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PRELIMINARY DESIGN FOR HOT DIRTY GAS CONTROL VALVE TEST FACILITY
FINAL REPORT

Prepared by
Mittelhauser Corporation

January 1980

Prepared for
UNITED STATES DEPARTMENT OF ENERGY
Morgantown Energy Technology Center
Morgantown, West Virginia

TECHNICAL INFORMATION CENTER
UNITED STATES DEPARTMENT OF ENERGY

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Prepared for
United States Department of Energy
Morgantown Energy Technology Center
Morgantown, West Virginia
Under Contract No. DE-AC21-79MC12209

METC Project Manager
J. F. Gardner
Valve Testing and Development Projects

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Mittelhauser Corporation hereby acknowledges the team members who made contributions to this project:

- The BDM Corporation performed the instrumentation and control work for the project.
- Morgan Engineering Company prepared project drawings and investigated solids addition, feeding, and the hot system piping.
- Milton R. Beychok, Consultant, reviewed the preliminary process design and control scheme.

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1.0 EXECUTIVE SUMMARY

This report presents the results of a preliminary design and cost estimating effort for a facility for the testing of control valves in Hot Dirty Gas (HDGCV) service. This design was performed by Mittelhauser Corporation for the United States Department of Energy's Morgantown Energy Technology Center (METC).

The objective of this effort was to provide METC with a feasible preliminary design for a test facility which could be used to evaluate valve designs under simulated service conditions and provide a technology data base for DOE and industry. In addition to the actual preliminary design of the test facility, final design/construction/operating schedules and a facility cost estimate were prepared to provide METC sufficient information with which to evaluate this design.

Section 3.0 of the report gives bases, assumptions, and limitations of this study effort.

The tasks carried out in this study were as follows:

- METC Facility Review
- Environmental Control Study
- Gas Generation Study
- Metallurgy Review
- Safety Review
- Facility Process Design
- Facility Conceptual Layout
- Instrumentation Design
- Cost Estimates
- Schedules.

Section 4.0 of the report provides information regarding the methods of approach used in the various tasks involved in the completion of this study. Also provided in Section 4.0 are the preliminary decisions, and the reasons therefore, used as an intermediate step, where necessary, between the basis of the study provided in Section 3.0, and the results of the study.

Section 5.0 of this report presents the results of the study effort. The results obtained from the above-defined tasks are as follows:

- Of the existing METC facilities only land, utilities, and the METC data acquisition system are usable for the HDGCV Test Facility.
- The test facility design as shown would be environmentally acceptable. The only outstanding consideration requiring final resolution, as of the completion date of this report, is the disposal of solids laden purge water from the HDGCV Test Facility.
- The test facility should be a closed loop design using a test gas made up from gas cylinder trailers and individual cylinder bottles.
- The design and operating requirements of the test facility can be met, from an equipment piping viewpoint, with the careful application of corrosion resistant materials, refractory lined where necessary.
- The test facility will be made a safe design by incorporating available equipment and instrumentation safeguards and applying standard fire/safety criteria at final design time.
- The valve test conditions are generated by a test facility patterned after proved process units, using state-of-the-art equipment to assure reliable steady-state operation.
- The test facility is laid out to consume as little space as possible while minimizing installation costs, and allowing adequate working/maintenance clearances.
- The instrumentation, as was the case with the other equipment, is based on currently available reliable components which provide for METC's data acquisition needs, and reliable overall test facility operation.
- The turnkey cost of the test facility is estimated to be \$9,774,700 in fourth quarter 1979 dollars, and the annual operating cost is estimated to be \$960,000 plus utilities costs which are not included because unit costs per utility were not available from METC.

- It is estimated that final design and construction to a point ready for startup can be completed in 26 months after release to begin work.

It is recommended that during the evaluation of this preliminary design for the HDGCV Test Facility, consideration should be given to the opportunities for expanded use of the facility described in Table 5.14. A greatly expanded testing capability for the test facility, encompassing equipment other than the control valves, could be realized through increase of plot space only with very low incremental cost.

2.0 BACKGROUND

The U.S. Department of Energy, Morgantown Energy Technology Center (METC) has been designated the lead center for the development and testing of components for coal conversion and utilization applications.¹ As part of this program, METC has been active for several years in the development and testing of valves for coal conversion services.

2.1 HOT DIRTY GAS CONTROL VALVES

In the past, nearly all coal gasification processes have used wet scrubbing immediately downstream of the gasifier to clean and cool the raw product gases. However, advanced processes which use hot gas cleanup to improve thermal efficiency are being developed. Some of these processes require control valves for throttling the hot raw gas from the gasifiers, as shown in Figure 2.1.

Experience to date by METC and industry on pilot-scale gasifiers and pressurized fluid-bed combustors, indicates that serious problems exist in placing, operating and maintaining hot dirty gas control valves (HDGCVs) in these units. The problems arise from the high temperatures of the uncooled raw gas, the fact that it may contain corrosive sulfur compounds and high concentrations of hydrogen, and the relatively high concentrations of erosive entrained particulates carried out of the gasifier in the raw gas. Some control valves placed in these services have had actual operating lives of only a few hours.

2.2 NEED FOR DEVELOPMENT PROGRAM

Commercial development of advanced coal gasification processes could be severely impeded if reliable HDGCVs were not available when needed for commercial service. Therefore, METC has decided to undertake a development program for these valves. Such a program would involve testing of HDGCVs in a controlled environment at a scale smaller than that envisioned for

Simplified Schematic Showing Hot Dirty Gas Control Valves Proposed for Use in the COGAS Process

Simplified Schematic Showing Hot Dirty Gas Control Valve in a Combined-Cycle System Using Hot Gas Cleanup

FIGURE 2.1 HOT DIRTY GAS CONTROL VALVE APPLICATIONS
(Excerpted from Document METC/CR-79/10)

commercial service (28-30 inch diameter), but large enough to allow for reasonable scaleup. Figure 2.2 represents METC's current concept of the valve test portion of such a facility.

2.3 FACILITY OPTIONS

Options for the HDGCV Test Facility include choices of on-site (at METC) or remote location, and existing versus new facilities. An on-site test facility would allow METC to monitor design, construction and operation of the facility more conveniently than at a remote site. Also, an on-site facility would offer the possibility of using existing METC facilities for generation of the hot dirty gas, acquisition and analysis of process data, and provision of utilities.

2.4 CURRENT STUDY DEFINITION

Mittelhauser Corporation is providing technical services to METC under Contract No. DE-AC21-79MC12209. Pursuant to this contract, Mittelhauser was requested to undertake a study of an on-site HDGCV Test Facility. The principle work areas were as follows:

- Review available facilities at METC
- Study environmental control requirements for a HDGCV Test Facility at METC
- Study methods of generating hot dirty gas
- Perform a preliminary process design of a HDGCV Test Facility, including energy and material balance, Process Flow Diagram, Piping and Instrumentation Diagrams and Conceptual Layouts. The design was to be in detail to permit a ± 30 percent "factored" cost estimate for the facility
- Carefully investigate instrumentation requirements and availability for the HDGCV Test Facility with emphasis on the valve test loop itself
- Prepare design, construction, and operating schedules for the HDGCV Test Facility.

Mittelhauser has assembled a project team and performed the study described above. This report describes the results of the study.

FIGURE 2.2 Test Schematic for Hot Dirty Gas Control Valve Cycling Test
(Excerpted from Document METC/CR-79/10)

3.0 BASIS OF STUDY

3.1 INFORMATION

The primary source of information to be used in this preliminary design for the HDGCV test facility was document METC/CR-79/10, Facility Requirements for Testing Control Valves for Hot Dirty Gas Service. Supplemental data, as required to augment information in the above document, were obtained from the following:

- METC/CR-79/6 Specification Requirements for a Control Valve for Hot Dirty Gas Service.
- METC/CR-79/8 Test Plan for a Control Valve for Hot Dirty Gas Service.
- METC/CR-79/12 Design Criteria for a Control Valve for Hot Dirty Gas Service.
- Engineering Specification No. MERC 12-77 2000°F Fluid Bed Solids Heater.
- Drawings from past METC projects.
- Letters and telephone conversations with involved METC personnel.

Based on the background and development need for a HDGCV test facility, as stated in Section 2.0 of this report, this preliminary facility design was undertaken to provide a valve test system which would meet the detailed objectives as follows:

- Evaluate valve designs under simulated service conditions.
- Provide test data to form the basis for design changes to improve valve reliability and reduce maintenance costs.
- Compare novel valve design performance with current available designs.
- Provide verification of design modifications.
- Provide technology data base for DOE and industry.

- Identify design features and materials of construction which are superior for this type of service.
- Predict life or performance as a basis of dimensional or physical changes of valve components.
- Identify in-service maintenance or test procedures to tell users when repairs are needed.

In order to accurately produce test data from which these objectives could be met, it was decided that the gas used in the testing would have to be equal to that specified in METC/CR-79/10 in composition and operating conditions. The test gas characteristics are as found in Table 3.1.

The actual testing of the control valves, in order to provide the data base to meet the desired objectives, is to be carried out in accordance with the rigorous inspection/testing/re-inspection program as shown in the HDGCV Test Sequence, Figure 3.1. It is noted here, however, that one point in this overall test sequence, and the original concept of test loop itself, has been modified by the addition of the hot leak test shroud. This addition would preclude the need for the cold stem leak test, and, it is felt, would provide more accurate data at operating conditions.

The on-line testing of the control valves is to take place in accordance with the HDGCV Test Schedule, Figure 3.2. This test schedule shows the varying-length valve tests, the switching requirements from one test loop to the other, and the total on-line time for any one valve tested.

The operation of the valves during testing is accelerated in order to accommodate as many types of designs as possible within the set on-stream time. An operating cycle of 15 seconds, full open to partial closure, has been specified by METC.

TABLE 3.1 TEST GAS CHARACTERISTICS

<u>Gas Composition:</u>	<u>Component</u>	<u>Volume %</u>
	N ₂	0.1
	H ₂ S	1.1
	H ₂	44.0
	H ₂ O	15.9
	CO	25.3
	CO ₂	12.7
	CH ₄	0.9
	Average Molecular Weight	19.96
	Temperature	1650°F ± 50°F
	Pressure (Case 1)	250 psig
	Pressure (Case 2)	50 psig
<u>Solids:</u>	<u>Size</u>	<u>Weight %</u>
	>60μm	0
	10-60μm	11
	5-10μm	40
	1-5μm	39
	0.1-1μm	9
	<0.1μm	1
	Percent Solids	2 grains/SCF
	Type	Equivalent to Char and Fly Ash

FIGURE 3.1 Hot Dirty Gas Control Valve Test Sequence
(Excerpted from Document METC/CR-79/10)

FIGURE 3.2 Test Sequence for Two Valves Undergoing Testing Simultaneously in a Special Test Loop Test Facility
(Excerpted from Document METC/CR-79/10)

After it has been established that the equipment required to simulate the service in which the valves were to operate would be extensive, METC directed that the only plot limitation would be the use of 20,000 to 30,000 square feet of clear level land within the METC facility. The proposed HDGCV Test Facility location, as it fits into the overall METC site, is as shown in Figure 3.3. The ambient conditions at the site are shown in Table 3.2. These conditions were used in the mechanical design and duty ratings of component equipment.

Available utilities for the operation of the test facility are summarized in Table 3.3. The availability of certain utilities, or the lack thereof, was used as a selection criterion for final equipment design. As an example, the lack of high-pressure steam dictated that all equipment drivers, including the main gas compressor, would be electric motors.

3.2 ASSUMPTIONS

In order to complete the preliminary design of the HDGCV Test Facility, in the absence of firm data for certain design-schedule and economic criteria, some assumptions with regard to these topics were necessary.

Design assumptions made were as follows:

- Base case for mechanical design and operating duty of components is 250 psig/1750°F at the tested valve inlet.
- No prototype equipment would be used in test facility for the generation of test conditions.
- Graded and mixed solids for solids contamination will be provided by METC.
- Process water, demineralized boiler feedwater quality, is available from METC.

FIGURE 3.3 HDGCV TEST FACILITY SITE

TABLE 3.2 METC SITE CONDITIONS

Plot Size:	20,000 to 30,000 ft ² clear level land
Site Altitude:	970 feet above M.S.L.
Average Barometric Pressure:	28.85 in. Hg (14.17 psia)
Maximum Dry Bulb Temperature (95% Significance Level)	88 ⁰ F
Maximum Wet Bulb Temperature (95% Significance Level)	75 ⁰ F
Average Dry Bulb Temperature	60 ⁰ F
Minimum Ambient Temperature	-15 ⁰ F
Maximum Ambient Temperature	98 ⁰ F
Rainfall	No firm data at this point. Assume moderate to heavy.
Snowfall	No firm data at this point. Assume moderate to light.
Earthquake	No firm data at this point. Assume low probability.

TABLE 3.3 AVAILABLE UTILITIES

Electricity:	Motors under 1 hp	120 v, 1 ϕ , 60 Hz
	Motors 1-50 hp	460 v, 3 ϕ , 60 Hz
	Motors 50-100 hp	2300 v, 3 ϕ , 60 Hz
	Motors 100 hp and larger	2300/4160 v, 3 ϕ , 60 Hz
	Instruments and Controls	120 v, 1 ϕ , 60 Hz
Air:	Valve Operators, etc.	100 psig (500 scfm)
	Instruments	50 psig
Nitrogen:		1200 psig (120 scfm)
Fuel:	Oil	#2 (0.5%S)
	Gas	Natural
Cooling Water:	Flow (Note 1)	1000 gpm
	Pressure	110 psig
	T inlet	90°F
	ΔT maximum (Note 2)	40°F
Process Water: (Note 3)	Flow	100 gpm
	Pressure	350 psig
	Temperature	90-100°F
	Quality	Demineralized Boiler Feedwater

-
- NOTES: 1. This is total METC capability. No dedicated allotment has been established for Hot Dirty Gas Control Valve test facility as yet.
2. Although an allowable ΔT of 40°F was given (130°F discharge temperature), a ΔT of 30°F (discharge temperature 120°F) was used in this design to allow for the more conservative 20°F approach to the test gas compressor recycle discharge temperature of 140°F.
3. Process water properties are assumed values.

- Process water discharged from the HDGCV test facility will go directly to the METC facility wastewater ponds.
- Overall design of equipment would be preferably independent of interruptible utilities provided by METC.

The schedule assumptions made, with regard to design and construction, and operation of the test facility, are as follows:

- All U.S. Procurement.
- Only top three or four vendors solicited for quotations on any one commodity or component.
- Standard specifications such as API, TEMA, HEI, ANSI, etc., used to maximum extent; minimum custom mechanical specification of components.
- Long lead items are critical path items.
- Permits and approvals are not critical path items.
- A 90-day startup would be required prior to commencement of valve testing.

Economic assumptions made in the preliminary design are as follows:

- Cost basis is fourth quarter, 1979 dollars.
- Factored estimates for installed cost are acceptable if based on predominantly vendor supplied equipment cost estimates.

Additional economic bases used for the development of cost estimates and other economic analysis of this project are as presented in Section 4.8 of this report.

In general, an attempt was made to minimize the impact of assumptions on the overall preliminary design. The effort

is made here to clearly depict these assumptions so that the final design of, and financing for, the HDGCV test facility will be accurate.

3.3 STUDY LIMITATIONS

It is recognized that the valve test facility in question will likely be constructed if deemed feasible. To establish the limitations of the preliminary design effort, the following is a list of items not provided in this effort.

Exclusions

- Electrical Drawings
- 2-Line Piping Drawings or Isometrics
- Piping Stress Analysis
- Detailed Plot Plan (general layout is provided)
- Foundation and Structural Drawings
- Competitive Price Quotations on All Equipment (a limited number of multiple quotations on certain items was obtained in the current work, as necessary)

In addition, the energy and material balances were limited to the detail necessary to define major equipment requirements. No detailed process simulation of the facility was made, although limited partial simulations were made of specific areas of the facility, as required.

These limitations were placed on this preliminary design effort due to time and budget constraints and to the fact that many of them would be best handled in the final design.

3.4 FACILITY DESIGN BASIS

In addition to the preceding study bases, Sections 3.1 through 3.3, the following additional premises were used for this preliminary design.

The design of this test facility was initiated with two main objectives. The first objective was to design a facility which would, to the maximum practicable extent, incorporate existing equipment and capabilities at the Department of Energy's Morgantown Energy Technology Center. The second objective, considered to be the more important of the two, was to devise a system which would accurately approximate conditions in which control valves are expected to operate (as specified by METC), and to provide a means to evaluate the valves' performance.

Since the degradation of the control valves would be directly related to the specific composition of the testing medium, and since the process service in which the valves are to operate necessarily dictates the gas composition, it was decided to target for a system design which produced the average gas consistency as specified in METC/CR-79/10. A system which does not utilize the full corrosive/erosive potential of the specified gas would not produce totally usable data.

Using a maximum scale-up ratio of 10:1 from tested valves to demonstration plant size valves to ensure that gas erosion/corrosion on the tested valves would be representative of the demonstration valves, a test loop valve size was established. From this valve size and the test loop maximum gas velocity of 175 ft/sec, required gas throughput and solids addition (at 2 grains/scf) were established.

The test criteria also dictated that the test facility should be capable of producing a continuous, steady-state test condition with a high degree of repeatability so that valve designs tested for a particular service could be evaluated on a uniform basis.

The expected life of the test facility, three to five years, and the requirement for continuous operation established the criteria that whatever the final facility design might be, any component of the process simulator would have to be well within the current state-of-the-art for its function, and of design reliability equivalent to that found in an operating process plant. Using this approach, component failure potential would be limited as much as possible to the tested valve.

Since there are two operating pressures, 50 psig and 250 psig, associated with the other operating criteria for the test system, the 250 psig case plus a design over-allowance established the mechanical design criteria for test system components. It was decided that the 250 psig case would be the base case for the system design. By doing this, if it were found that any component(s) of the test facility did not have a sufficient turn-down ratio to meet the requirements of each end of the potential operating range, then the tests and data gained therefrom would be for the most severe application. Valve designs yielded through this method could be directly applied in the low pressure cases as over-designs. Alternatively, the designs, particularly stem packing developments, could be derated to the service.

Instrumentation and control systems for the HDGCV Test Facility were established as an extremely critical consideration. The test system and data gathering for the tested valve are to be accomplished through the use of one operator and one supervisor per shift. The test facility would be required to be essentially self-regulating against the preset test valve criteria. Instrumentation placed in the test section was required not only to control the test gas stream conditions, but to provide accurate data on the gas stream conditions and the performance of the valve to METC's data acquisition system.

The test facility also is required to meet or exceed the acceptable standards for safety, noise, and air/water emissions, from both the worker and community exposure aspects.

4.0 WORK PERFORMED

The following sections detail the ways in which each of the tasks, as presented in Mittelhauser Corporation's original proposal, were approached and carried out.

4.1 METC FACILITY REVIEW

The review of METC's existing facilities was done in parallel with other study tasks, notably the Gas Generation Study discussed in Section 4.3. The objective of the METC Facility Review was to determine what existing METC facilities could be used in and by the HDGCV Test Facility.

Two separate trips to METC were made by Mittelhauser personnel. On each of these trips, discussions were held with METC personnel and the following existing facilities surveyed:

- Data Acquisition System
- Available utilities
- METC 42" Stirred Bed Gasifier
- 2000°F Hot Solids Generation Facility.

