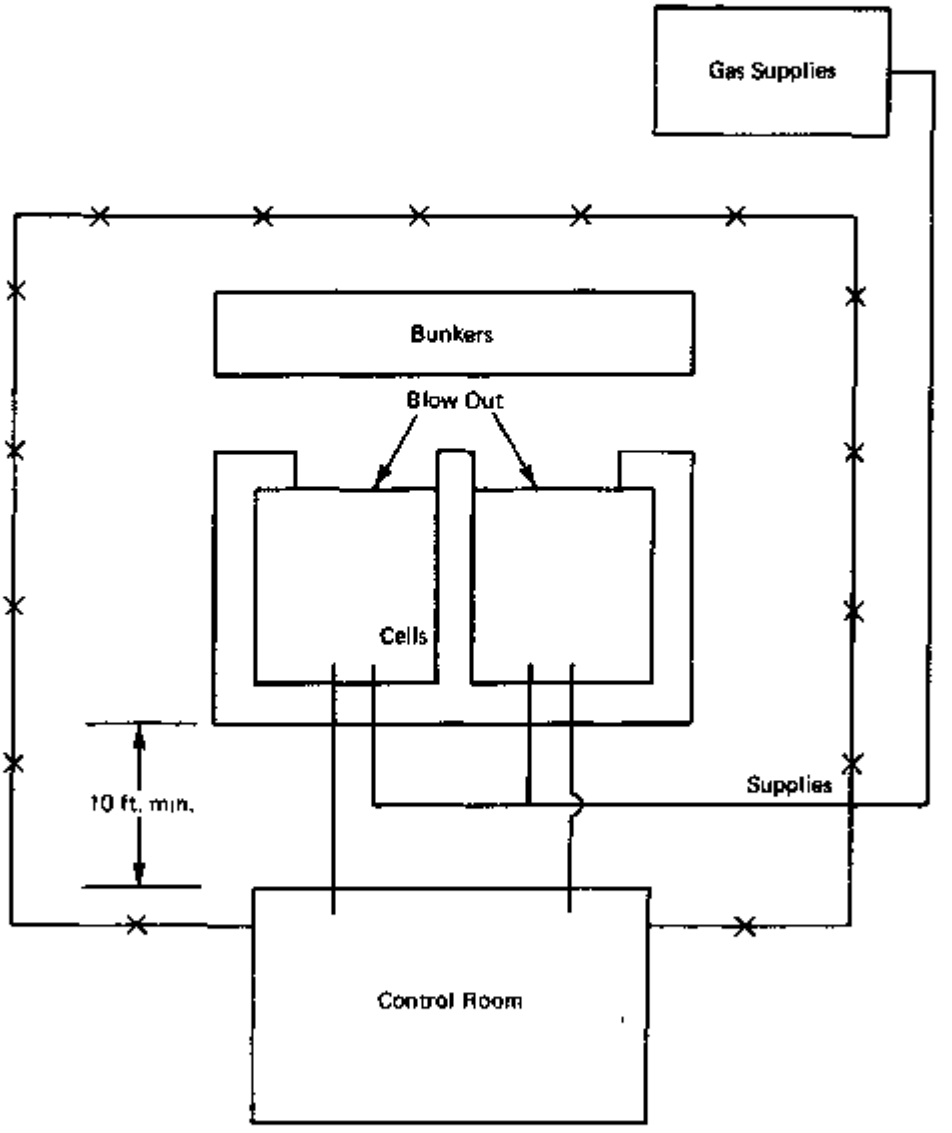

FIGURE 6-1 - Suggested facility and exclusion layout.

- Minimize cross-ventilation problems.

6.2. Ventilation

To enable the monitoring system to be used to detect leaks, the cell ventilation should be set at the minimum level required to prevent heat buildup. To further reduce required ventilation, all heat generating equipment that is not an explosion hazard can be placed outside the cell. This will also reduce exposure of maintenance personnel to hazards presented by the process equipment in the cell.