The information gathered in these surveys was evaluated in the light of the general design concept developed in the Gas Generation Study. The evaluation led to the following conclusions:

- Use of the METC 42" Stirred Bed Gasifier, at its current state of development, to generate hot dirty gas was not consistent with the operational reliability requirements (8000 hours per year for 5 years) of the HDGCV Test Facility.
- Use of the 2000°F Hot Solids Generation Facility to generate hot dirty gas was not consistent with the compositional requirements for that gas in the HDGCV Test Facility.
- Both the existing data acquisition computer and the utility systems should be utilized to the greatest practical extent by the HDGCV Test Facility.

These conclusions were used in the design of the Facility, discussed in Section 4.6.

4.2 ENVIRONMENTAL CONTROL STUDY

The work done under this task was to review the air and water standards which would either set limitations on emissions and discharges, or require permits for operation and construction, of the HDGCV Test Facility located at METC. This review was at Federal, state, and local levels. The review was compiled from the Bureau of National Affairs "Environment Reporter" and telephone conversations with applicable local or regional personnel.

Since the test facility will be located in an area of the country where all the ambient air quality standards are now being met, the PSD requirements were reviewed. Also, the PSD requirements are currently being contested in the Alabama Power vs Costle (EPA) court case, and its decisions are being carefully followed.

The discharge of the wastewater was not defined in the sense of where it was going to be discharged. Three possibilities were reviewed in detail and are as follows:

- discharge into the local sewer system
- discharge into the (local) Monongahela River
- discharge to the DOE local wastewater treatment facility.

A letter was sent to METC's project manager concerning the untreated water quality asking what pretreatment requirements would be needed if discharged into DOE's existing treatment plant. Also, the Morgantown Municipal Treatment Facility and West Virginia Water Resources Board were contacted concerning industrial discharges and water qualities.

The applicable air emission and water quality limitations are discussed in Section 5.2 of this report. The results of this task were incorporated into the overall design of the test facility to comply with the applicable emissions and limitations.

4.3 GAS GENERATION STUDY

The initial work done within the gas generation study was carried out concurrently with the initial conceptual development of other tasks. That is, the method by which the test gas is created cannot be isolated from the preliminary process design for maintenance of test system operating conditions, the environmental control study, or the accuracy requirements of the instrumentation design.

Generation of the gas used in the valve test facility in the specified composition, was originally felt by METC to require the operation of a gasifier (reference document METC/CR-79/10). Because the construction and operation of a gasifier, or reliance on the existing 42" gas producer at METC, would be impractical, other test generation techniques were considered including the use of METC's Fluid Bed Solids Heater.

For the purposes of this preliminary design effort, the following methods of obtaining the test gas were considered:

- Inert/combustion gas with additional contaminants added
- Reforming/shift conversion of natural gas with additional contaminants added
- Purchase of bulk gas with contaminants.

The criteria used for the acceptance or elimination of these methods of gas generation consisted of the following points:

- Consistency with specified gas composition
- Complexity of operation (equipment and personnel)
- Relative cost of operation
- Controllability/reliability of system
- Environmental effects/required treatment.

The method used for the selection of the gas generation system to be employed did not entail an elaborate technoeconomic analysis, but

relied more on engineering judgment based on experience and/or conceptual evaluation of the possible gas generation systems.

4.3.1 Once-Through versus Closed Loop Operation

Since the gas must be equivalent to the specified test gas as discussed in Section 3.4 of this report, the evaluation criteria of operating cost, system reliability/controllability, complexity of operation, and environmental effects/required treatment were used to consider once-through versus closed loop operation.

The once-through system, from an overall viewpoint, would appear to be less complex in that a test valve by-pass loop and a gas cooler would not be required as they would be in a closed system. The compressor and heater could be somewhat smaller in a once-through system than a closed loop system, depending on which gas generation technique was employed, but they would still be required to meet the operating pressure and temperature. However, when environmental effects/required treatment are added to the evaluation, the cleanup and disposal of effluent streams becomes a major factor.

The flashing of dissolved gases is necessary in a closed loop system for recovery and reinjection to the system, and in the once-through system for proper disposal. The gas disposal system for the once-through operation would be larger and more complex than for the closed loop case and could be subject to environmental regulations regarding continuous source emissions particularly with respect to H_2S , CO , and possibly nitrogen compounds. Therefore, the complexity of the once-through concept shifts from the main process gas handling equipment to the disposal and cleanup of effluent streams, and the cost of operation would shift in a proportional manner.

A once-through system, being open-ended, also tends to be more subject to transient disparities than the closed loop system. That is,

the properties of the test gas stream itself are subject to more irregularities in the once-through operation, being fed from an external source, and may not be as readily determinable except by after-the-fact recordings analysis.

The closed loop operation, on the other hand, is not directly affected by external irregularities, and changes in the process test gas should be readily predictable and capable of preset compensation. This allows for more repeatability in obtained data from one time frame to another over the life of the test facility.

The major cost consideration which eliminates open-loop operation from consideration is the cost of the raw materials, be they natural gas, oil, or bulk purchased gas, required to generate the process test gas. For example, if natural gas were used to generate inert gas in a once-through system, the cost of the natural gas alone at a price of \$1.50 per 10^6 BTUs, HHV, would be on the order of $\$1.7 \times 10^6$ per year for the 250 psig operating case. Cost for additional contaminants such as H_2S would add over $\$1.0 \times 10^6$ per year to this cost.

In summary, the complexity of operation appears to be equivalent for the once-through and closed loop operations when the comparison is carried through each case's environmental effects/required treatments. The closed loop operation must receive more favorable consideration for its ability to maintain system controllability and reliability of total data generated and for its significantly lower raw materials costs compared to the open-loop system.

4.3.2 Inert/Combustion Gas Generation

The first gas generation method considered was that of using inert gas, such as pure nitrogen, or combustion gas and upgrading this gas through gaseous contamination to the specified gas composition.

The use of the pure inert gas nitrogen was ruled out by virtue of the decision to use a test gas equivalent to that specified in METC/CR-79/10, 0.1% volume N_2 , and because by the time enough gaseous contaminants were added to achieve the specified gas composition, the gas generation alternative discussed in Section 4.3.4 would effectively be employed.

The use of a combustion gas suffers from a similar problem. The combustion of natural gas, for example, would result in a gas composed approximately of: 88% N_2 ; 11.5% CO_2 ; traces of CO , H_2 , and O_2 (which would require removal); and water vapor (to saturation). To meet the specified test gas composition this combustion gas would have to be upgraded, compressed, and heated to meet the operating case requirements specified. This method of gas generation would result in the addition of the inert gas generation system, and its inherent maintenance and reliability concerns, without a reduction in complexity anywhere else in the test system.

4.3.3 Reforming/Shift Conversion

Another possibility for test gas generation would be through reforming/shift conversion, in particular, steam methane reforming for the production of H_2 , CO , and CO_2 . This method would involve a detailed process in itself and require superheated steam at a pressure of approximately 400 to 450 psig to produce products at 250 psig. Temperatures equal to that required in the test loop, 1750°F, are obtainable in the discharge products of the reforming process.

The process requires the use of a reformer heater, which could be used to produce the required steam. The methane and steam are fed to the reforming section of the heater to produce a gas containing H_2 , CO , CO_2 , and excess steam. The gas stream flows to a shift converter where the required amount of carbon monoxide is reacted with steam to produce carbon dioxide to the required composition. The produced gas would then require the addition of CH_4 , N_2 , and H_2S to the required specified test gas composition.

This detailed process would be acceptable for a once-through process of gas generation; however, a once-through system has the disadvantages stated in Section 4.3.1. For a closed-loop test system, reforming/shift conversion suffers from the capital requirement of a detailed process unit to generate a gas containing only four of the test gas components, over and above the equipment required to maintain the test loop operating conditions.

This system of gas generation would meet the selection criteria of consistency of generated gas with the specified test gas and environmental concerns. However, due to the addition of the reformer/shift conversion system, initial and operating costs would go up, reliability would decrease, and ease of operation would decrease.

4.3.4 Prepared Gas Mixtures

During the consideration of the other gas generation alternatives, the common requirement for additional gaseous contamination from a bottled source became apparent. It was decided to pursue the investigation of supplying the test gas totally from a bottled gas supplier.

It was assumed, and confirmed by vendor contact, that all of the required test gas components were available in bottled form. Therefore, any predetermined gas constituency, or variations thereto, could be readily mixed at the project site. The evaluation criteria of consistency with specified test gas was met. Also, by purchasing premanufactured gases, the cost of gas generation equipment and operating personnel shifts to the gas supplier who has a larger user base over which to distribute these costs. Therefore, the criteria of relative ease of operation and lower cost of operation could be met.

By purchasing gas from the large industrial gas distributors, the requirement of reliability is met by virtue of the fact that this is the supplier's product and equipment redundancies to produce his product and adequate reserves of this product are maintained by him to assure the

continuity of sales/income. Also, by purchasing the required gas, no environmental concerns are created other than those associated with the test facility itself.

4.3.5 Results

The results of the Gas Generation Study are presented here rather than in Section 5 because they lead directly into the preliminary facility design described in Section 4.6 and serve as a useful preface to that section.

Closed Loop System

The first result of the Gas Generation Study was the selection of the closed loop test system rather than a once-through system. This was done due to the conclusion that, for the once-through system, although the compressor and heater required to produce the test system operating conditions may be smaller than for the once-through system, the gas disposal system would be more expensive and complex. The once-through test system gas disposal system would most likely involve the following:

- Gas flashing system to remove dissolved gases from effluent water, for addition to main gas stream and disposal
- Gas incinerator
- Flue gas desulfurization system
- NO_x removal (possible).

The closed loop system, due to its minimal gas losses primarily during loop blowdown for test valve removal, would involve the following:

- Gas flashing system to remove dissolved gases from effluent water, for reinjection to system
- Small elevated flare.

Also, the closed loop system lends itself to more reliable/ repeatable operation since the test gas is not subject to direct external influences, and is expected to be lower in overall operating cost.

Bottled Gas Purchases

The method selected for test gas generation was the purchase of bottled gas from an industrial gas supplier. By using this method, the capital and operating expenses of gas generation are shifted to the supplier, who has a larger product base over which to distribute these costs.

Telephone conversations were initiated with Airco Industrial Gases to determine the means of supplying the required bottled gases and the costs thereof. It was found that large transport tube trailers could be supplied with the proper mixture proportions of H_2 , CO_2 , and CO . The other components, N_2 , H_2S , and CH_4 would be supplied in additional separate smaller cylinders for the following reasons. H_2S would not be put in the main tube trailers because it would permeate cylinder walls and the trailers would not be usable for other services. The quantities of N_2 and CH_4 required for the specified test gas are so small, relative to the quantities of other components, that the supplier would not be able to guarantee acceptable accuracy for these components from the bulk supply terminal and felt these could be best introduced at the user facility from individual cylinders. The addition of water to the test gas is best balanced at the test facility in any event.

The estimated consumption of the test gas, consists of two initial trailers to charge the system and four additional trailers consumed during a year's operation. Additionally, it is estimated three cylinders of CH_4 , 15 cylinders of H_2S , three cylinders of N_2 , and 14 cylinders of CO_2 would be consumed during a year's operation. The annual cost of the above gas is \$36,039.

As a point of comparison, the operation of the reformer/shift conversion gas generation system, which would probably be the most probable on-site gas generation system to achieve the specified gas composition, would require full-time operator attention. Direct full-time operator attention alone would cost approximately \$78,800 per year. Capital cost of the system, and operating feed stream costs, would have to be added.

Mittelhauser believes that the closed loop test system, using purchased cylinder gas, is the best overall test system approach to meet the criteria shown at the beginning of Section 4.3. The conceptual configuration of the closed loop HDGCV Test Facility is as shown in Figure 4.1.

4.4 METALLURGY REVIEW

The demands on materials of construction for this HDGCV Test Facility are substantial.² One percent H₂S environments at temperatures in excess of 1800°F are very aggressive to most metallic materials.³⁻⁴⁻⁵ Also, in the gas cooling area of the loop, there is increased potential for high corrosion rates on carbon steel equipment because of dissolved gases.⁴

In the convection section of the fired heater, the clean gas will be heated from approximately 300°F to about 1200°F. The high H₂S concentration (~1%) dictates the use of an 18-8 type stainless steel.⁶ Type 347 stainless steel is suggested as it is stabilized to operate in the temperature range of 800 to 1500°F without potentially harmful chrome carbide precipitation. Also, the resistance of type 347 to hydrogen damage at these temperatures is excellent.⁶

The radiant section of the heater will heat the gas mixture up to 1825°F. This environment will be very demanding on most common high temperature alloys.⁷⁻⁸⁻⁹ Forgetting the corrosive environment for a moment, process pressure containment, at tube wall temperatures in the vicinity of 2000°F, limits what is available to use. Normally, HK type cast tubes are limited to 1800°F maximum tube wall temperature.⁹ This is based on 1% creep

FIGURE 4.1 CONCEPTUAL CONFIGURATION OF SELECTED FACILITY

deformation during a 100,000 hour life. The creep strength of HK tails off greatly as temperatures exceed 1800°F.

The Fossil Fuel Energy Research Department of DOE conducted coupon tests for materials at 1800°F in a gasifier environment at 1000 psi containing 0.5% H₂S.⁵ The corrosion rate on HK was about 20 mpy (mils. per year). Besides containing less H₂S than the test facility gas, gas used for the DOE test contained about 40% H₂O and the environment tended to be oxidizing. The test facility gas mixture tends to be more reducing and, therefore, more aggressive since HK alloys depend on protective oxide films for their resistance. Under reducing conditions both iron and nickel sulfides form. However, their eutectic compositions melt at a temperature below 1800°F and would therefore be non-protective at the heater discharge temperature of 1825°F. Clearly, H₂S in the test gas stream is a very great concern.

The use of other alloys for radiant tube service, such as HP type castings, offers some advantage in higher strength at elevated temperature, but, the higher nickel content makes it less resistant than HK to the relatively high H₂S environment.³⁻⁴⁻⁵

Refractory lined piping will be resistant to the test gas environment.⁵⁻¹⁰ Current experience with 50% Al₂O₃ castable refractory has been good.⁵ Consolidated Controls Corporation, in El Segundo, California, manufactured a system with a 94% Al₂O₃ inner layer, an insulating refractory intermediate layer with a metallic outer shell.¹⁰ The outer metallic shell material is determined by temperature. For metal wall temperatures up to 1500°F, type 347 stainless is suggested. For temperatures in excess of 1500°F type 310 stainless is the choice.

Another possibility for not clean gas piping would be to use HK alloy, heavily insulated. This would be a distant second choice. Problems might arise from heat loss and, as mentioned above, the environment is extremely aggressive at elevated temperatures to metallic materials.

The introduction of solids to the hot gas stream, of course, introduces erosion/abrasion.¹¹⁻¹² The key to success here is to avoid any unnecessary turbulence. Piping runs should be kept short and straight. This is an area where the best material can still fail because of inadequate design. Downstream from the test valve should be the most aggressive environment in the test loop. Refractory lined piping is the best, and perhaps, the only practical selection for this environment.

The venturi is subjected to both abrasion and the corrosive environment over a broad temperature range. The first choice would be refractory lining, with a somewhat distant second choice of HK alloy. Abrasion resistance, primarily, coupled with resistance to the environment, are the important considerations. Once into the venturi separator the environment has cooled to the point where austenitic (300 series) stainless steel can be used. The bottoms effluent from the venturi separator can be handled in carbon steel with an adequate corrosion allowance. This stream contains solids and will be somewhat abrasive.

The moisture-laden recovered gas is potentially corrosive to carbon steel equipment.¹³⁻¹⁴⁻¹⁵ Dissolved gases, primarily CO₂, in any water phase that might be present renders the water phase corrosive. Any condensate will contain carbonic acid which is very corrosive to carbon steel. Eighteen-eight type stainless steels are completely resistant to this type of attack. The 18-8 type stainless steels are also much more resistant to H₂S corrosion, than is carbon steel, at the moderate temperatures of the recovery system.

H₂S cracking of carbon steel welds is also a potential problem.¹⁶ It is best controlled by limiting weld hardness to 200 BHN for carbon steel piping and equipment.

Another approach to corrosion control in the gas recovery equipment would be to build everything of carbon steel and inhibit against corrosion. While this approach offers some savings in capital equipment costs, it would require maintenance of the inhibitor system and is not as fool-proof as using materials that are resistant by their nature.

The preliminary design package assumes demineralized boiler feed-water. Chlorides that might be present in other water can cause austenitic stainless steels to fail by stress corrosion cracking. As a hedge against this occurring, the stainless steel equipment could be stainless clad carbon steel. This will not prevent cracking from occurring, but will insure that cracking will not proceed into the strength portion of the vessel, that is, the carbon steel substrate.

All metallic components in the test loop are readily weldable. It is suggested that vendor qualified welding procedures and welder performance qualifications be reviewed prior to fabrication. Also, limitations on welding processes and filler metals should be written into purchasing specifications. This is particularly true of the fired heater tubes which will be in very demanding service.

The above materials of construction have been included on the process flow diagrams, drawings 231-C-001 and 231-C-002, in the Appendix of this report. Because this study task was done concurrently with the facility design, not all of the recommendations contained here were incorporated in the vendor quotations for equipment, but the overall cost contingency should cover any minor necessary upgrading of materials in the next design phase.

4.5 SAFETY REVIEW

The approach taken to the safety review task was to include necessary safety related design considerations on a piece-wise basis as individual equipment components were finalized, and then provide an overall review of the facility for general safety considerations.

On the individual equipment, or component, basis the following inclusions were made. All driven equipment includes coupling guards when accessible from walkways or working locations. All electric motor drivers are supplied with totally enclosed-fan cooled enclosures. All electrical enclosures for contacting/sparking potential service will be suitable for installation in hazardous area location Class I, Group B, Division

1 (NEMA, Type 7). All pressure containing components have adequate paths of relief with relief valves set at the components' design pressure. The fired heater will be furnished with a burner management system and snuffing steam connections. All hot piping, outside wall temperature 150°F and greater at operation, accessible from walkways and work areas, shall be furnished with expanded metal personnel protection insulation.

With regard to noise, from both worker and community exposure considerations, the following noise reduction methods have been included by contingency and will require further definition in final purchase specification. Air cooler noise has been reduced by the use of six-bladed fans and the associated reduction of blade tip speed. Provision has been made, by way of contingency, for the full enclosure of the compressor/gear/driver skid. Provision has been made, by way of contingency, for the supply of individual burner silencers for the fired heater. Noise generated by the test valves themselves may also create a problem. This would probably be best handled by the use of noise shadowing walls, being careful not to interfere with maintenance or personnel escape paths.

Local mounted pressure indicators have been furnished on equipment piping in order to reduce the possibility of service/maintenance breaks while the system is pressurized. Particular attention has been paid to this aspect at the test valve flange breaks in the test loop as removal of these valves is a frequent occurrence. Also, critical service components, vessel liquid levels, compressor temperature and pressure, and heater temperature are provided abnormal operation alarms to the test facility control room.

From an overall facility standpoint, the following design features should be included in the final design. Due to the nature of the components of the test gas, gas detectors for at least H_2 and H_2S should be placed at the following locations; at grade at each valve test station in the test loops, at the process water blowdown discharge location, and at compressor seals. Also, final design elevated walkways and work locations should include OSHA/NIOSH guardrails and ladders.

Since the location of the HDGCV Test Facility relative to the balance of the METC facility is only proposed, per Figure 3.1.3, a final selected location will be necessary prior to resolution of concerns as to relative availability of emergency medical facilities to HDGCV Test Facility personnel. Modification to existing firewater system, or addition of separate firewater system, to provide fire protection to the HDGCV Test Facility, has been provided for in the cost allowance for off-site facilities. An approximation of firewater requirements for a facility of this size would be 1000 gpm at 100 psig.

It is also noted here that, because of the elaborate materials of construction requirements of this facility, dictated by the severe operating conditions, a detailed quality assurance/quality control program would be a necessary part of the final design and construction of this test facility. This program should include materials of construction source inspection and certification, vendor shop quality control review and approval, and detailed shop and field welding, and inspection quality control procedures. All of the above will provide positive points in a failure mode analysis and will help assure the successful and safe operation of the HDGCV Test Facility.

4.6 FACILITY DESIGN

4.6.1 Characterization of Valve Failure Modes

Work performed under this task began with attempts to characterize the ways in which valves had failed when placed in service equivalent to that simulated in this test facility. This would provide insight into where emphasis might be placed in the valve testing while reducing the cost and complexity of the test facility.

It was found, however, that no accurate analysis records were kept for valves which had failed. Due to this, it became necessary to identify generalized potential methods of failure, and to consider that any of the valves' components (body, seats, seals, stem, or stem packing) could fail.

Since the gas contains corrosive compounds, corrosion of any of the valve components would certainly be possible. Potential corrosion failure is enhanced due to the elevated operating temperature and pressure.

Due to the size of the solids to be in the gas stream, less than 60 μm , erosion of the valve base metal would not be as much of a problem as would the erosion of corrosion-protective coatings formed by alloys or non-ferrous metals. The most probable contribution to valve failure due to the presence of the fine solids would be that of abrasion on sliding surfaces, that is, on seats and seals and/or at stem-to-stem-packing contact points.

Because of the varied ways, and combinations thereof, in which the tested valve could fail, it was decided that the approach to be taken would be to subject the valve to a gas/solids test medium, as close to the specified analysis as possible. The system would also have to operate at a temperature and pressure to produce the maximum 1750°F and 250 psig at the valve inlet to provide adequate driving force for the corrosion and erosion/abrasion to take place. This led to the work described in Section 4.3, in which a conceptual closed-loop system was defined.

4.6.2 Reliability of System Components

The scope of work was now expanded beyond the test valve segment of the facility. Since the conditions being simulated at the test valve should be a continuous steady-state operation with a high degree of accuracy and repeatability, a process approach to the facility design was taken. It was decided that the best method to accomplish this would be to use a continuous loop system employing state-of-the-art equipment throughout, depending on the operating conditions at any point within the test loop. Also, due to the fact that the system-simulating equipment would potentially see the same failure-inducing conditions as the tested valve, equipment protection additions would be incorporated so that only the valve would be the potential point of failure, and the operating constraints of any other piece of system equipment would not be exceeded.

4.6.3 Characterization of System Operations

The specified test gas composition at this time in the design process was assumed to be reproducible and the generation thereof either external to, or built into, the loop. In any of the gas generation cases being considered, a fired heater would be necessary for gas production itself and/or additional heating of the test gas. To minimize long runs of hot piping, the heater was positioned just upstream of the valve test section.

The gas feed to the heater, in order to overcome the pressure drop through the heater and hot piping, is compressed. The compressor includes a spillback, or recirculation loop with cooler, to handle the flow and pressure ranges of operation in both the 250 psig and 50 psig cases.

The compressor suction, other than that from the spillback, loop, comes from the valve test section discharge. Even though the quantity of solids in the test loop is small, the solids must be removed before the gas goes to the compressor. The gas, exiting the test valve at 1750°F, also requires cooling prior to recompression. In order to facilitate both of these requirements, the valve test loop discharge to the compressor suction first goes through a gas cooling and cleanup. In order to accomplish this, it was decided to put the hot, dirty, contaminated gas through a venturi scrubber, followed by a trayed-column scrubber, and a direct contact cooler for final gas cleanup and cooling to compressor suction requirements.

Since some of the gaseous contaminants would be removed from the gas during cleaning and cooling, a gaseous contamination makeup system was added between the heater and the test section. The evolved schematic concept of the test system, including some of the required data acquisition valves and the valve cold stem leak test equipment envisioned by METC was shown in Figure 4.1.

In order to comply with the requirement that a valve could be undergoing testing while another is coming off-stream for disassembly/inspection,

second test loop, duplicating the first and using the common compressor and heater, was added. A third loop was added parallel to the two test loops so that instabilities generated while cycling the tested valve, or changing test loops, would not affect the operating conditions at the compressor and heater. This third loop, the bypass loop, does not have a solids addition package and the test valve is replaced with a fixed orifice simulating the fixed pressure drop in a test loop. Even though there is no solids addition in this loop, the gas cleaning and cooling is the same as the two test loops. This allows for full bypass of the test loop gas in the event that one test loop was off-stream for valve inspection, and the second test loop encountered an unplanned shutdown, without catastrophic consequences to the test system equipment.

4.6.4 Selection of Major Equipment

Once the total test facility was established in conceptual form, each component was then designed in more depth. By this point the method of gas generation had been established to provide gas as specified in document METC/CR-79/10. By using a maximum scaleup ratio of 10:1, test valve to demonstration plant sized valves (28 to 30 inch diameter), the test loop bore diameter of 10 inches was established. Also stated in document METC/CR-79/10 was a maximum test loop gas velocity of 175 ft/sec. Combining the above with the worst case criteria of 250 psig and 1750°F, the mass flow rate of gas through the test loop was determined. In order to assure stability of the system, an additional 25% of the test loop throughput was provided to the bypass loop.

Heater and Compressor

The heater discharge flow rate was now known. By approximating the heat losses from piping between the heater and the test loops, all required conditions at the heater discharge were found. The inlet conditions to the heater were now required. An inlet temperature to the compressor of 140°F was assumed to be a reasonable value for this system. Secondly, the compressor suction pressure was set at approximately 150 psig (164

psia). This was done so that at the time the tested valve was at maximum closing position, resulting in approximately 50 psi pressure drop, and allowing for 20 psi differential pressure through the gas cooling and cleanup system, a 30 psi pressure drop to be taken across a self-regulating pressure control valve, would be available to ensure less than saturated conditions at the compressor suction. Also, an additional 10% of the heater's required inlet flow rate would be put through the compressor spillback loop at all times to ensure positive control of the spillback system.

A process water balance also illuminated the need for water makeup injection, between the heater convection and radiant sections to account for the different water content values found in the valve test section and the compressor suction.

With the required conditions now known from the compressor suction to the heater discharge, the test system's heater and compressor were then rated and sized for their respective services.

Gas Cooling/Cleanup

The gas cooling/cleanup requirements of the HDGCV Test Facility were then analyzed by rough energy and material balances and by rough performance calculations. These performance calculations resulted in a determination that, due to the particle size distribution of the solids, an overall removal efficiency of approximately 98.5% could be expected in the Venturi, and that uncaptured particles 0.5 μ m and smaller would not be removed even with the use of the trayed-column scrubber. For this reason, the trayed-column scrubbers were deleted and replaced with an entrainment separator, V-100 A, B, C, following the venturi scrubbers, ME-100, A, B, C. The 0.5 μ m and smaller particles, approximately 5 pounds per hour in the 250 psig 1750°F case, would circulate throughout the system unless lost through attrition elsewhere. Vendors of compressor equipment indicated verbally that the size and rate of the residual dust would not unduly affect the performance or reliability of the equipment.

The three parallel direct contact coolers originally envisioned were changed to one cooler, V-101, fed through a common manifold. By using the one cooler, a more uniform backpressure would be encountered by the individual test and bypass loops, and it would also provide some pulsation damping for the compressor suction. The cooler was designed to handle 125% of the required flow through a test loop (100% through the test loop, and 25% through the bypass loop), and is a valve-tray type unit.

An indirect heat exchanger could be substituted for the direct contact cooler since the principal function of the device is heat transfer. However, by selecting the direct contact cooler, some protection against larger particulate breakthrough from the venturi scrubbers is gained.

Due to the relatively limited overall METC cooling water capacity, and in the interest making the HDGCV test facility less dependent on interruptible utility services, an air cooler, E-100, was used for the direct contact cooler water recirculation loop. A shell and tube exchanger for the same service would require 3000 to 4000 gpm of cooling water, which is three to four times the stated METC cooling water system capacity.

Gas Recovery

Computer process simulations made as discussed in Section 4.6.6 indicated that significant losses of test gas components would be encountered through the direct discharge of scrubbing water from the venturi scrubber separator vessel. To diminish these gas losses, a dissolved gas recovery system was designed using low-pressure stagewise flashing of the dissolved gas from the condensate. Resultant dissolved gas concentrations of approximately 3 ppmw CO₂ and 5 ppmw H₂S are found in the water discharged from the test facility for solids removal.

To account for these gas losses and other losses through piping connections and equipment seals, gases lost during test loop blowdowns, and to bring the initial test facility bulk gas charge up to specified

component percentage levels, a gaseous contamination package was added. This consists of a rack of cylinder bottles, with metering valves, which will cover all test gas components except water.

By maximizing the recirculation of water in the direct contact cooler, venturi scrubbers, flash gas cooling, and heater reinjection, the effluent water from the test system was limited to the solids laden water from the venturi scrubbers by way of the low pressure purge water flash drum.

Solids Addition

After overcoming the initial design problems of the test facility equipment to handle the corrosive/erosive gas (e.g., compressor, heater scrubbers, etc.), it was found that the most difficult problem to overcome was that of accurate solids metering required to the gas stream. The problem was complicated due to: the size of solids particulates involved, the maximum rate required, and requirements for the feed rate to be variable from 50% to 100% over a 15-second cycle corresponding to the cyclic operation of the test valve.

In addition to contacting several vendors experienced in the field of solids addition, investigation was initiated into published information regarding development of solids handling/addition systems with particular interest in very fine solids. Several publications^{17,18,19,20} were found with information regarding solids addition to gas streams.

Most of the work discussed in the above referenced publications is of an experimental/developmental nature, generally of laboratory scale, at least as of the dates of publication which, in most cases, are several years old.

In lieu of further extensive research for additional publications, which might yield information only on developmental work which is unusable in this state-of-the-art test facility, it was decided to use the publications already available to select a feasible system from the above referenced vendor contacts.

The solids addition system offered by Petrocarb, Inc., of Bloomfield, New Jersey, closely resembles the pneumatic feeding system described in "Pneumatic Feeder for Finely Divided Solids,"¹⁷ a joint development project of the U.S. Bureau of Mines, and West Virginia University, both at Morgantown, West Virginia. This system consists of an overhead batch receiving vessel which is depressurized to receive a charge of solids from a central storage silo. The batch vessel is then closed and repressurized to system pressure. The batch receiving vessel then feeds a primary injection vessel through a valve-controlled feedpipe and solids are maintained in a fluidized state. The solids are then additionally fluidized and metered in a standpipe feeding into the hot gas piping just upstream of the HDGCV being tested.

Although this solids addition system offered appears to be feasible, and is included in this preliminary design package, a detailed investigation into its past applications and successes, to assure total operation and construction compatibility with the remainder of this test system, is needed in the next design phase.

4.6.5 Valve Test Loop Configuration

The valve test loop portions, two each, of the test facility are designed to be completely independent of one another. They are completely identical parallel trains from the point they split off from the hot gas header, and remain separate until they rejoin at the cool/clean gas header into the direct contact cooler.

Separate solids additions packages were used to avoid bends and diverter valves in hot dirty gas piping leading up to the two valve test stations, because such bends and diverter valves would be subjected to the HDGCV test conditions. On the discharge side of the test valves, the test loops remain separate through the venturi scrubber and scrubber separator for the same reason.

The test loops are isolatable from the balance of test system by valves at each end of the loop. These isolation valves will not be subjected to the same conditions as the test valve because: on the hot end, the valve will be exposed to only hot, gaseous contaminated gas,

as it is upstream of solids addition; on the cool end, the valve is after the venturi scrubber and separator, and will be exposed to cool, low-solids content gas.

Hot Leak Rate Test Shroud

In an effort to assure accurate measurement of the deterioration of a test valve at a high point of probable failure, the stem packing, the concept of the HDGCV Hot Leak Rate Test Shroud was developed. The concept came about primarily during discussions of problems associated with the correlation of data projected for the original concept of hot valve testing and cold stem leak rate testing. For example, with the large flow of test gas circulating in the test system, it would be virtually impossible to determine at exactly what point in the test the maximum stem leak rate of 0.1 scfm per inch of valve diameter²¹ had been exceeded without such a shroud. Also, clearances in the valve would change drastically between the valve operating temperature of 1750°F and cold leak rate testing at ambient temperature. In order to limit temperature effects on valve operator components, as these will be totally enclosed in the shroud, a nitrogen purge was used to keep the temperature in the test shroud below 450°F maximum. Additional details of the Hot Leak Rate Test Shroud are found in Section 5.4.3.

Details of the valve test loop are shown in Drawing 231-C-101 in the Appendix of this report.

4.6.6 Material and Energy Balances

Detailed but preliminary material and energy balances were developed through a combination of process computer simulations and hand calculations. The initial work was done for the Case I operating conditions, 250 psig/1750°F. The results of this work were incorporated into the performance specifications design basis for all of the mechanical equipment.

Operating Case II, 50 psig/1650°F, was then developed by using the required operating conditions balanced against the turndown capability of the mechanical equipment where possible.

These detailed energy and material balances, showing conditions for all main process streams and effluent water, are presented on the Process Flow Diagrams in the Appendix of this report. Drawing 231-C-001 is the Case I process flow diagram, and Drawing 231-C-002 is the Case II process flow diagram.

4.7 INSTRUMENTATION DESIGN

4.7.1 Summary

This section describes the approach taken to instrumentation design for the HDGCV test facility. A detailed investigation was performed of actual requirements for the specific instrumentation necessary to monitor the environment directly associated with the test valve itself. Additionally, the instrument specification for process mode of control for the balance of the HDGCV test facility was specified.

The work performed on instrumentation design was separated into the following four phases:

- Analysis of the measurements necessary for the HDGCV test facility of the physical environment which the sensing elements must be capable of surviving.
- Determination of materials for instrumentation in the HDGCV test facility.
- Search of available off-the-shelf and state-of-the-art instrumentation; to specify specific instrumentation in the immediate environment of the test valve.
- Analysis of special instrumentation design problems.

4.7.2 Instrumentation and Control Requirements

Valve Test Loop

Instrumentation requirements for the valve test loop are shown in Table 4.1. The location of each of these instruments is shown on Drawing 231-C-101. The HDGCV Test Facility operating conditions relevant to these requirements are as follows:

- Particulates with erosion properties of fly ash, all less than 60 microns with 10% less than one micron in size.
- Valve test loop gas superficial velocity of 175 feet per second.
- Maximum heater outlet temperatures of 1800°F at 300 psig.
- Continuous operation for 8000 hours per year for five years.

Because the HDGCV Test Facility has two test modes of operation, one at 50 psig and the other at 250 psig, in some instances two sets of instrumentation will have to be specified in order to maintain the necessary accuracy under such widely different operating regimes.

Valve Stem Leak Test Equipment

Instrumentation requirements for the valve stem leak portion of the valve test loop are also detailed in Table 4.1. Instrumentation will be required to withstand the corrosive/erosive environment of the valve stem leak test loop but under reduced temperature, pressure, and flow. The temperature will be kept below 450°F by a nitrogen purge. A small differential pressure from inlet to outlet at an absolute pressure above atmospheric is required to maintain the purge. At a maximum tolerable leak rate of 1.0 scfm (0.1 scfm per inch of valve size), above which the system shuts down, a flow of about 10 scfm would be required, which in a 5/8-inch ID line results in a fluid velocity of about 6-8 ft/sec.

TABLE 4.1 INSTRUMENT REQUIREMENTS FOR VALVE TEST LOOP

<u>Instrument Type</u>	<u>Instrument Numbers^d</u>	<u>Range</u>	<u>Accuracy^a</u>
PI ^b	2.1, 2.2, 2.3, 2.4	0-300 psig	±1
PT	2.1, 2.2	0-300 psig	±1
PDI	2.3, 2.4	0-50 psig	±1
PDT	2.1, 2.2	0-50 psig	±1
PDI ^c	2.1, 2.2	0-50 psig	±1
TE	2.1, 2.2	0-1800 ^o F	±1
TI ^c	2.2	0-1800 ^o F	±1
TT ^c	2.2	0-1800 ^o F	±1
PI ^b	2.7, 2.8	0-250 psig	±1
PI ^c	2.5, 2.6	0-250 psig	±1
PT	2.3, 2.4	0-250 psig	±1
TSH	2.1	N/A	N/A
FI ^c	4.1	0-35,000 scfm	±2
FT	4.1	0-35,000 scfm	±2
TW	2.1, 2.2	N/A	N/A
FT	2.1	0-130 gpm	±2
FT	2.2	0-120 gpm	±2
PT	13.1	0-30 psig	±1
TE	13.1	0-90 ^o F	±1
FT	13.1	0-10 scfm	±2
PT	14.1	0-20 psig	±1
TE	14.1	0-500 ^o F	±1
FT	14.1	0-11 scfm	±2
WT	14.1		
ZT	14.1	Test Valve Specific	
ZT	14.1		

^a% full scale^bLocal indication^cPanel mounted^dRefer to Drawing 231-C-101

The low fluid velocity (compared to the valve test loop) reduces the abrasive effect of the particulates in the process. Also, the process is diluted about 10 to 1 by the N₂ purge, thus reducing concentration of particulates as well as lowering the corrosive properties of the process itself. Finally, the particulates, especially at initially low leak rates, will not be able to pass through the stem packing as readily as the gases, resulting in further reduced particulate concentration in the valve stem leak test equipment. This presents an overall less severe environment from a materials standpoint than that of the valve test loop.

Other Requirements

All instrumentation specified for use in the HDGCV Test Facility must be compatible with the existing METC data acquisition system. The major METC hardware components are as follows:

- Data General Corporation, ECLIPSE 5/200 computer and peripherals
- DATUM, Inc., System 70 data acquisition system
- Tektronix, Inc., CRT terminals.

Analog inputs to the METC data acquisition system are 1 to 5 volts DC or 0 to 10 volts DC (ground based), interfaced to DATUM, Inc., multiplexer (Part No. 7218), or signal conditioner (Part No. 7234). Analog outputs from the METC system are 1 to 5 volts DC, 0 to 5 volts DC, or 0 to 10 volts DC (ground based) (output current limited to 5 MA), interfaced to DATUM, Inc., digital to analog converter (Part No. 7925). Signal conditioners are necessary to insure the interface conditions summarized above.

Other instrumentation to be specified includes various analyzers as well as recorders and indicators. A timer/cycle generator is also required. These and other remaining system instrumentation requirements are depicted on Drawings 231-C-102 and 231-C-103, and discussed in a later section.

4.7.3 Materials Findings

The process gas composition requires SS 316 for temperatures under 1000°F. Stainless 310 has better corrosion resistance properties at higher temperatures.

High nickel steels are not recommended. None of the Hastelloy materials are recommended, as they require the presence of oxygen to perform well.

Studies²² have shown that the performance of various materials changes markedly with temperature, H₂S concentration, and time, in the ranges encountered in the HDGCV Test Facility. Studies at 1000 hours and 4000 hours show in some cases radically different behavior. Thus extreme caution is to be exercised in the assignment of materials. The use of standard charts or tests of limited scope (i.e., insufficient duration, low H₂S, or low temperature) could lead to erroneous results. Because SS 316 has been extensively tested and is readily available, it becomes the material of choice for applications under 1000°F. Additional long duration studies are currently underway sponsored by the Metals Property Council, Inc., in New York City.