Sensing monitors should be strategically located (including monitoring the exhaust ventilation duct). If toxic gases are monitored, a "leak" alarm can be activated. If gas concentrations begin approaching "Lower Explosive Limits (LEL), the cell ventilation should automatically switch to high-speed. High-speed ventilation should occur at no less than 50% LEL.

Manual switching to high-speed ventilation should be available to sweep the cell of toxic gases prior to personnel entry into the cell.

A similar two-speed ventilation system may be considered for the Control Room. Pipe lines entering the Control Room carrying flammable and toxic gases should be minimized. If some dangerous gases are required for analytical purposes, monitors should be near these pipes and in the exhaust ducts. The manned Control Room should be ventilated when levels of toxic gases reach the "action level."

6.3. Services

Emergency power should be supplied to all system components and sub-systems necessary to control or shut down the process and ensure personnel safety when commercial power is lost. Such components or sub-systems should include

- Instrumentation - both process indicators as well as gas detectors for personnel safety.
- Lighting for the control room.
- Ventilation for the cells (if this method is to be used as a protective feature).
- Air compressor and control system for the air operated valves if this type of valve is to be used.

6.4. Fire Protection

In addition to standard sprinkler systems in the Control Room, special dedicated automatic fire suppression may be considered for remote and expensive systems. Dedicated "dry" or antifreeze sprinkler systems and other isolated process support systems may be advisable. The need of these sprinklers should be determined by a cost/benefit trade-off.

A dedicated automatic Halon system for the electronic console is recommended, based on the cost of the electronic equipment (several hundred thousand dollars, plus time lost to replace). If dedicated Halon protection for the electronics is not feasible, smoke detectors should be considered in the equipment areas. Smoke detectors will allow fire control action prior to sprinkler ignition.

Water may damage the electronics. If the electronics are water sprinklered and become wet during an incident, the electronic instruments should be dried as quickly as possible to minimize losses or damage caused by water.

It is suggested that the Morgantown representative of Fenwall Explosion Suppression Systems be contacted to evaluate the practicality of protecting the cells from explosions. The equipment contents of the cells are valuable enough to warrant a cost/benefit, feasibility analysis of this type of protection. The Fenwall explosion suppression system would serve to reduce loss of or damage to equipment, rather than serve as a personnel protection device because the cell should be unoccupied at any time the process system is in operation.

All the automatic fire suppression systems recommended above should automatically notify the Fire Department or some 24 hr/day manned, emergency response office. Hand extinguishers of the proper type (i.e., Halon in the electronics areas) are recommended.

6.5. Communications

Intercom systems are suggested for use in the cell area to enable continuous and reliable communications with the Control Room.

Emergency procedures should be revised to provide for immediate notification of the Fire Department and/or Safety Department upon occurrence of a fire, before control actions are initiated by operators. Delays in notifying fire departments too often result in catastrophic losses.

6.6. Gas Supply

Appropriate relief devices throughout the gas supply systems are always the first line of defense against overpressurization. Venting of relieved toxic and flammable gases requires attention to ensure no additional hazards are created. An overview of the design indicates relief devices were considered.

Further design evaluation, however, raises the possibility that flash-back arrestors need to be considered. Wherever burning gases may reach large energy sources, flash-back arrestors should be considered. Also, in long pipe runs that contain flammables, the possibility of detonations resulting from sonic deflagration should be evaluated. Detonations are prevented by avoiding long straight pipe runs where deflagrations can accelerate to sonic levels. Consultations with Dr. Grelecki of Hazards Research Corp. (Ph 201/627-4560) concerning system explosion characteristics are strongly recommended.

All piping containing high pressure gases should be heavily anchored (at frequent intervals) to prevent pipe - whip upon failure. This is particularly true of small diameter thin walled pipes. High flow check valves (inertial shut-off valves) should be considered at cell wall penetrations in lines carrying combustible gases. This would prevent flooding the cell if a major leak or rupture occurs.

6.7. Process/Hardware Design

Gages containing process fluids that are flammable or toxic should not be located in manned areas (Control Room, etc.).