In addition to corrosion problems, abrasion problems are caused by the particulates in the stream. Thus, it is usually not recommended that SS 316 nor any other metal be placed in the hot dirty gas flow stream of the process. To survive such an environment refractory materials are usually considered necessary. Although they have the advantages of being extremely hard, able to resist abrasion, corrosion, and very high temperature, they bear the disadvantage of being expensive, brittle, very hard to machine, and not readily available in off-the-shelf items. A particular material having had extensive use is alumina. Another material, silicon carbide, has been reportedly²³ used successfully in many applications. One concern is that the H₂O will leach out the silicon, but that has not been observed in some similar applications.

4.7.4 Investigation of Available Instrumentation

Virtually every manufacturer of process instrumentation in this country, and some abroad, was contacted for information. This included inquiries by mail, telephone conversations, and meetings with technical personnel. The following sources were utilized:

- Attendance at conferences and meetings,
- Use of proceedings from other conferences.
- Journals,
- Directories/references,
- Personal contact with personnel at installations having similar instrumentation problems.

The ISA 1979 show in November at Chicago and the Chem Show '79 in December at New York were both attended to obtain information. Discussions with relevant exhibitors were held and information solicited from virtually every exhibitor of instrumentation equipment.

The proceedings from previous conferences involving process instrumentation, especially related to coal conversion, were obtained. Lists of exhibitors were used to identify more manufacturers.

Various journals in the areas of chemical engineering, process engineering, hydrocarbon, and coal technology were reviewed. Additional sources of manufacturers as well as insight into some of the measurement problems and solutions were obtained.

In trying to locate a specific type of instrumentation, directories used included the Chemical Engineering directory of manufacturers,²⁴ the ISA directory, the Thomas Register,²⁵ and Instrument Engineer's Handbook,²⁶ edited by B. G. Liptak.

In order to ensure the broadest possible data base for the determination of candidates for applicable instrumentation, personnel at various installations having similar instrumentation problems to HDGCV Test Facility were contacted. These included Combustion Engineering (coal

gasification), National Bureau of Standards Center for Absolute Physical Quantities, IIT Research Center, Exxon Research and Engineering Co., and Argonne National Laboratory. Valuable information on the types of instrumentation most applicable to the HDGCV Test Facility was provided by the above sources.

4.7.5 Special Design Problems

Problems associated with performing required measurements of the environment directly associated with the test valve are described in this section. System process environmental conditions are shown in Drawings 231-C-001 and 231-C-002.

Flow in the Valve Test Loop

Measurement of flow in the valve test loop hot dirty gas stream is a major instrumentation problem due to the severe environment imposed on any sensor immersed in the process. To avoid material problems the flow of gas through the test valve is determined by a combination of three simultaneous measurements made downstream of the venturi separator, V-100 A or B, where the process is considerably cooler, as indicated in Drawing 231-C-101. The flow signals from the transmitters labelled 2.1, 2.2, and 4.1 from the liquid to venturi, liquid from separator, and gas overhead streams, respectively, go to the METC data acquisition system, where they are converted to a common basis and a mass balance performed. Thus, the flow through the test valve can be readily determined.

Pressure in the Valve Test Loop

The pressure is a fairly standard measurement. To protect the pressure transducer from the high process temperature, a dead end tap is used, going upward far enough so that there is sufficient cooling of the process gas by heat loss to the surroundings. The vertical direction is taken so that any condensate falls into the hotter process gas and vaporizes. This system can be zero adjusted to account for the weight of gas in the tube. An isolating valve for protection of the pressure transducer upon surge is included. A purge is provided for cleaning the tap of particulates deposited by the process.

Temperature in the Valve Test Loop

The temperature of the process in the main flow stream is to be measured by a thermocouple placed inside a protective thermowell. In order to minimize the effect of conduction of heat energy along the thermowell itself from the process to the colder surroundings, which results in the thermocouple reading "low," the thermocouple must extend several inches into the process.²⁷ Since this imposes a severe burden on the thermowell, a careful examination of available thermowells is required to insure their survival during 8000 hours in the process. Furthermore, as indicated in Drawing 231-C-101, several thermowells are to be used for redundancy thereby increasing reliability.

Valve Stem Leak Rate Measurement

Valve stem leak rate is determined by measuring the flow into and out of the test shroud as shown in Drawing 231-C-101 and taking the difference. The inlet flow is simply the nitrogen purge, and the outlet flow is the combination of nitrogen and process gas leakage through the valve stem. By transmitting these two flow rates to the METC data acquisition system where they are converted to scfm, the test valve stem leakage is computed as the outlet flow minus the inlet flow.

Because the leak rate is determined from the difference of two flows, each about ten times that of the leak rate, relatively low flows must (10 scfm) be measurable to 0.1% in order to have a measured leak rate accurate to 2% at maximum leakage (1.0 scfm).

In order to retain the ability to measure leak rates at flows below the maximum tolerable leak rate, it is necessary to minimize the nitrogen purge so that small leaks are not completely masked. Thus a temperature controller on the nitrogen purge is used as indicated on Drawing 231-C-101 so that only enough nitrogen is purged to keep the temperature in the shroud below 450°F.

Since the valve stem leak rate is an important characteristic of the test valve, an effort should be made in the design of the valve stem leak rate flow detection system to allow accurate measurement of leak rates over a wide range of flows. Because of this consideration head meters (orifice, nozzle, etc.) are ruled out for this service since the differential pressure which is measured by such a device is proportional to the square of the flow (i.e., differential pressure varies by a factor of four as the flow varies by a factor of two).

Turbine meters are chosen for the measurement of these flows due to their accuracy over a wide range. Furthermore identical meters are used for both inlet and outlet to reduce the effect of nonlinearities. Wear on the downstream meter is considered to be mitigated because of the following effects:

- The process is diluted by the nitrogen
- All parts in contact with the process gas can be fabricated from all SS 316 parts thereby resisting corrosion
- Few particulates should pass through the valve stem (especially at first before the stem packing gets worn away)
- The fluid velocity in the outlet is low compared to the flow through the valve thereby reducing the ability of the particulates to cause erosion of the turbine blades
- The turbine blades are not fixed but are made to "give"
- The turbine meters are to be cleaned and inspected and worn blades replaced after each valve is tested.

An alternative method for determining valve stem leak rate, although indirect, consists of measuring the N_2 flow into the shroud and the H_2S concentration in the outlet flow. By comparing the H_2S concentration in the process (which is constantly monitored by a gas analyzer) to that diluted by the N_2 in the outlet, the ratio of leak rate to N_2 purge flow could be very accurately determined. Thus the leak rate

determination would be essentially as accurate as the N₂ flow measurement since gas analyzers are easily accurate to parts per million. Also this method eliminates the costly and potentially troublesome temperature controller in the shroud for the N₂ purge. One could simply leave the N₂ purge at a constant rate capable of maintaining the shroud temperature below 450°F even at 1.0 scfm leak rate without any difficulty in measuring low leak rates.

Valve Stem Position Measurement

The measurement of the valve stem position is complicated by the fact that the sensor must lie within the shroud and be subject to temperatures of up to 450°F in a corrosive and erosive environment. In addition due to the wide variation possible in test valves, a great deal of flexibility will be required in the application of the position indicators of a chosen manufacturer to this task.

Valve Stem Force Measurement

The determination of the valve stem force like the valve stem position is also complicated by the fact that the sensor must be in the shroud. In addition, the sensor must be able to detect compression and tension corresponding to opening and closing the valve. Furthermore, a variation in ranges is required due to the differences to be encountered in the test valves themselves.

Both valve stem force and valve stem position measurements can be greatly simplified by designing the valve stem and shroud such that the stem bonnet penetrates the shroud and is accessible directly from outside. This allows more conventional devices for making the above determinations. However, the potential leakage of gas through the test shroud shaft seals, through which the valve actuator would have to pass, might complicate the overall problem.

4.8 COST ESTIMATES

Both capital investment and some operating costs were determined for the HDGCV Test Facility. The capital investment was developed based on estimated costs for the major equipment, selected piping, instrumentation and associated off-site facilities. In most cases these costs were obtained from equipment vendors who were contacted either by letter or by telephone. These vendors were given the operating conditions under which their equipment was required to perform, along with background information on the HDGCV Test Facility. In many cases these vendors responded with price quotations, in others they furnished insufficient information or declined to quote. Records of correspondence with vendors are given in Appendix 7.1 of this report.

A careful and thorough "factored estimate" was made of the turnkey plant investment with a target accuracy of ± 30 percent. The Richardson Rapid Estimating System²⁸ was to have been used as the methodology for this estimate. However, Mittelhauser recognized early in the study that the level of detail required to furnish data for the Richardson System was greater than afforded by the scope or budget of the study. Mittelhauser had developed a proprietary cost-estimating system of its own, leaning rather heavily on the Guthrie System²⁹ while borrowing from the Richardson System²⁸ where appropriate. This system allows for in-depth cost analysis of equipment components for which detailed data are available, while allowing a less-detailed but consistent analysis of equipment components costed more roughly.

In making the capital investment estimate for this study, careful attention was paid to the individuality of the equipment components and the circumstances of their application. The well-known Guthrie²⁹ "modular" factors were not applied blindly to a given item; rather, the applicability of each factor to that particular item was evaluated, and the factor adjusted or deleted based on Mittelhauser's in-house cost estimating experience.

As a particular example of this attention, no "modular" instrumentation material costs were included; rather, the material costs calculated by BDM Corporation were used. The installation labor factor applicable to each equipment module was then adjusted to reflect the higher instrumentation equipment costs obtained by BDM.

Discussions of the estimation methods used for each type of modular account are given in Section 4.8.2.

4.8.1 Determination of Major Equipment and Piping Costs

Discussions with Vendors

The following paragraphs are summaries of the discussions held with each vendor concerning the provision of equipment and materials for the HDGCV Test Facility.

AIRCO, Inc. An AIRCO representative was contacted by telephone for information on the cost of supplying gas for the initial fill and makeup of the HDGCV Test Facility. He furnished prices for both tube trailers and cylinders (which would be used in ME-106, Gaseous Contaminant Makeup Package).

Allis-Chalmers. Allis-Chalmers was asked to supply specifications and a cost estimate for K-100, Main Compressor Package. They replied in writing with price and delivery information. Although they had the lowest quoted price, Mittelhauser staff believed it more prudent in the preliminary design to use a conservative cost for this highly sensitive application. For this and other reasons discussed later, this quotation was not used in the cost estimate.

A. P. Green Co. A. P. Green was contacted by Morgan Engineering concerning refractorics for the hot piping between the Fired Heater H-100, through the valve test loops and bypass, to the inlet of Venturies V-100 A, B, C. They furnished

written technical and pricing information which was not believed sufficient to develop a reliable cost for the overall hot piping package.

Combustion Engineering. C - E Lummus, a division of Combustion Engineering, Inc., was asked to furnish a quotation for Fired Heater H-100. They replied in writing with cost and materials information which was used as the basis for the cost estimate for this component.

M. H. Detrick Co. This organization was contacted by Morgan Engineering to supply cost and technical data on refractories for the hot piping between the Fired Heater and the Venturis. They responded with a quotation for a silicon carbide-lined pipe which appeared quite interesting. This quotation was used for guidance in estimating the cost of this hot piping.

Elliott Company. This widely-known vendor of compression equipment was asked for price and technical data for K-100, Main Compressor Package. They responded in writing with the desired information. Further, they stated verbally that they believed that their machinery was capable of operating under both Case 1 (250 psig nominal pressure) and Case 2 (50 psig nominal pressure) conditions, and would experience no undue wear from the small concentrations of fine (<0.5 microns) particles remaining in the gas after cleaning. On consideration of their past successful record in similar applications, and conservative pricing, Mittelhauser elected to use this equipment as the basis for its cost estimate.

Fuller Company. Fuller was contacted by Morgan Engineering and asked to furnish price and delivery information on the Solids Receiving and Loading Package, ME-102. They furnished this information, which was used as the cost estimating basis for this item.

F. W. Glitsch & Sons. This supplier of pressure vessels was asked to supply telephone price quotations for the major vessels in the system. They declined to do so, stating their preference for written quotations. On consideration of the schedule requirements for the estimate, Mittelhauser decided to use the Guthrie Estimating System to rough-estimate the prices of these vessels.

Coulds Pumps, Inc. Upon request, Coulds submitted a telephone quotation on price and delivery for pump and drivers for all services in the HDGCV Test Facility. These values were used as the basis for the equipment cost estimates.

Harbison-Walker. Morgan Engineering asked Harbison-Walker to supply cost and delivery information for refractories in the hot piping between the Fired Heater and the Venturis. Their written quotation was not usable since it specified an outside pipe wall temperature of only 281°F with an ambient temperature of 70°F, no wind. During winter, the pipe wall will undoubtedly be colder than this, leading to condensation of water at the inside pipe wall with consequent destruction of the refractory. Therefore, this information was not used.

Hudson Products Company. In response to a telephone request, Hudson furnished written price and delivery quotations for the two air-cooled heat exchangers, E-100 and E-102. These quotations and other verbal information received from Hudson were the basis for the equipment costs for these items.

Ingersoll-Rand. Ingersoll-Rand was asked to supply price, technical and delivery information on Main Compressor Package K-100. Their verbal offering consisted of a reciprocating machine at essentially the same price as Elliott's offering. Because of historically higher maintenance requirements associated with reciprocating compressors, a spare would likely be required for this high-reliability service. Therefore, their offering was not considered further for this preliminary design.

KTI, Inc. This vendor of fired process furnaces was contacted to supply a quotation for Fired Heater H-100. They replied with a brief price quotation which corroborated Combustion Engineering's price quotation. Their offering should be considered in more detail in the next phase of design.

Koch. Several conversations were held with Koch concerning the Venturi Scrubbers and Venturi Separators, ME-100 A, B, C and V-100 A, B, C. A written quotation was received containing price and delivery information; however, it was based on a misunderstanding of the inlet process gas condition. After telephone clarification of these conditions they submitted a revised price which was used as the basis for the estimated cost of these items.

National Air Oil Burner Co. This company manufactures various types of fired equipment; they were asked for a quotation on a packaged flare system, ME-107. They replied with a telephone quotation giving price, technical, and delivery information. This information was the basis for the estimated cost of this item.

Petrocarb, Inc. This vendor was contacted for information on a package for feeding the fine solids into the hot gas stream just upstream of the test valve. Their response was

a lengthy report which gave general information but few specifics. A budget price for each of two twin units (one for each valve test loop train) was also furnished. Because of the lack of available information on these systems, and Petrocarb's position as a leading manufacturer of such systems, Mittelhauser decided to use Petrocarb's budget price as the basis for the cost estimate.

Southern Technical Service. One of the principals of this firm, Mr. Dick Roberts, was responsible for design of the hot piping used at the IGT.HYGAS Pilot Plants located in Chicago, Illinois. These piping systems handled hot, high-pressure gas containing solids, much as in the current study application. Therefore, Mr. Roberts was contacted as a possible supplier of cost and design information. He expressed a willingness to cooperate but the information was received too late to include in the estimate. An independent estimate was made as described in Section 4.8.3.

Smoot Co. Smoot Co. supplied a written budget price and some design information on a solids feeding system to be used as ME-101 A, B. Although the quoted budget price was much less than Petrocarb's, it was Mittelhauser's opinion that the quoted system contained several elements (e.g., an expansion joint and a butterfly-type shutoff valve) which would need much more detailed investigation before the system could be accepted with confidence. Therefore, Smoot's information was not used in the design.

Sprout-Waldron. The Sprout-Waldron, Division of Koppers Co., Inc., was contacted for information on rotary-feeding devices which might serve as the basis for a solids feeding system to be used as ME-101 A, B. Their replies consisted of catalogue information which would require much more development than possible under the schedule and budget of

this study. Therefore, their offerings were not used in the preliminary design.

Preparation of Specifications

The selected vendor information on each equipment component was combined with knowledge of the specific application of that component in the process, and of the component's relation to the other process components, to prepare a specification suitable for use in cost estimating and as a basis for later design work. Where vendor information was lacking or insufficient, equipment was sized using proven techniques and Mittelhauser's process and equipment design experience. The specifications prepared as a result of these efforts are presented in Appendix 7.2.

4.8.2 Determination of Installed Equipment Costs

For each item of major equipment, a "cost module" was created. This module contained, in addition to the equipment cost, costs of associated piping, concrete, steel, etc, plus installation labor. The total of these items represents the "direct cost" associated with that piece of equipment. The following paragraphs describe the estimation of these "modular" costs.

Piping

For estimating purposes, the term "piping" includes all shop- or field-fabricated piping material, plus field assembly material (valves, flanges, expansion joints, etc.), small utility piping, valves, and fittings, underground piping for drain and sewer lines, shoes, guides, clamps, brackets, hangers, and scaffolding as required for installation. Mittelhauser was faced with a choice between detailed and modular piping estimation. Due to the preliminary nature of the design and layout, it was decided that detailed estimation was not justified at this stage. This is consistent with Mittelhauser's staff experience in preparing factored-type estimates for major A/E firms, of accuracy comparable to that desired here by METC. Modular techniques were therefore used, based

on the equipment type and its specific application conditions. The modular factors were adjusted to account for the effect of the associated materials of construction in the related equipment component, and for the pressure rating, on the cost of the process piping.

A special estimate was made of the added cost of the hot refractory lined piping between Fired Heater H-100 and the Venturis, ME-100 A, B, C. This estimate was only a rough attempt to allow for the known fact that this piping would have an extra cost over and above the normally-estimated "modular" piping cost.

Concrete

The concrete account includes concrete materials, formwork, reinforcing steel, accessories such as anchor bolts and curb angles, trench and basin covers, and weather protection during curing.

Concrete was estimated based on modular factors applied to the "base" equipment cost. Where the equipment cost was obtained from a vendor, and contained special design features or materials, the equipment cost was de-escalated to remove the effect of these cost adders and thus to avoid over-estimation of concrete costs.

Structural Steel

Structural steel materials include process equipment and piping access and support structures, ladders, platforms, and walkways. Structural steel costs were estimated based on recognition of specific pipeways and foundation requirements within the battery limits of the HDGCV Test Facility, and also on recognition of the need for racks for interconnecting piping between those battery limits and the rest of the METC Site. Steel costs were, however, prorated back to individual components on a "modular" basis, for presentational purposes.

Instrumentation

Instrument costs for this estimate were furnished by the BDM Corporation based on their design work described in Sections 4.7 and 5.4 of this report.

Electrical

Electrical materials associated with major equipment components include switchgear, motor control centers, transformers, circuit breakers, bus ducts, power feeders and motor runs, lighting systems, grounding and cathodic protection, battery-limits communications equipment, and pole lines if any.

For this estimate, electrical materials were estimated using modular factors applied to base equipment costs, where the base costs were calculated as described under "Concrete" above.

Insulation and Paint

This account contains materials for external equipment and piping insulation (not internal refractory materials), tie wire, mesh, paint and sandblasting material as required, and scaffolding for installation. These items were estimated using modular factors applied to base equipment costs as under "Electrical" and "Concrete" above.

Installation Labor

A different mix of craft skills, plus unskilled labor, is required to install different types of equipment. For this preliminary estimate, Mittelhauser did not attempt to disaggregate these craft skills for individual types of equipment, except as described above to account for the installation labor associated with the extra cost of instrumentation in the HDGCV Test Facility, and as described hereafter.

METC had furnished Mittelhauser with informal observations on the productivity of certain craft groups in the Morgantown, West Virginia area. Mittelhauser used these productivity factors to adjust the overall modular labor factor associated with each type of major equipment. However, no attempt was made to apply these observations in more detail at this time.

Escalation

Mittelhauser's in-house cost estimating procedures contain modular factors and curve-type base equipment costs on a mid-1978 basis. However, because labor, each type of material, and equipment all escalate at different rates, these modular factors are different for the fourth quarter of 1979, on which the estimate is based, than they are for 1978. Recognizing this, Mittelhauser individually adjusted each of the modular factors for each equipment type to account for these relative escalations, prior to any individual adjustment for special materials or designs. The bases for these adjustments were published cost indexes such as the Chemical Engineering Equipment Cost Index and The Nelson Cost Indexes.

Individual equipment items estimated by Mittelhauser were escalated to a fourth-quarter 1979 basis, also by using published indexes for the particular type of equipment.

4.8.3 Turnkey Plant Cost

From the modular direct costs, a turnkey, or contractor's lump-sum, cost was developed. This represents the cost which an engineering and construction firm could be expected to charge for designing and constructing the facility. To develop a turnkey cost for this study, consideration was given to special piping, offsite facilities, and the normal contractor's indirect engineering and overhead charges. Also considered were freight, local and sales taxes, and contractor's insurance.

Special Piping

As described earlier, Mittelhauser made a special cost allowance for the special refractory-lined piping between Fired Heater H-100 and the Venturis, ME-100 A, B, C. This extremely rough allowance was only to recognize the fact that this piping will cost more than conventional process piping, and in no way is it a detailed estimate of the cost of that piping system.

Offsites

Mittelhauser carefully considered the types of offsites, and how much of each one would be required by the HDGCV Test Facility. Among these considerations were the following:

- The compactness of the facility would tend to minimize the cost of fire loops and hydrants.
- The fuel gas and fuel oil distribution systems would be minimal, since there is only one fired equipment item (H-100) in the facility.
- A plant air system is existing and available; only tie-ins need be made.
- Inert gas distribution and steam distribution and tracing systems will be small due to the small area of the facility.
- Because of the large electric motor drive on the Main Compressor K-100, a significant allowance for electrical power distribution must be made.
- General water and sewer piping and a control building, are included in the offsites investment.
- The relief system is small and is tied into a packaged flare system (ME-107).
- A cooling water supply and return system will be required.
- Battery-limits water treating and receiving/shipping facilities were assumed not to be required, as they already exist elsewhere at the site.

Construction Overhead Costs

This category includes field supervision, temporary facilities during construction, equipment rental, construction services such as security, medical, expendable supplies, etc., plus fringe benefits and payroll burden on direct labor costs. Mittelhauser estimated this cost as a percentage of direct material and labor costs, adjusted to reflect the particular labor-to-materials cost ratio for the facility.

Engineering and Home Office Costs

The cost of contractor engineering and home office support is related to the dollar value of equipment and materials in the project. Mittelhauser first estimated engineering and home office costs based on the total direct costs and the labor-to-materials cost ratio. In a separate calculation, individual hour-estimates of engineering costs were calculated based on published data for the design of individual types of equipment. This latter workup was also used as input to the design schedules discussed in Section 4.9.1. The two estimates agreed to within 20 percent, and the higher one was used to provide a degree of conservatism in the estimate.

Contractor's Fee

The contractor's fee is set by each individual contractor and is typically based on total monies handled or disbursed by the contractor. These monies include equipment, field materials, all labor, indirect construction costs, and a contingency. Mittelhauser estimated this cost based on previous experience with A/E firms. This cost was then combined with the engineering and home office costs to provide a single overall cost which may be less variable from contractor to contractor than the two individual values.

Freight, Taxes, and Insurance

Freight was estimated for each item between its point of origin and Morgantown, West Virginia. Sales taxes were assumed to be

5 percent on equipment and materials, and insurance costs were estimated at 1.25 percent of the equipment and materials.

4.8.4 Contingency

For this project, a weighted average contingency was used. The critical items in the project, namely the Main Compressor K-100, the Fired Heater H-100, and the Solids Addition Packages ME-101 A, B, were assigned a contingency factor of 20 percent to account for modifications required as new information is gathered in final design. Other major process equipment was assigned a contingency factor of 10 percent, and the offsites, 5 percent. A weighted average contingency factor was calculated by multiplying each item's direct module cost by its contingency factor and dividing the sum by the total direct cost of the facility. The resulting factor of about 14.5 percent was applied to the turnkey cost to estimate the contingency funds which would probably be included by the turnkey contractor in his bid price.

4.8.5 Other Capital Items

Working Capital

Working capital represents that amount of capital which must be kept on hand to sustain day-to-day operations. Usually the following items are included:

- Initial charge of catalyst and chemical.
- Raw materials and feedstock for 30 days of design rate operations.
- Inventory of materials and supplies. This is often taken as one percent of total plant investment.
- Cash reserves, usually equal to 45 days of net cash operating expenses, excluding raw materials and feedstock.

Because utility values were not furnished for all utilities by METC, it was agreed that Mittelhauser would furnish METC with consumption rates in lieu of costs, for the utilities for which no unit costs were provided. Therefore, no net annual operating costs were calculated, and working capital for this project likewise was not calculated.

Startup Costs

Between the time a plant is mechanically complete and the time it achieves design-rate operations, it experiences nearly full-scale operating costs without achieving its design goals. Usually these goals are in the form of revenue generation. Also some one-time expenses are incurred such as organizational charges, personnel hiring and training, and fixing of malfunctioning equipment. All of these charges may be referred to as "startup costs". For this study Mittelhauser did not calculate detailed startup costs for the following reasons:

- Normal factors usually used for grass-roots plants do not apply to a new facility at any existing site.
- Operating costs, of which startup costs are usually taken as a percentage, were not calculated.
- A detailed analysis of the startup operations was beyond the scope of the study.

"Owner Costs"

The engineering and construction contractor will be responsible for engineering, design, procurement, and construction management of the HDGCV Test Facility. However, the DOE will also incur expenses such as project monitoring, construction inspection and liaison, and overall contract administration. These expenses should be directly charged to the project; however, Mittelhauser, due to the limited scope of the study, and believing that DOE would wish to develop its own cost projections for this activity, did not calculate "owner costs" for the HDGCV Test Facility Project.

4.8.6 Operating Requirements and Costs

Operating Labor

Operating labor for the facility was specified by METC as one full-time operator, around the clock. The operating labor rate assumed for the study was \$9.00 per hour exclusive of the fringe benefits.

Maintenance Labor

Maintenance expenses were estimated as a percentage of the facility direct costs. Since the facility is designed to operate 8,000 hours per year, there will be a scheduled "turnaround" each year during which intensive maintenance activities will take place. Due to the corrosive/erosive nature of the process fluids in much of the plant, it has been assumed that annual maintenance costs for the battery limits equipment will be five percent of total direct costs. Maintenance for offsites was taken at one percent of their direct costs. The labor component of total maintenance cost was assumed to be 60 percent.

Supervision

As specified by METC, a full-time shift supervisor was assumed to be assigned to the HDGCV Test Facility around the clock. The hourly rate for this supervisor was assumed to be \$12.00 per hour, exclusive of fringe benefits.

General and Administrative Expense

To cover the effects of payroll burden and supervision above the shift-level, a "G & A" expense of 45 percent of the total operating and maintenance payroll was added to annual operating expenses.

Operating and Maintenance Supplies

Cost for operating supplies were estimated at 30 percent of operating payroll. Costs for maintenance supplies were assumed to be 40 percent of total maintenance.

Utilities

Requirements for utilities such as steam, electric power, and cooling water, were taken from the facility design or vendor-supplied information. Requirements were tabulated for both of the operating cases, inasmuch as they differed significantly between the cases. By mutual agreement with METC, utility costs were not calculated, since a determination of the value of incremental utilities to METC had not been made and was outside the scope of this study.

Raw Materials

The only raw materials supplied to the plant are the solids to be added to the gas. It was assumed that these would be made available by an electric utility company in the area, at no net cost to METC.

Catalysts and Chemicals

The primary chemicals used in the process are the contaminant gases. Based on estimated system loss rates and the costs furnished by Airco, annual fill and demurrage charges were calculated for the facility under both startup and normal conditions.

Plant Insurance

Annual plant insurance was estimated at 1.2 percent of total plant investment.

Property Taxes

Property taxes were assumed to be 2.0 percent of total plant investment per year.

Waste Disposal Costs

Information on the requirements for disposal of the solids-bearing waste liquid from the HDGCV Test Facility was not received from METC in time for inclusion in this report. For this reason, and because no value was assigned to the waste water itself, no waste disposal costs were calculated for the facility. Waste Disposal Requirements are shown in Table 5.3 of the report.

Byproduct Credits

No byproduct credits were calculated for the facility.

4.9 SCHEDULES

In accordance with the study work plan, schedules for design, construction, and operation of the HDGCV Test Facility were prepared. The design and construction schedule was prepared first, followed by the operating schedule.

4.9.1 Design and Construction Schedule

In preparing the design and construction schedule, the critical path items were assumed to be the long-lead-time major equipment items. Chief among these are the Main Compressor, K-100, and Fired Heater, H-100. The Main Compressor was assumed to have a lead time between vendor's receipt of purchase order and delivery of the completed equipment to the site, of 15 months. Based on this lead-time and the pre-engineering required to place the purchase order, the construction crew move-in could be determined such that foundations were ready when the compressor arrived.

The design schedule was determined by estimating the size and skill mix of the required design team, and allocating this over the preconstruction period. The construction schedule was set by considering the time required to install equipment, erect piping, insulate, wire and paint, install instrumentation, and checkout all systems prior to initial startup. All of these estimates were made using Mittelhauser's prior staff experience in process plant design and construction projects.

4.9.2 Operating Schedule

The foundation of the operating schedule is the Valve Test Plan furnished by METC, which was presented as Figure 3.1 in this report. It was assumed that the HDGCV Test Facility would undergo an initial startup period of 90 days, after which the initial valve would begin its test run. Each year a scheduled maintenance turnaround of 31 days was planned.

5.0 RESULTS

5.1 METC FACILITY REVIEW

The results of the METC Facility Review were presented in Section 4.1.

5.2 ENVIRONMENTAL CONTROL STUDY

For air emissions, there are three possible emission points in the HDGCV test facility. These are as follows:

- the heater system
- the flare system
- solids unloading system.

The heater has been designed for heat input of 77.2×10^6 BTU per hour, HHV and is capable of burning either natural gas or Number 2 fuel oil. It operates for 8,000 hours per year.

For computing the potential sulfur dioxide and nitrogen dioxide emissions, the sulfur and nitrogen content of the fuel oil was estimated at 0.5% and 0.1% by weight respectively. For a maximum emission calculation fuel oil was used for the total 8,000 hours of operation. The potential amount of SO₂ to be emitted is 160 tons per year while the potential for NO₂ is 53 tons per year.

The flare system will be in continuous operation. The system will be designed to good engineering practice (GEP) to control smoke and noise. The solids unloading system will have best available control

technology incorporated within the design to control any fugitive dust and particulates at transfer points. The emissions from these sources should be negligible in amount after applying controls. A complete description of the HDGCV Test Facility can be found in Section 5.4.

The standards of performance for new sources, 40CFR60, were reviewed. From this review there are no applicable federal emission standards due to size and function of the heater.

The West Virginia Regulations on Air Pollution Prevention and Control, Ambient Air Quality Standard, and Stationary Source Permit, Registration and Evaluation Procedures and West Virginia Air Pollution Control Law were reviewed for applicability. The emission standards for particulates from the heater were found in Regulation II - To Prevent and Control Particulate Air Pollution from Combustion of Fuel in Indirect Heat Exchangers. The heater is classified as a type "b" fuel-burning unit meaning a gas or oil-fired unit, the main purpose of which is not the generation of steam or other vapors to produce power.

The state visible emission requirements for the heater, Regulation II - Section 2.03, are as follows: no person shall cause, suffer, allow, or permit emissions of smoke into the open air from any fuel burning unit which is darker in shade or appearance than 0.5 Ringelmann of ten percent opacity.

The particulate emissions requirement was found in Section 3.01 (a) (2) of Regulation II. It states that the discharge in pounds per hour shall not be in excess of the amount determined as follows: the product of 0.09 and the total design heat input for such units in million BTUs per hour with an upper limit of 600 pounds per hour. For the heater on this project, the design heat input is 77.2×10^6 BTUs per hour. At this rate an allowable discharge limit on particulates is 6.9 pounds per hour. The projected amounts of particulate discharge are one pound per hour which is well within the limit.

Section 6.01 of Regulation II is directed towards permits required. It states that construction on any fuel burning unit will not commence without a permit.

The emission requirement for sulfur oxide is covered in Regulation X - To Prevent and Control Air Pollution from the Emission of Sulfur Oxides. Section 2 of this regulation classifies West Virginia into three priority regions. The test facility will be located in a Priority III Region.

Section 3 of this regulation sets the sulfur dioxide standards for fuel burning units. The heater in this project would be covered by Section 3.03 (6) which states: For Type "b" and "c" fuel burning units, the product of 3.2 and total design heat inputs in million Btu's per hour times the allowable emissions in pounds per hour. For the heater in this project, the maximum emission of sulfur dioxide would be 247.04 pounds per hour but the heater is projected to emit only 40 pounds per hour.

Section 5.01 of Regulation X pertains to permits. It states that no person shall construct any source of sulfur dioxide without first obtaining a permit for such construction. A summary of the standards is found in Table 5.1.

As noted above, Section 6.01 of Regulation II and Section 5 of Regulation X mention permit requirements. Regulation XIII - Permits for Construction, Modification, or Relocation of Stationary Sources of Air Pollutants, and Procedures for Registration and Evaluation - describes the procedures for registration and reporting, and the criteria for obtaining a permit to construct a new source. This project is considered a new direct affected source by West Virginia laws.

The West Virginia Air Pollution Control Board in Charleston was contacted. The test facility was discussed and the applicable

**TABLE 5.1 WEST VIRGINIA EMISSION STANDARDS
FOR HDGCV TEST FACILITY**

**Visible Emission
Regulation II, Section 2.03**

**0.5 on Ringelmann Chart
10% Opacity**

**Particulate Emission
Regulation II, Section 3.01(a)(2)**

**0.09 lb per million BTU
Heat Input Per Hour but
Not More Than 600 lb per
Hour**

**Sulfur Dioxide Emission
Regulation X, Section 3.03(6)**

**3.2 lb per Million BTU
Per Hour Input**

regulations were also discussed. The Board verified that the regulations above were applicable. They also stressed fugitive dust control and Regulation XIV - Permits were a large concern in West Virginia. As a result of this conversation, best available control technology was incorporated into the design of the solids unloading and transfer system. They also mentioned the West Virginia Ambient Air Quality Standards which are shown in Table 5.2.

Since this project will be located in a clean air region where all ambient air quality standards are being met, a brief review of the Prevention of Significant Deterioration (PSD) requirements and the Alabama Power vs Costle (EPA) case was performed to see if the requirements were applicable. For this project to fall under PSD requirements, the project would have to emit 250 tons per year of any regulated pollutant and be located in a clean air area. This project does not emit 250 tons of any regulated pollutant so PSD would not be applicable under "de minimas" levels. However the project still must obtain permits from the state before construction starts.

Unlike air emissions where there are three possible emission points, there is only one possible wastewater discharge point from this project besides plant runoff. After the gas goes through the test valve it is scrubbed to remove the solids from the gas. The quality of this untreated wastewater is presented in Table 5.3.

At the beginning of this project, the destination of the wastewater discharge was not defined. It was determined that there were three possibilities for discharge:

- to the municipal sewer system
- to the Monongahela River
- to the DOE local wastewater treatment facility

TABLE 5.2 WEST VIRGINIA'S AMBIENT AIR QUALITY STANDARDS (REGULATIONS VIII, IX, and XII)

Pollutant	PRIMARY STANDARDS ($\mu\text{g}/\text{m}^3$)			SECONDARY STANDARDS ($\mu\text{g}/\text{m}^3$)		
	Annual Standard	Short-Term Standard		Annual Standard	Short-Term Standard	
Sulfur Dioxide	80	365	(24 hours)	--	1300	(3 hours)
Particulates	75	260	(24 hours)	60	150	(24 hours)
Carbon Monoxide	--	10,000	(8 hours)	--	10,000	(8 hours)
		40,000	(1 hour)		40,000	(1 hour)
Ozone	--	160	(1 hour)	--	160	(1 hour)
Hydrocarbons	--	160	(3 hours)	--	160	(3 hours)
Nitrogen Dioxide	100	--		100	--	
Lead (National Standard)	1.5 (3 months)	--		1.5 (3 months)		

TABLE 5.3 UNTREATED WASTEWATER QUALITY
FROM HDGCV TEST FACILITY*

Water, lb/hr	17,675
Solids, lb/hr	332.3
Solids concentration, mg/l	18,800
Solids Size Range	0.5-60 μ m
Temperature	228 ⁰ F
Dissolved Gases	
CO ₂	3 ppmw
H ₂ S	5 ppmw

* Note: Based on worst percent solids case, Case I.

The assumption has been made that the wastewater will be discharged into the DOE wastewater treatment facility. This assumption is based on a letter sent to METC concerning the disposition of the wastewater and pre-treatment requirements.

If the water cannot be sent to DOE's facility, treatment of the water would be required to discharge either into the municipal system or directly into the Monongahela River. This treatment would involve additional equipment which was not included in the total cost estimate for this project.

The EPA has issued New Source Performance Standards (NSPS) for numerous industrial categories. These were reviewed and this project was not included in any of the standards which means it is not a "new source." The project still would be required to apply for a permit but would be treated as an existing discharger. The permit would be based upon demonstration that the facility's discharge would not degrade the river water quality below the standards set forth in Table 5.4. The discharge limits would be based upon the water quality standard for the receiving stream namely the Monongahela River. The water quality requirements of the river are shown in Table 5.4. These requirements did not include suspended solids. The West Virginia Water Board was contacted and stated that the suspended solids level requirement would be in a range of 30-60 mg/l.

If the water were discharged into the municipal sewer system, the wastewater would require pretreatment. Personnel at the local treatment facility, stated that the suspended solids level would be in the range of 200-300 mg/l but they would need more information regarding flows, time of discharge, analysis of the wastewater, and an overall facility plot diagram to set the final discharge quality requirements.

5.3 GAS GENERATION STUDY

The results of the Gas Generation Study were presented in Section 4.3.5.

TABLE 5.4 WATER QUALITY STANDARDS FOR THE MONONGAHELA RIVER

Dissolved Oxygen, mg/l	Not less than 5
pH	6-8.5
Odor	Less than #8 at 40°C (Reference 30)
Temperature, °F May-November December-April	Less than 5 above natural 87 Maximum 73 Maximum
Toxicity	Less than 1/10 of the 96 hr median tolerance level based on "fathead minnows"
Heavy Metals, mg/l	
Arsenic	0.01 maximum
Barium	0.5 maximum
Cadmium	0.01 maximum
Chromium (+6)	0.05 maximum
Lead	0.05 maximum
Silver	0.05 maximum
Other Compounds, mg/l	
Chlorides	100 maximum
Phenol	0.001 maximum
Cyanide	0.025 maximum
Fluoride	1.0 maximum
Selenium	0.01 maximum

5.4 FACILITY DESCRIPTION

5.4.1 Process Description

Process Flow Diagrams 231-C-001 and 231-C-002 depict the process flow arrangement of equipment, operating conditions and stream flows and compositions for the 250 psig, Case 1, and 50 psig, Case 2, systems, respectively. Piping and Instrumentation Diagrams 231-C-101, 231-C-102 and 231-C-103, in the Appendix of this report, show the detailed arrangements of the equipment required for both operating conditions.