Transducers and digital/remote read-outs are recommended. Backup gages in the remote cells are recommended as a means of observing pressure trapping points in the systems, when cell entry is required.

The capability to remotely vent the char and liquid pots, before the cell is entered to remove them, is recommended in order to prevent personnel from sustaining injury while opening the pressurized containers.

A method of unmanned leak testing of the cell system is recommended. Elevating helium pressures in the system, with no cell ventilation, and observing strategically placed monitors, or monitoring pressure losses from the system may be acceptable techniques.

The relief valves provided on pressure vessels should go to the flare instead of the atmosphere. If carbon steel relief valves are used, they should be located away from the hot equipment. Also, it would be safer to have some system to alert personnel when relief valves are actuated. Pressure sensing and venting devices should be incorporated at all points where pressures may be isolated.

It is recommended that inert gas, such as nitrogen, be used to pressurize the feed hopper instead of the flammable gases to avoid unnecessary accumulation of flammable gases where not required by the process.

All system components that are not significantly hazardous should be located outside the cell. This will allow maintenance activities without endangering maintenance personnel.

In system designs and operations, such as this one, it is generally observed that operating personnel and system components are usually well protected. Deaths, injuries, and other catastrophies are then usually related to improper maintenance or incomplete identification of all possible unusual failure modes. Thus, special precautions should be taken so that maintenance personnel are not endangered.

A system safety analysis, such as "fault-tree" or FMEA, should be considered in addition to the planned SAR since a detailed analysis was not included in the "Operating and Safety Manual" provided by SAI.

6.8. Information Systems

The wide range of temperatures and pressures used necessitates the use of a system to positively indicate to the operator what temperatures and pressures exist at various locations within the process system.

Notification of out-of-limit parameters such as excessive temperature or pressure or the presence of gases in excess of predetermined concentrations should be made to operators in a positive, active method rather than rely upon the operator obtaining this information from a passive readout. This is particularly important where the out-of-limit parameter may indicate some hazard to operators. It is also important that such alarms or notification devices be placed where the operator who must react will be notified immediately.

The synergistic effects of H_2S, HCN, and CO are such that the acceptable concentration levels should be evaluated. For

further reference, the NIOSH criteria document, Coal Gasification Plants, lists suggested concentration levels for various contaminants.

A hydrogen concentration of 25% of the Lower Explosive Limit (LEL) should trigger an alarm or notification to the operators that a leak has occurred. A concentration of 50% LEL should trigger an automatic shutdown and high-speed ventilation as discussed previously. These action levels should be applied to all flammable gases unless health concerns require lower action levels.

Because gas supply and pressures are essential to the process, it is suggested that the supply of gases be verified prior to starting an operation.

Visual monitoring of the cell from the Control Room could be accomplished by a closed circuit video system. Such a system could also allow for remote damage and risk assessment before personnel enter the cell after a problem occurs.

The design of the controls and instrumentation readouts should consider human factors such as physical man-machine interfaces and visual displays/information transfers. This is particularly important when the operator must react promptly to information he receives. This system has many alarms associated with it, with several alarms possibly indicating different process deviations. The design of the controls and readouts could have a significant impact on the operator's ability to control the system.

The Automatic Data Acquisition System may be usable for controlling the process or advising operators of the proper response to take to alarm signals.

6.9. Written Procedures

Written operating and maintenance procedures should be prepared and used for all operations where risk to personnel is significant. An example of a procedural step which should be documented and followed is verification that high pressures do not exist in the char pot or liquid receiver before initiation of steps to remove these components.

In the area of emergency procedures, actions should be prioritized when they cannot be performed simultaneously. Specifically, the Fire Department should be notified immediately before other actions are taken to control a fire.

Emergency Shutdown Procedures should be prepared both for situations originating within the system/facility and for situations external to the facility (i.e., a fire in an adjacent building).

6.10 Personnel Readiness

Emergency equipment such as supplied breathing air and protective clothing and equipment should be readily available and personnel should be adequately trained in their usage.

Additional emphasis on training in emergency procedures and in training others such as fire/rescue and maintenance personnel may need to be considered.

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