In Case 1, clean, cool test gas at 164 psia and 150°F flowing from the gas cleanup and cooling section of the test loop mixes with 140°F compressor spillback and flows through Main Compressor Suction Drum, V-103. In this drum, any entrained liquid is removed before compression. The vertical drum is constructed of carbon steel and contains either a mist eliminator pad or inertial impaction plate packing to assure complete liquids removal to avoid compressor damage. Under normal, steady state operating conditions no free liquid is expected to be entrained in the test gas at the inlet to the compressor suction drum.

The liquid free gas at 149°F in Case 1 is compressed to 292 psia in a five-stage, motor driven centrifugal compressor, K-100. The compressor normally operates at 138.9% of the Case 1 test valve design flow rate on a clean, cool gas basis, with a discharge temperature of 284°F in Case 1. In Case 1, 10% of the compressor throughput flows continuously back to Main Compressor Suction Drum, V-103, after being cooled to 140°F in Compressor Spillback Cooler, E-101. In case 2, about 72% spillback is required to maintain the maximum test loop velocity. A portion of the spillback flows through Flash Gas Eductor, ME-108 which draws the flashed vapors from Sour Condensate Knockout Drum, V-104, back into the test loop.

In Case 2, the clean, cool test gas leaving the gas cleanup and cooling section is at 40 psia and 141°F. After mixing with the compressor

spillback and flowing through the suction drum it enters the compressor suction at 140°F. In this case, the compressor discharge conditions are 85 psia and 322°F.

The spillback cooler, E-101, has a normal operating duty of 0.4×10^6 BTU/hr in Case 1 and 2.8×10^6 BTU/hr in Case 2 with the heat being rejected to cooling water. This cooler is designed for a maximum duty of 4.0×10^6 BTU/hr to accomodate facility startups, shutdowns and upsets. The design materials of construction are carbon steel for the shell with stainless steel tubes.

The pressurized test gas leaving Main Compressor Package, K-100, amounting to 125% of the test loop requirement, flows to Fired Heater, H-100, where the gas temperature is increased to 1825°F in Case 1 and 1725°F in Case 2. In both cases the heater discharge is controlled to a temperature which is 75°F above the valve test conditions to allow for piping heat loss between the heater outlet and test valve. Flow to the heater is controlled to maintain a set heater outlet pressure. To maintain a relatively constant compressor discharge pressure the spillback control valve is operated by the same pressure control signal but acting in the opposite direction, i.e., as the heater flow control valve opens, the spillback flow valve closes.

The Fired Heater H-100 has a horizontal tube convection section and a vertical radiant section. The gas leaves the convection section at 1000°F in Case 1 and 1250°F in Case 2 and flows through Hot Gas Humidifier, ME-105, where water is injected to bring the clean gas composition up to the required test gas concentration. The humidified gas then flows through the radiant section of the heater. The total absorbed duty in Case 1 is 59.8×10^6 BTU/hr where approximately 68% of the heat transfer occurs in the radiant section. In Case 2, about 53% of the heat transfer occurs in the radiant section. The total absorbed duty in the latter case is 13.4×10^6 BTU/hr. The nominal design absorbed duty in the Fired Heater is 62.5×10^6 BTU/hr, to allow for process design uncertainties at this point in the HDGCV Test Facility project.

The Fired Heater is equipped with dual firing controls and hardware so that either No. 2 fuel oil or natural gas can be fired. The efficiency is expected to be 90% or 92% based on the fuel's lower heating value, or about 81 percent based on higher heating value when firing natural gas (methane). Tubes in the lower temperature end of the convection section are constructed of low chrome steel while the high temperature end is stainless steel. The radiant section tubes will be either cast HK or HP alloy.

Makeup water for the heater interstage humidification step is process condensate pumped from Direct Contact Cooler, V-101, in Case 1. In Case 2, makeup water is required from the METC water supply. This water should be demineralized boiler feed water quality. The water injected to the gas accounts for 91.5% and 70.2% of the test gas humidity requirement in Case 1 and Case 2, respectively. The difference is due to the higher water carrying capability of the compressor suction gas in the lower pressure system; 5.3 mol% versus 1.6 mol% in Case 1. Because the low pressure gas does carry more water with it from Direct Contact Cooler, V-101, there is no excess process condensate available for humidification; therefore, the makeup must be supplied from an external source.

The hot gas leaving the heater is analyzed continuously for contaminants. To account for the contaminant loss in the test facility purge water, H_2S and CO_2 are continuously added to the test gas from Gaseous Contaminant Makeup Package, ME-106. The addition rate of each constituent will have to be manually adjusted on a periodic basis to maintain the desired concentration. Additionally, a new gas charge, received from the gas trailer, which is free of H_2S , N_2 and CH_4 , will have to be corrected for those deficiencies from ME-106.

The hot, pressurized test gas leaving Fired Heater, H-100, and containing the required amount of gaseous contaminants is split

between one of the two parallel test loops and the bypass loop. The second test loop is not normally in operation. The following descriptions assume that the "A" loop is in operation while the "B" loop is idle. The bypass loop, which normally handles 25% of the test loop design gas flow rate, has been provided to maintain a relatively constant flow through the fired heater during test valve cyclic operation thus avoiding undue maintenance on the heater. The bypass loop will be described shortly.

The particulate matter is added to the test loop gas from Solids Addition Package, ME-101A. Solids received at the facility are pneumatically conveyed from the bulk transport trucks to the storage silo provided with Solids Receiving and Loading Package, ME-102. The silo will hold approximately an 18-day charge of solids for Case 1. The receiving and storage package contains an air blower which provides the transport medium. All transport air is vented from the silo through a bag filter to the atmosphere.

Solids from the storage silo are transferred by a second pneumatic system to one of two batch atmospheric storage bins directly above the test loops, on an intermittent basis. The solids flow by gravity from this bin to the Solids Addition Package, ME-101A, where they are stored in a batch storage vessel. The batch storage vessel can be isolated from the silo and pressurized for subsequent feed of the solids to a fluidizing primary injection vessel through a feeding and isolation valve system. Before filling the batch storage vessel from the silo the vessel is depressurized to the Flare System, ME-107. Before feeding the primary injection vessel from the batch storage vessel the vessel is pressurized with gas from the discharge of the Main Compressor, K-100, and equalized with the pressure in the injection vessel through an equalizing line. Solids are then injected into the hot gas stream from the primary injection vessel through a fluidizing standpipe. Fluidizing gas is also supplied from the Main Compressor discharge.

The hot, solids-laden, contaminated gas flows through the HDGCV to Venturi, ME-100A. The conditions, flows and compositions at the control valve inlet are:

<u>Component-Mol%</u>	<u>Case 1</u>	<u>Case 2</u>
H ₂	44.03	44.03
CO	25.34	25.34
CO ₂	12.66	12.66
CH ₄	0.88	0.88
H ₂ S	1.13	1.13
N ₂	0.06	0.06
H ₂ O	<u>15.90</u>	<u>15.90</u>
	100.00	100.00
Total lb-Mol/hr	3111.64	758.83
Solids-Free, lb/hr	52,800	12,900
Solids, gr/scf	2.0	2.0
Temperature, °F	1750	1650
Pressure, psig	250	50

The valve stem is fitted with a shroud which is continuously flushed with inert gas. The flow of inert gas is controlled to maintain a predetermined temperature in the shroud. Flow of inert gas is measured to and from the shroud to determine the valve stem leak rate. A description of the measurements related to the HDGCV is given in Section 5.6.

The test gas leaving the HDGCV flows through Venturi, ME-100 A, where it is saturated and washed with a combination of recycled process condensate from Direct Contact Cooler, V-101, and Sour Condensate Knockout Drum, V-104 and makeup water from the METC water supply. The makeup water must be of demineralized boiler feed water quality. The venturi is designed to remove 98.5% of the particulates at a liquid-to-gas ratio in the venturi of 26.5 gallons per 1000 actual cubic feet of hot, dirty gas. However, the venturi water flow is controlled to maintain a fixed liquid-to-clean, saturated gas ratio from Venturi Separator, V-100 A, because of the difficulties in measuring the actual flow of hot, dirty gas from the control valve. On a cool, saturated basis the liquid-to-gas ratio is about 37

gallons per 1000 actual cubic feet of gas. This is a higher ratio than normally used in venturi scrubbers, due to the stringent removal efficiency required to protect the downstream equipment.

In the Venturi Separator the solids laden scrubbing water is separated from the gas. The water, contaminated with trace quantities of H_2S , CO_2 and H_2 , flows from the separator, under level control, to Purge Water Flash Drum, V-102, where the dissolved gases are flashed from the purge water. The flash drum operates at 20 psia. The resulting purge water at 228°F and containing 3 ppmw CO_2 and 5 ppmw H_2S is pumped by Flash Drum Bottoms Pump, P-101 A,B to the METC dewatering system.

The Venturis and Venturi Separators are constructed of 316 L stainless steel. Additionally, the separators are supplied with mist eliminator pads to avoid carryover of entrained droplets of process condensate to the downstream equipment. The flash drum and bottoms pump are constructed of carbon steel.

The gases flashed from the purge water are washed with process condensate across two valve trays inside of the Purge Water Flash Drum to remove any entrained solids. The flashed gases are then cooled to 140°F in Sour Flash Gas Condenser, E-102, where the bulk of the water vapor flashed from the purge water is condensed. The cooled flash gas flows through Sour Condensate Knockout Drum, V-104, where the condensate is removed before being educted into the compressor spillback loop as discussed earlier. The condensate from the knockout drum is pumped back to the venturi by Sour Condensate Recirculation Pump, P-103 A, B. A slipstream of the sour condensate is drawn off of the pump discharge and fed to the trayed section of the Purge Water Flash Drum. This water is used to wash the flashed gas free of particulates. The water leaving the last wash tray flows back to the Sour Condensate Knockout Drum. The flow of wash water is manually adjusted to maintain an approximate 9 gpm flow through the recirculation pump.

The hot gas entering the bypass loop flows through Restriction Orifice, ME-104, which establishes a pressure drop in the bypass loop equal to the test valve pressure drop in the wide open position. The gas

then flows through Venturi, ME-100 C, where it is cooled and saturated, and Venturi Separator, V-100 C, where the entrained liquid is separated from the gas. A liquid-to-gas ratio of about 26 gallons per 1000 actual cubic feet of gas is maintained to the venturi. The water to the venturi is made up of fresh water supplied from the METC water supply and water collected in the Venturi Separator. The makeup water is controlled to maintain the separator level while the recirculation flow is controlled to maintain a fixed liquid-to-saturated gas ratio. Intermittently, a purge of the separator liquid inventory must be made to control the fine solids concentration within acceptable limits. Limits for this application have not yet been established.

The gas leaving the bypass loop Venturi Separator flow through a flow control valve and mixes with the clean, quenched gas from the test loop venturi separators. The flow control valve is controlled by the cycle generator, which also controls the position of the test valve. As the test valve is stroked closed the bypass loop flow control valve will be stroked open to maintain a constant flow through the fired heater.

The scrubbed, saturated gas at 213 psia, 331⁰F and 48 psia, 237⁰F, for Cases 1 and 2, respectively, flows from Venturi Separators V-100 A and C through Direct Contact Cooler, V-101, where it is cooled by countercurrent contact with cooled process condensate. Process condensate is pumped by Direct Contact Cooler Recirculation Pump, P-102 A, B, from the bottom of the vessel, through Recirculation Cooler, E-100, where it is cooled to 140⁰F, and fed to the top tray of the Direct Contact Cooler. The flow of the contacting process condensate is controlled to maintain the cooled gas temperature between 140⁰F and 150⁰F.

The water condensed from the gas in the Direct Contact Cooler is drawn off the recirculation pump discharge and routed back to Venturi, ME-101 A. In Case 1, where there is a sufficient amount of water condensed from the gas, a slipstream of the recirculating process condensate is fed to Hot Gas Humidifier, ME-105.

The direct contact cooler is constructed of 304L clad carbon steel and contains 10 stainless steel valve trays. The recirculation pump is constructed of 304 stainless steel.

The cooled, clean test gas flows from the direct contact cooler through a pressure control valve which maintains the Main Compressor suction pressure. The initial fill and intermittent refills of test gas are made downstream of the pressure control valve where the system is at the lowest pressure.

All process gas blowdown and safety relief points connect to the flare header system. The flare is sized to handle the emergency blowdown of one test loop volume, 250 psig case, in one minute. This is approximately 1420 lbs/hr. The flare is an elevated type, 3 inch diameter tip, and includes a self-supporting stack which provides an overall height, grade to tip discharge, of 30 feet. A pilot ignition system is also included. The flared gas would not produce smoke, therefore steam injection for smoke suppression is not required.

An equipment list showing equipment types, a brief description, estimated costs, and the source of the cost estimate, is given in Table 5.5. Additional detailed specification sheets for major equipment items are in Section 7.2.

5.4.2 Instrumentation Design

Recommendations for Instrumentation and System Process Control

Criteria for product evaluation are presented followed by a discussion of the recommended instrumentation. Additional recommendations for consideration are also presented. Instruments have been evaluated on the following basis:

- Manufacturer specifications
- Choice of materials
- Verified track record
- Cost
- Quality of service
- Special design features

TABLE 5.5 EQUIPMENT SUMMARY (Page 1 of 2)

EQUIPMENT TYPE	ITEM NO.	DESCRIPTION	COST ESTIMATE	COST ESTIMATE SOURCE
Pressure Vessels	T-100 A, B, C	Venturi scrubber separators, 3 identical units, 3½ ft I.D. x 6 ft T/T. Design pressure = 305 psig. Design temperature = 1750°F. All 316L S.S. construction. Vertical with mist eliminator pad. (Supplied with items ME-100 A, B, C, and cost included.)	\$ 60,000 EA.	Vendor quote
	A-101	Direct contact cooler, 6½ ft I.D. x 26 ft T/T. Design pressure = 305 psig. Design temperature = 350°F. 304L clad on carbon steel. Vertical with 10 valve trays, stainless steel.	\$128,200	In-house
	A-102	Purge water flash drum, 2½ ft I.D. x 7-¾ ft T/T. Design pressure = 30 psig. Design temperature = 350°F. Carbon steel construction with 1/8" corrosion allowance. Vertical with two valve trays and chimney, carbon steel.	\$ 5,600	In-house
	A-103	Compressor suction surge drum, 3½ ft I.D. x 10 ft T/T. Design pressure = 305 psig. Design temperature = 300°F. Carbon steel construction with ¼" corrosion allowance. Vertical with mist eliminator pad or inertial impaction plate pack.	\$ 18,300	In-house
	A-104	Sour condensate knock out drum 1½ ft I.D. x 4½ ft T/T. Design pressure = 30 psig. Design temperature = 300°F. Carbon steel construction with 1/8" corrosion allowance. Vertical.	\$ 4,000	In-house
Shell & Tube Exchanger	E-101	Compressor recirculation/spillback cooler, 1 shell/unit, 1090 ft ² /shell. TEMA type R. Shell design pressure = 305 psig, shell design temperature = 300°F. Tube design pressure = 150 psig, tube design temperature = 300°F. Carbon steel shell with ¼" corrosion allowance, stainless steel tubes.	\$ 46,800	In-house
Air Cooled Exchanger	E-100	Direct contact cooler water recirculation, 2 bays/unit, 2650 ft ² bare surface/bay. 2 fans/bay, 2½ hp/fan. Design pressure = 350 psig. Design temperature = 350°F. Tubes and headers all stainless steel. Variable pitch fans and louvers, winterized.	\$222,200	Vendor quote
	E-102	Flash gas condenser, 1 bay/unit, 310 ft ² bare surface/bay. 1 fan/bay, 7½ hp/fan. Design pressure = 30 psig. Design temperature = 350°F. Tubes and headers all stainless steel. Variable pitch fans and louvers, winterized.	\$ 23,700	Vendor quote
Compressor	C-100	Main gas compressor. Five stage centrifugal, 2430 ICFM rated. Suction pressure = 164 psia, discharge pressure = 292 psia, 1484 gas hp, 1750 hp TEFC motor. Includes: compressor, motor, speed increaser gear, and couplings on common base frame. Also includes complete, separate lube/seal oil system	\$490,000	Vendor quote
Fired Heater	H-100	Gas heater, 82.5 x 10 ⁶ BTU/hr absorbed duty, at 90% to 92% LHV efficiency, accommodating dual firing No. 2 fuel oil or natural gas. Inter-section water injection. Horizontal tube convection section starting in low chrome and ending in stainless steel. Vertical radiant section, double fired, of cast HK or HP alloy. Design pressure = 305 psig. Discharge temperature = 1825°F.	\$500,000	Vendor quote
		Heater field erection.	\$200,000	Vendor quote
		Heater control package.	\$ 75,000	In-house

TABLE 5.5 EQUIPMENT SUMMARY (Page 2 of 2)

<u>EQUIPMENT TYPE</u>	<u>ITEM NO.</u>	<u>DESCRIPTION</u>	<u>COST ESTIMATE</u>	<u>COST ESTIMATE SOURCE</u>
Pumps	P-100 A, B	Recirculation pump for V-100C. Multi-stage centrifugal (high head/low flow). 11 agpm, 0.908 S.G., 455 ft T.D.H. 316 stainless steel case and impellers. 5 hp, 3600 r.p.m., TEFC motor.	\$ 4,450 <u>EA.</u>	Vendor quote
	P-101 A, B	Flash gas drum water pump. Single-stage centrifugal. 37.2 agpm, 0.952 S.G., 80 ft. T.D.H. Carbon steel case and impeller. 1½ hp, 3600 r.p.m., TEFC motor.	\$ 1,050 <u>EA.</u>	Vendor quote
	P-102 A, B	Direct contact cooler recirculation pump. Two-stage centrifugal. 746 agpm, 0.908 S.G., 560 ft T.D.H. 304 stainless steel case and impellers. 150 hp, 3600 r.p.m., TEFC motor.	\$ 20,000 <u>EA.</u>	Vendor quote
	P-103 A, B	Sour condensate knock out drum pump. Multi-stage centrifugal (high head/low flow). 9 agpm, 0.984 S.G., 775 ft T.D.H. Vendor standard materials. 5 hp, 3600 r.p.m., TEFC motor.	\$ 1,750 <u>EA.</u>	Vendor quote
Venturi Scrubbers	ME-100 A, B, C	Particulate removal scrubbers. Design pressure = 305 psig. Design temperature = 1750°F. All 316L stainless steel construction. Approximately 98.5% removal efficiency. Package system with V-100 A, B, C.	(cost included with V-100 A,B,C)	Vendor quote
Solids Addition Package	ME-101A, B	This system consists of an overhead batch storage vessel, intermittently refilled by ME-102. The batch storage vessel feeds a fluidizing primary injection vessel through a feeding and isolation valve system. Solids are then injected into the HDGCV pipe through a fluidizing standpipe. Fluidizing gas is "cold" compressor discharge gas.	\$200,000 <u>EA.</u>	Vendor quote
Solids Receiving/Loading Package	ME-102	This system consists of a blower package and piping for pneumatic transfer of solids from bulk carrier trucks to a furnished 11 ft x 11 ft x 23 ft high atmospheric pressure storage silo. Also included is a pneumatic transfer system for charging the overhead batch storage vessels in ME-101 A, B.	\$ 61,000	Vendor quote
Stem Leakage Test Shroud	ME-103 A, B	Fabricated enclosure which will enclose valve stem and actuator area of tested valve to assure accurate leakage determinations at operating conditions. Design pressure = 30 psig. Design temperature = 750°F. Carbon steel construction.	\$ 500 <u>EA.</u>	In-house
Bypass Loop Restriction Orifice	ME-104	Establishes set pressure drop in bypass loop equal to tested valve in test loop in open position. Design pressure = 305 psig. Design temperature = 1750°F. High temperature high alloy or ceramic.	\$ 1,500	In-house
Hot Gas Humidifier	ME-105	Nozzle for inter-section injection of water into gas heater. Design pressure = 350 psig. Design temperature = 1200°F. Constructed of 316L or 310 stainless steel.	\$ 2,000	In-house
Gaseous Contamination Package	ME-106	The gaseous contamination package consists of 6 gas cylinder bottles to cover all the test gas components except water. Initial charges of N ₂ , H ₂ S, and CH ₄ will be supplied from these cylinders and subsequent use should be for makeup of losses only.	\$ 2,000	Vendor quote
Flare Stack and Tip	ME-107	The flare system will handle both normal and emergency flaring of test gas. The design criteria for the flaring rate is handling the gas blow down from one test loop, at 250 psig/1750°F, in one minute. The tip is 3 in. diameter, Incoloy 800-H with a fluidic seal. The stack is all stainless steel, self-supporting, with a base water seal. Pilot Ignition system is included.	\$ 17,000	Vendor quote
Flash Gas Eductor	ME-108	The eductor is used for reinjection of recovered flash gases into the compressor recirculation/spillback loop to compressor suction. Eductor can be carbon steel but stainless steel would be preferable.	500	In-house

The recommended instrumentation must perform reliably and accurately over its expected lifetime in the process. The most meaningful guide to an instrument's expected reliability is its demonstrated use in a similar environment; hence, references were obtained on each recommended device. The references given in Table 5.6 are other users of a recommended device in service similar to that anticipated in the HDGCV Test Facility. Some of these users were contacted to establish a "verified track record" on each instrument recommended for use.

It was decided to try to deal with one major supplier of instrumentation to the extent possible rather than with small firms, for the following reasons:

- Major suppliers have a larger user community. This allows more detailed information on service; i.e., more references can be provided of similar use to check for reliability.
- Instruments made by large suppliers are routinely made from a wide range of materials so that by using proper codes in the specifications, one can have an off-the-shelf item of necessary special material in explosion-proof housing. Such an undertaking ordinarily is a custom, one-of-a-kind, job for the small firm.
- The broader range of instrumentation offered by larger suppliers allows one to find a device whose range more precisely matches the application needs.
- With one specific manufacturer used as much as possible, the overall convenience in interchangeability, interfacing, and reordering, in addition to a greater commitment by the manufacturer to servicing, becomes evident soon after the plant is in operation.

The recommended instrumentation specifications, including cost, accuracy, range, and delivery date, are listed in Tables 5.7 and 5.8. Table 5.7 denotes instrumentation for the valve test loop and Table 5.8 specifies process analyzers, an optional controller, signal conditioners, recorders, indicators, and other ancillary equipment. The location of

TABLE 5.6 REFERENCES FOR SPECIFIED INSTRUMENTATION

1. Standard Oil of Ohio
Lima, Ohio	18. Union Camp Corporation
Franklin, Virginia
2. Hudson Bay Oil & Gas
Fox Creek, Alberta	19. Fairbanks Morse Toledo Scale Co.
Ohio
3. Texas Oil & Gas
Pacuta, Mississippi	20. Howe Richardson Scale Company
4. Mobil
Joliet, New Jersey	21. Argonne National Laboratory
Argonne, Illinois
5. Imperial Oil (Exxon)
Canada	22. Union Carbide
Oak Ridge, Tennessee
6. Amoco, Empire ABO
Eddy City, New Mexico	23. Wheaton Glass
New Jersey
7. Lago Oil
Aruba	24. Eli Lilly
Indianapolis, Indiana
8. Vickers Petroleum
Ardmore, Oklahoma	25. General Electric Company
Lynchburg, Virginia
9. Merck Chemical Corporation
Elton, Virginia	26. Battelle
Columbus, Ohio
10. Phillip Morris, Inc.
Richmond, Virginia	27. Union Carbide
West Virginia
11. E.I. DuPont
Waynesborough, Virginia	28. Ohio Brass
12. Owens Illinois Corporation	29. Naval Research Laboratories
Washington, D.C.
13. Burlington Industries
Glasco, Virginia	30. Lawrence Livermore Labs
Livermore, California
14. ICI Americas Corporation
Hopewell, Virginia	31. Exxon Research
15. Westvaco Corporation	32. Auburn University
16. Allied Chemical	33. Atomic Energy Commission of
Canada
Ontario, Canada
17. Chesapeake Corporation
Westpoint, Virginia	34. Canadian General Electric
	35. Atlantic Richfield Cherry
Point Refinery
Ferndale, West Virginia

TABLE 5.6 REFERENCES FOR SPECIFIED INSTRUMENTATION (CONTINUED)

36. Pittsburgh and Midway Coal Co.
Pittsburgh, Pennsylvania
37. Energy Systems Group
Rockwell International
38. IBM Corporation Federal
Systems Division
Huntsville, Alabama
39. DuPont, Inc.
Louisville, Kentucky
40. General Electric Company
Silicon Products Business
Department
Waterford, New York
41. General Electric Company
42. Westinghouse
43. Euratom
44. Exxon Nuclear
45. E.G. & G.
46. Lockheed Aircraft
Sunnyvale, California
47. United Texas Transport
Texas
48. Frito-Lay, Inc.
Dallas, Texas

TABLE 5.7 SPECIFICATION OF RECOMMENDED INSTRUMENTATION FOR VALVE
TEST LOOP (Page 1 of 3)

INSTRUMENT TYPE	INSTRUMENT NUMBERS **	TOTAL NO.	MANUFACTURER	MODEL NO.	COST (UNIT)	RANGE	ACCURACY %FULL SCALE	REF. *	DELIVERY TIME (WEEKS)	REMARKS
PI	2.1, 2.2, 2.3, 2.4	8	Taylor	44S450-3	\$113	0-350 PSIG	±0.5	9 thru 13	10-12	316 S.S., Pressure Element and Socket
PT	2.1, 2.2	4	Taylor	3356 TA 41 12 6-04	\$1,000	0-350 PSIA	±0.35	9 thru 13	8-10	
PDI	2.3, 2.4	8	Wallace & Tiernan	65-120	\$1,000	0-30 PSIA	±0.1	15, 16, 17	8-10	
PDT	2.1, 2.2	4	Taylor	3333-D 41 22 1-01	\$800	0-300 PSIA	±0.5	9 thru 13	10-12	To be used with Taylor Intrinsic Safety Barrier Mdl. 12451134 for Class 1, Group B, Div. 1 Oper.
TE	2.1, 2.2	4	National Basic Sensor	9K #4351	\$115	0-2300°F	±0.75		6	Type K T/C Assembly 3/8" O.D.
TT	2.2	2	Transmaton	330T	\$285	0-2000°F	±0.25	14, 15	8	RFI Shielding
TW	2.1, 2.2	4	National Basic Sensor	LT-1 Tube	\$1,150	0-2300°F	±0.75		6	3/8" x 1/2" NPT Compression Fitting, 1" Inconel Pipe Nipple and 9" Insertion Length
TE	2.1, 2.2	4	ARI Industries	T-50230-12 AE 7	\$950	0-3000°F	±0.75	1 thru 8	8	Type WSRE/W26 RE Tungsten 5% Rhenium/Tungsten 26% Rhenium (TE 2.1, 2.2) 5" Insertion Length. Associated Electronics to include: 1) Digital Thermometer, Mdl. 640 \$590, 2) Thermocouple Switch, Mdl. 101 \$80 (Opt.), 3) Compensating Lead Wire: Teflon \$0.70/ft. (100 ft.).
PI	2.7, 2.8	4	Taylor	44S490-3	\$113	0-350 PSIG	±0.5	9 thru 13	10-12	316 S. S. Pressure Element and Socket
PT	2.3, 2.4	4	Taylor	3356TA 21 126-01	\$950	0-350 PSIA	±0.35	9 thru 13	8-10	
TW	4.3	2	CGS	K1A18-5 1/2 2A	\$100	0-2000°F	±0.75	9 thru 13	8-10	Tapered well 316 S.S. with Std. Type K Thermocouple Included (TE 4.3)
TT	4.3	2	Transmaton	830T	\$285	0-2000°F	±0.25	14, 15	8	RFI Shielding
TSH	2.1	2	Fenwall	40-723014-425	\$200	0-400°F	±1.0		8-10	
EP	4.2	2	Devar	18-150	\$1,000	N/A	±0.1	11	8-10	
FT	2.1	2	Ramapo Instrument Co., Inc.	MARK V-2-2YF2	\$1,052	15-150 GPM	±.5	33 thru 37	12-14 FOB	316 S.S. Wetted Parts, 1.0 PSI Max. Press. Drop, Repeatability & Hypothesis 0.15% of Reading
FT	2.2	2	Ramapo Instrument Co., Inc.	MARK VI-2PY20	\$1,490	15-150 GPM	±.5	32 thru 36	12-14 FOB	316 S.S. Wetted Parts, 1.0 PSI Max. Press. Drop, Repeatability and Hypothesis 0.15% of Reading. Note Electronics and Indicators to go along w/ft 2.1 & ft 2.2 all by Ramapo: ft - SGA-835 or Strain Gage Transmitter, 0-10 VDC Output Linear with Flow Rate \$347; ft/ft SGA-8535RDI Digital Flow Indicator 3 1/2 Digit Display at 1999 0-10VDC Output \$727

*Denotes Number in Table 5.6

**See Drawing 231-C-101

TABLE 5.7 SPECIFICATION OF RECOMMENDED INSTRUMENTATION FOR TEST VALVE LOOP
(Page 2 of 3)

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INSTRUMENT TYPE	INSTRUMENT NUMBERS**	TOTAL NO.	MANUFACTURER	MODEL NO.	COST (UNIT)	RANGE	ACCURACY % FULL SCALE	REF *	DELIVERY TIME (WEEKS)	REMARKS
FT	4.1	2	Thermal Instrument Co.	60 TIC 390	\$5,000*	0-40,000 SCFM**	±1.0		6-8 ARO	316 S.S. Flow Wetted Parts *Includes Electronics Package, Pwr. Supply, Signal Conditioning to provide 0-5 VDC Linear Output Repeatability .2% of Reading Response Time .5 Sec. **Multiple Ranges available. Approx. 0.0 PSI Pressure Drop
FC	2.2	2	Taylor	444RN132	\$1,600	0-100%	±0.3	9 thru 13	8-10	
HIK	2.2	2	Taylor	1441NZ11110	\$400	0-100%	±0.5	9 thru 13		
ZT	2.1	2	Rochester Masonneilan	SC2372R 496-3	\$350 \$275	Adj. Length 0-100%	±0.25 ±0.25	10, 18 10, 18	8 10-12	
EY	4.2	2	Devar	18-150	\$1,000	N/A	±0.1	11	8-10	
HIK	2.1	2	Taylor	1441NZ11110	\$400	0-100%	±0.5	9 thru 13	8	
LG	2.1	2	-	-	\$200	N/A	N/A	-	-	Dependent upon Venturi Separator Specifications
LSH	2.1	2	C. E. Invalco	Model 52C	\$800	N/A	±1.0		10-12	Nuclear Switch Radium/Cobalt 60 Source
LSL	2.1	2	C. E. Invalco	Model 52C	\$800	N/A	±1.0		10-12	Nuclear Switch Radium/Cobalt 60 Source
LIC	2.1	2	Taylor	444RN121E1	\$1,800	0-100%	±0.3	9 thru 13	8-10	Accuracy Defined as Repeatability
ZT	2.2	2	Rochester Masonneilan	SC2372R 496-3	\$350 \$275	Adj. Length 0-100%	±0.25 ±0.25	10, 18 10, 18	8 10-12	
PT	13.1	2	Taylor	3332 TF 41 221-C1	\$750	10-80 PSIG	±0.5	9 thru 13	8-10	
PSL	13.1	2	SOR	4LK5 N4 CIA	\$50	25-600 LBS	±1.0	18	8-10	
TE	13.1	2	National Basic Sensor	6J8646-6"-MF-RD-13	\$32	0-1400°F	±0.75		6	Type J T/C Sys. with 1/8" O.D. Well (TW-13.1) Net Connector.
TT	13.1	2	Transmaton	330T	\$285	0-2000°F	±0.25	14, 15	8	RFI Shielding
TIC	13.1	2	Taylor	444RG 12 17	\$1,000	0-100%	±0.3	9 thru 13	8-10	
ZT	13.1	2	Rochester Masonneilan	SC2372R 496-3	\$350 \$275	Adj. Length 0-100%	±0.25 ±0.25	10, 18 10, 18	8	

*Denotes number in Table 5.6.

**See Drawing 231-C-101.

TABLE 5.7 SPECIFICATION OF RECOMMENDED INSTRUMENTATION FOR VALVE TEST LOOP (Page 3 of 3)

INSTRUMENT TYPE	INSTRUMENT NUMBERS**	TOTAL NO.	MANUFACTURER	MODEL NO.	COST (UNIT)	RANGE	ACCURACY %FULL SCALE	REF*	DELIVERY TIME (WEEKS)	REMARKS
HIK	13.1	2	Taylor	1441NZ11110	\$400	0-100%	±0.5	9 thru 13	8	
FT	13.1, 14.1	4	Electronic Flo-Meters, Inc.	F/5/6/15	\$400	75-7.5 ACFM	±0.5	45, 46, 47	16	316 S.S. Flow Wetted Pts., Repeatability 0.02%, Max Pressure Drop 2 PSI. Assoc. EFM Computational Electronics Include: 2) TR-25P/T Totalizers w/Flow Alarm \$2600, 2) SQ-2 Square Wave Amplifiers \$160, 2) Resistance Thermometer RTD-210 \$125, 2) Pressure Transducer PT-125 \$425, 1) Comparator \$1700, 1) 4620 2 Pen Recorder \$1,425, & 2) 25 Point Calibration Curves \$400.
ZT	14.1	2	Schaevitz Engineering	2000XS-ZT	\$2,123.30	±2,000"	±.5 (Linearity)	39 thru 44	14-16	Power Supply Signal Conditioning and Readout (ZI 14.1) by Schaevitz, Mdl. for Extreme Environment up to 1100°F and 2500 PSI
WT	14.1	2	Hottlinger Baldwin Measurements, Inc.	LF 30	\$3,000		N/A	19, 20	12-14	KWS 73.A6 Amplifier, Power Supply, Indicator \$2000
PSH	14.1	2	SOR	4LK 4 N 4 C14	\$50	25-600 LBS	±1.0	18	8-10	
TSH	14.1	2	Fenwall	40-7230 14-425	\$200	0-400°F	±1.0		8-10	
PT	14.1	2	Taylor	3332TF 41 22 1-01	\$750	10-80 PSIG	±0.5	9 thru 13	8-10	
TW	14.1	2	National Basic Sensor	6J8646-6"-MF-RC-13	\$32	0-1400°F	±0.75		6	Type J T/C System with 1/8" O.D. Well (TW 13.1) NPT Connector
TT	14.1	2	Transmatron	330T	\$285	0-2000°F	±0.25	14, 15	8	RFI Shielding

*Denotes number in Table 5.6.

**See Drawing 231-C-101.

TABLE 5.8 SPECIFICATION OF AUXILIARY EQUIPMENT (Page 1 of 2)

<u>INSTRUMENT</u>	<u>MANUFACTURER</u>	<u>MODEL</u>	<u>DEL. TIME (WEEKS)</u>	<u>COST UNIT</u>	<u>REMARKS</u>
Programmable Controller (Optional)	Tencer Co., Inc.	761 PC+	14-12	\$50,300	PC+ provides the following features: 1) designed to implement process control and data manipulation using high level programming language; 2) compatible with any data terminal having standard ASC II keyboard; 3) PC+ to computer option; 4) PC+ to PC+ communication option; 5) 12K word memory per unit; 6) I/O modules include Digital, Analogs, and 8CD; 7) Programmable Timer/Counters available with time base of 0.1 sec., 1.0 sec., 0.1 min, or 1.0 min.
Plug-In Instrument System (Card Cage)	Acromag, Inc.	791-GG-115	8	\$335	1) Accommodates up to 10 plug-in circuit modules; 2) Enclosure includes main AC power transformer, 24 VDC and 15 VDC power of all 10 card locations; 3) Fits standard 19" relay rack.
Power Supply Module	Acromag, Inc.	781-CG-AC	8	\$85	1) Overvoltage and overcurrent protection; 2) Fuse protection in case of component failure; 3) L.E.D. indicates power applied to cards; 4) D.C. model designed to work over a wide range of source voltage.
Power Supply	Acromag, Inc.	781-CG-DC	8	\$85	Same as 781-CG-AC.
Current/Voltage Alarm Relay	Acromag, Inc.	731-2-1G	6-8	\$190	1) Each module can be used as either two independent alarms or as a dual alarm; 2) Single pole double throw relay standard per trip-point; 3) 1 to 10% deadband adjustment; 4) L.E.D.'s to indicate energized relays; 5) Field schedule high or low fail safe operation.
Match Pak Signal Conditioning	Research, Inc.	50720	8	\$170	This instrument accepts inputs as potentiometer, voltage or current commands and retransmits their non-isolated analog as current or voltage. 1) INPUTS: 1000 ohm potentiometer 0-5 VDC into 100 K ohm 1-5 ma 1 K ohm (Switch Selectable) 4-20 ma 250 ohm 10-50 ma 100 ohm 2) OUTPUTS: ma into maximum R ohm 1-5 5 K 4-20 1.2 K 10-50 300 ohm VDC into minimum R ohm 0-5 100 (Switch Selectable) 0-10 200 0-15 300

TABLE 5.8 SPECIFICATION OF AUXILIARY EQUIPMENT (Page 2 of 2)

<u>INSTRUMENT</u>	<u>MANUFACTURER</u>	<u>MODEL</u>	<u>DELIVERY TIME (WEEKS)</u>	<u>REF.*</u>	<u>COST (UNIT)</u>	<u>REMARKS</u>
Panel Indicator	LFE Co-p.	AP08020400	4		\$ 175	General purpose plug-in display, DC current/ voltage
Recorder	Taylor	1333JA14102	8		\$ 1,935	1) 3 pen recorder; 2) Electric chart drive.
Mass Spectrometer (Optional)	Anacon Aero Vac	180-730	16	39	\$15,000	1) 1-100 amu mass range; 2) no computerized data analysis capability provided; 3) electromagnetic scanning option
Mass Spectrometer (Optional)	CVC Products, Inc.	600	20	21-32	\$87,750	1) 1-600 amu mass range; 2) CVC software and data acquisition system available as single package; 3) response time less than 1.0 second for 6 or more gasses
Particulate Analyzer	Leeds & Northrop	Microtrac	18		\$40,000	1) on-line and batch-loaded modes available; 2) 2 minute sample rate; 3) outputs include 13 channel histogram of particle size distribution between 1.9 and 176 micron
Gas Chromatograph	Bendix	7000	16		\$15,000	1) Dual Sample process using N ₂ carrier gas for H ₂ process gas component sample and He ₂ carrier gas for other process gas components; 2) Sampling time 5-6 min.; 3) System uses thermal conductivity detector; 4) analog output.
Universal Driver Output	Research, Inc.	81900-13DME	8		\$ 2,815	1) provides signals for driving all commonly used process control elements 2) manual/computer controlled signal sources accepted; 3) time proportioning off/on or "one shot" off/on outputs available; 4) time frames of 4.28 seconds to 18 minutes available.
Barnett Dead-Weight Testers	Volumetrics	S390/1	8-10		\$ 2,457	1) 0.030% indicated pressure; 2) air operated single piston (for field calibrating PI's & PT's); 2-500 psi.

*Denotes number on Table 5.6.

all the instrumentation as well as the control philosophy is contained in Drawings 231-C-101, 231-C-102, and 231-C-103. The overall control strategy is summarized in Figure 5.1.

The various factors which led to the choice of detailed instrumentation for the valve test loop specified above are discussed in terms of the criteria for product evaluation also presented above.

- **Manufacturer Specifications**

A comparison of the manufacturer's specifications given in Tables 5.7 and 5.8 with system requirements discussed in Section 4.7 reveal that in every case the manufacturers' specifications meet or exceed system requirements.

- **Choice of Materials**

Most flow wetted parts are SS 316, consistent with the materials investigation presented in Section 4.7.4. Exceptions are the thermowells, which are alumina or silicon carbide refractories, and the targets to the Ramapo Flowmeters, which are "Alonized" SS 316.

- **Verified Track Record**

Each device has several references from Table 5.6, some of which established its successful use in similar applications to that anticipated in the HDGCV Test Facility.

- **Cost**

The recommended instrumentation compares very favorably in cost with its competitors. The fabrication of SS 316 and Class 1 Group B Division 1 housing increased the cost of much of the instrumentation, but that was unavoidable. On the other hand, use of SS 316 over more exotic and costly alternatives is recommended to avoid unnecessary "over engineering."

- **Quality of Service**

Quality of service was investigated in contacting the references used to obtain a verified track record. Furthermore, since Taylor Instrument Co. will be providing much of the instrumentation, it is believed that they will be especially committed to maintaining a high quality of service. In addition, the other manufacturers recommended have provided good service to their customers.

FIGURE 5.1 CONTROL STRATEGY FOR THE HDGCV TEST FACILITY

Discussion of Special Design Features

In this section specific solutions to the difficulties associated with the measurement of flow, pressure, temperature, valve stem leak rate, valve stem height, and valve stem force are presented. These problems were discussed in Section 4.7.5.

Measurement of hot dirty gas flow in the valve test loop was a major design problem area. No currently available device can reliably withstand the high process temperature in the immediate vicinity of the test valve. Although one could fabricate a specialized orifice for this environment, it would be a prototype, not off-the-shelf. Furthermore, so little metering of high temperature gas is performed that orifice coefficients above 1500°F are not readily available. Thus a calibration effort would have to be undertaken to ensure maximum accuracy. Therefore, the flow sensing elements are placed downstream of the test valve after the gas has been cooled and cleaned. A mass balance is made, as discussed in Section 4.7.5, to determine the flow through the valve. The overhead gas from Venturi Separators V-100 A, B, C still presents a harsh environment, since even after cleanup small particles of 0.5 microns or less remain in the gas. It is believed that no conventional obstruction type flow meter could guarantee reliable service over extended operation in this environment. Thus, the Thermal Instrument Co., TIC-390 Model 60 noncontact Thermal Flowmeter is recommended for use in this stream. Although somewhat expensive compared to other more conventional flowmeters, the Model 60 is capable of long life even in harsh environments.

The Model 60 Thermal Flowmeter consists of a single, unobstructed flow tube with no moving parts. A sensing element located on the outside of the flow tube is energized with a small amount of electrical energy. The heat conducted off this element by the flow stream is directly proportional to the mass flow rate of the fluid. Additional sensing elements are located on the tube to compensate and correct for the effects of fluid and ambient temperature. No electrical contacts to the process fluid are

required. The response time is 0.5 seconds. The requirement that the process fluid composition be accurately known in order to properly calibrate the Model 60 Thermal Flowmeter is satisfied due to the use of an on-line process gas analyzer.

Although the Thermal Instrument Co. thermal flowmeters are capable of measuring the flows denoted by flow transmitter labels 2.1 and 2.2 on Drawing 231-C-101 (which are clean water input and dirty (particulate) water output, respectively) the Ramapo Mark V Target Flowmeters are chosen since they are considered capable of doing the job at reduced cost. Use of the same flow measuring device in both liquid streams is recommended for increased accuracy (same nonlinearities, etc.) which would result in a combined performance in excess of the manufacturer's specifications on the devices taken individually.

The Mark V Flowmeter senses the flow of liquids, gas or steam by measuring the force exerted by the flow on a target suspended in the flow stream. This force is transduced by a four active arm strain gauge bridge to provide a signal proportional to flow rate squared. The target is easy to get at and can be replaced or checked after each valve is tested. Furthermore the target can be "Alonized" or fabricated from more exotic materials than SS 316 if necessary to insure longer life. The Mark V Flowmeter has a large turndown ratio, making it suitable for both Case 1 and Case 2 operation, and extensive use in similar applications (coal slurries, etc.).

The basic system for measuring pressure in the valve test loop was described in Section 4.7.5. Taylor products are selected in that their standard line is able to meet the entire pressure measurement needs of the HDGCV Test Facility. Furthermore, in keeping with the policy of using a single large company for as many different devices when presented with equivalent alternatives, Taylor is able to provide other auxiliary equipment as well.

The material requirements, discussed in Section 4.7.4, that all process wetted parts be made of SS 316, is a standard specification, as well as the requirement that field mounted electric devices capable of sparking conform to Class 1, Group B, Division 1 criteria. An additional safety feature, overrange protection, allows up to full scale static pressure limitation for all spans. This protects the system's primary pressure detection components against accidental over-pressuring even in the event of diaphragm or bellows ruptures.

Unpowered Bourdon tubes are selected for local pressure indication to provide an independent check on the transducers for increased system reliability. It also provides for system monitoring even with the loss of all electrical power.

One particular feature of the Taylor pressure transducer is that they have two ranges of operation which coincidentally match the measurement requirements for Case 1 and Case 2 operations. They are field adjustable and using the pressure taps for a calibration device, the Barnett dead weight tester specified in Table 5.8, the full accuracy given in the manufacturer's specifications can be obtained for both modes of operation. This presents a substantial savings in equipment cost. Further Taylor is a large well known company having extensive experience in all phases of process industry instrumentation.

The measurement of temperature in the vicinity of the test valve poses severe material problems due to the high temperature, highly corrosive and erosive process. Two different manufacturers of thermowells, ARI Industries, Inc. and National Basic Sensor Corp., are chosen for reliability. Since extended service simply cannot be guaranteed in this environment, an installed backup is provided. Both manufacturers have had extensive experience in high temperature, corrosive environments.

The ARI Industries, Inc. T-50230 Industrial Thermocouple System was developed for the extreme environments found in sulfur recovery units

and coal gasification zones. The Tungsten 5% Rhenium/Tungsten 26% Rhenium element is protected against contamination through a double insulation-double wall construction that selectively eliminates all but the beneficial diffusion of hydrogen. The thermowell includes silicon carbide and magnesium oxide refractory.

The National Basic Sensor Corp. will supply a type K thermocouple in an LT-1 tube. The LT-1 is a metal ceramic tube (77% chrome, 23% aluminum oxide). This system has been used successfully in blast furnaces.

The method of measuring test valve stem leak rate described in Section 4.7.4 requires a high accuracy flowmeter to get a reasonable measurement. The Electronic Flo-Meters, Inc. Turbine Flowmeter is such a highly accurate flow measuring device. An additional feature of a turbine meter is that the output is linear with the flow, unlike head meters in which the output is the square of the flow. This becomes especially important in measuring flows over a wide range. Since valve stem leakage is an important parameter of the operation of the test valve, it is highly desirable to maintain accurate leak measurements over a wide range of values. Thus the accuracy and wide range of the turbine meter make it the method of choice. In addition, there is also a small pressure drop across the meter. An advantage of the EFM Turbine Flowmeter is that it operates well at the low flows expected in the inlet and outlet lines at the shroud. Two identical meters for inlet and outlet are used to reduce nonlinearities. Furthermore, an additional calibration to give 0.02% accuracy of reading (repeatability hysteresis) can be performed instead of the standard 0.15% accuracy full scale (linearity limit).

For valve stem position measurement, the use of Schaevitz Engineering LVDT displacement detectors is recommended. Schaevitz is the acknowledged leader in the manufacture of LVDTs, and has the broadest line of LVDTs so that compatibility with any valve can be assured. Also their

LVDTs are capable of handling the severe environment in the shroud. Schaevitz has extensive experience in supplying LVDTs to installations having severe environmental requirements.

Valve stem force/torque measurement is accomplished through the use of load cells. Hottinger Baldwin Measurements, Inc. is the manufacturer whose load cells are selected for this task. For the valve stem force detection a device is needed that can measure compression and tension in a high temperature (450⁰F) corrosive environment. HBM is the only manufacturer, of the many with whom discussions were held, capable of satisfying the above requirements in a single device. Furthermore, a special ceramic cement (good to 650⁰F) has to be specified to ensure good attachment of the load cell to the valve stem.

HBM has had extensive experience in the process industry. It is deeply involved in petroleum and coal projects. As a German company, most of its markets have been in Europe, but it also has markets in the United States.

Discussions of Other Features

Main facility control is maintained through the use of local pneumatic control loops monitored at a central control station. To provide the additional system control required for proper sequencing of test valve cycling, valve stem leak test initiation, and appropriate phasing between the test valve and the bypass line control valve which regulates process gas flow into the compressor, a timer/cycle generator will be required. Research Inc.'s Uni-Driver (Universal Output Driver) provides a single rack mounted unit with the capability of converting addressed binary commands from both manually controlled or computer controlled sources to signals available for driving all commonly used final process control elements. With this unit, switching, timing and valve phasing may be accomplished through the use of a time proportioning output circuit card. This card provides time proportioning off/on or "one-shot" off/on outputs. The on time is programmable with a resolution of 1 part in 255 within a time frame of 4.28

seconds to 18 minutes, which is more than adequate for the 15 second test valve cycle time presently envisioned.

Under the current scheme, control of the facility is maintained with local pneumatic control loops (the heater and compressor will have their own controls). However, the specification of an optional central programmable controller is included in the Appendix to this report.

The interface requirements between the METC data acquisition system and the remainder of the facility, as put forth in Section 4.7.2 can be satisfied by providing the following signal conditioning:

- In all cases a calibrated 1 - 5 volts DC or 0-10 volts DC is input to the METC data acquisition system.
- All instrumentation is prepared to receive a calibrated 0 - 5 volts DC, 1 - 5 volts DC or 0-10 volts DC output from the METC system.

Signal conditioners capable of satisfying the above such requirements, and recommended in Table 5.8, are produced by Research Inc. They have the advantage of ease of use, flexibility, low cost, and their modular design allows for purchasing the number of devices necessary for presently foreseen applications while retaining the option for future additions.

It is noted here that a zero-based signal is unable to distinguish a "zero" reading from failure of a device. Thus for signals from flow transmitters where a no-flow reading might occur, use of 1 - 5 volts DC signal is recommended. Devices like thermocouples, where output is in millivolts, will require 0 - 10 volts DC interface. However, a zero voltage output from the thermocouple would indicate the device had failed.

Analysis of the components of the process gas can be accomplished using two general techniques, namely mass spectrometry and gas chromatography.

Gas chromatography is slower than mass spectrometry, but lower in cost. An on-line gas chromatograph is recommended for application in the HDGCV Test Facility. A discussion of alternative mass-spectrometry equipment is given in the Appendix.

A Bendix Model 7000 gas chromatograph can be custom designed to meet the specific requirements of the HDGCV Test Facility. Due to the large quantity of H_2 44% by volume, a dual sample technique would be applied. H_2 sample values could be obtained by using N_2 as the carrier gas. The remainder of the process gas component sample values could then be obtained using a He carrier gas. Total sampling and analysis time for such a system would be approximately 5 to 6 minutes. A complete system including both analysis and sampling units would cost \$15,000.

Particle analysis is accomplished by an optical light scattering system using photo multiplier tubes for detection and computer analysis for actual particle distribution analysis. The Leeds & Northrop Microtrac Particle-Size Monitor specified in Table 5.8 is a state-of-the-art particle analyzer capable of reliable service in the HDGCV Test Facility. Using the Microtrac, successive samples can be analyzed as often as every two minutes, including sample extraction, transport, measurement and data recording. Both an on-time automatic mode and a batch-loaded mode are available.

Outputs include a 13-channel histogram of the distribution between 1.9 and 176 microns in both relative and cumulative form. In addition, summary outputs include mean diameter of the volume distribution, calculated mean specific surface area, percent passing for any three selectable channels, and a relative concentration measurement. Different combinations of these outputs are switch-selectable.

Special System Instrument Design Features

Special design features have been incorporated in all phases of the instrumentation design specification for the HDGCV Test Facility. Those associated with specific instrumentation are presented in the section describing the instrumentation. Additional overall features include the following:

- Pressure taps around each pump provide for performance tests to insure pump is operating up to the guarantee point. A manifold with pressure tap around each line to a pressure detector can be used for dead weight testing for field calibration of that pressure sensor. Also pressure taps provide a convenient place for the addition of more instrumentation, and they can be used for line purging.
- Air tanks are added around crucial control valves to allow a controlled system shutdown in the event of total loss of air supply (power failure, supply air pipe rupture, main compressor failure, etc.)
- Separate sensing elements are provided for signals sent to the control/indicator system and the METC data acquisition for redundancy and reliability.
- Temperature sensors (thermowells) are placed downstream of flow sensors to minimize the effect of the turbulence caused by the intrusion of the thermowell in the flow on the flow measurement.
- Valves are used on each side of every level switch for isolation during maintenance.
- Hand indicator control valves provide for hand operation of control valves in event the control system fails to operate properly.

5.4.3 Hot Leak Rate Test Shroud

As pointed out in Section 4.6.5, the development and incorporation of a Hot Leak Rate Test Shroud was considered by Mittelhauser Corporation to be a necessary part of this project so that valve stem degradation could

be accurately monitored at operating conditions. It is believed this approach will provide a more accurate data base yield from the HDGCV Test Facility.

Figure 5.2 shows the conceptual HDGCV hot leak rate test shroud. The shroud would be attached to the test valve by means of an adapter flange at the valve body to bonnet flange. It would be preferable if the valve manufacturer supplied the adapter flange with the valve since the bonnet flange size, configuration, and drilling pattern would vary from manufacturer to manufacturer, while the shroud mounting flange would be one standard pattern based on final design of the shroud.

The shroud has a flanged body split to facilitate the installation of flexible actuator and instrument connectors inside the shroud. Bulkhead type fittings would penetrate the top of the shroud for pneumatic type actuators. The bulkhead fittings would be capped in the event electric actuators were used and the insulated electrical pin lugs would be used. Similar electrical pin lugs would be used for force and position instruments attached to the valve stem.

Carrier gas inlet and outlet connections are to be furnished as shown. The carrier gas is used to keep the shroud internal temperature at less than 450°F to protect valve actuator diaphragms and seals. The stem leak rate is determined from the differential flowrate between the carrier gas inlet and outlet.

The shroud should be furnished with two other connections. One connection would be for a high level pressure switch to provide alarm function to the test facility control room. The second connection would be for overpressure relief to the flare header system.

The test shroud also provides a secondary function of stopping the release of the test gas to the atmosphere.

DESIGN PRESSURE 30 psig
 DESIGN TEMPERATURE 750°F
 OPERATING TEMPERATURE 450°F

FIGURE 5.2 CONCEPTUAL HDGCV
 HOT LEAK RATE TEST SHROUD

It is felt that competent valve manufacturers would not hesitate at the use of the test shroud if advised of its use and features at the time manufacturers were invited to participate in this program. The manufacturers would be being invited to join in a research and development program which would give them an advantage in advanced valve technology, at no great cost to themselves.

5.4.4 Conceptual Layout

The conceptual layout of the HDGCV Test Facility is as shown in Drawing 231-C-201, Appendix. The layout is predicated on overall equipment dimensions and connection elevation requirements. As an example, reference Drawing 231-C-201, the elevation to the centerline of the valve test loops is approximately 7 feet. This is to accommodate a straight pipe run into the venturi scrubbers and scrubber separators. Vessels V-100 A, B, due to the solids laden water, gravity feed to the gas recovery flash drum V-102.

Since the space limitation for plot was set at 20,000 to 30,000 square feet, it was originally conceived that the large air cooler, E-100, might require placement overhead. However, as the conceptual layout progressed and total consumed plot space firmed up, it was decided this large, heavy cooler could be readily placed at grade and an expensive support structure deleted.

Two other essential criteria were incorporated into the conceptual layout. One criteria was to keep the runs of hot and hot dirty gas piping, relatively expensive refractory lined pipe, as straight and short as possible while still leaving adequate room for thermal expansion, solids mixing and service. The other criteria was to provide adequate maneuvering room, both overhead and plot, so that maintenance and service vehicles can readily reach both the tested valves and other equipment.

The actual plot space consumed by the equipment bounds is approximately 12,800 square feet (128 x 100 ft). However, when the large periphery road is included, the total consumed plot space becomes approximately 24,780 square feet. The total HDGCV Test Facility, including the periphery road, fits into the overall METC facility as previously shown in Figure 3.3.

5.5 FACILITY COST ESTIMATES

5.5.1 Plant Investment

A cost workup for itemized equipment is presented in Table 5.9. This table shows, by item, the results of the modular estimating procedures described in Section 4.8. The largest cost items are for the Main Compressor Package, K-100, Fired Heater H-100, and the Solids Addition Packages ME-101 A; B. Direct costs for these three components account for nearly two thirds of the direct cost of the entire battery-limits facility. Therefore, future design studies aimed at reducing the cost of the HDGCV Test Facility should focus on these three items.

The primary reason that these components are so costly is that they are designed for 250 psig nominal operations. As shown in the Process Flow Diagram, Drawings 231-C-001 and 231-C-002, the Fired Heater absorbed duty in Case 2 (50 psig operation) is only 21% of the design duty of 62.5×10^6 BTU per hour. The compressor horsepower remains the same only because the spillback loop is used to maintain the throughput the same as in Case 1 so as to prevent surging of the machine. Finally, the solids addition rate in Case 2 is only 24% of that in Case 1. From these facts it can be concluded that a shift by METC to a 50 psig test program would result in a major cost reduction for the HDGCV Test Facility. This possibility is discussed further in Section 5.7.2.

TABLE 5.9 COST WORKUP FOR ITEMIZED EQUIPMENT (Page 1 of 2)
All Costs in Fourth Quarter 1979 Dollars

<u>Item</u>	<u>Purchased Cost, Each</u>	<u>Number Required</u>	<u>Total Major Equipment Cost</u>	<u>Field Materials (Note 1)</u>	<u>Installation Labor</u>	<u>Total Direct Cost</u>
Pressure Vessels						
V-100 A, B, C; Venturi Separator	60,000	3	180,000	174,630	47,700	402,300
V-101; Direct Contact Cooler	128,200	1	128,200	75,100	29,400	232,700
V-102; Purge Water Flash Drum	5,600	1	5,600	6,200	4,000	15,800
V-103; Main Compressor Section Drum	18,300	1	18,300	9,500	7,300	35,100
V-104; Sour Condensate K.O. Drum	4,000	1	4,000	3,700	2,500	10,200
Total Vessels		7	336,100	269,100	90,900	696,100
Exchangers						
Air-Cooled						
E-100; Recirculation Cooler	222,200	1	222,200	66,600	68,700	357,500
E-102; Sour Flash Gas Condenser	23,700	1	23,700	7,200	7,900	38,800
Shell and Tube						
E-101; Compressor Spillback Cooler	46,800	1	46,800	34,300	13,100	94,200
Total Exchangers		3	292,700	108,100	89,700	490,500
Fired Equipment						
H-100; Fired Heater	775,000	1	775,000	219,800	171,100	1,165,900
Total Fired Equipment		1	775,000	219,800	171,100	1,165,900
Compressors and Drivers						
K-100; Main Compressor Package	490,000	1	490,000	156,400	165,500	811,900
Total Compressors and Drivers		1	490,000	156,400	165,500	811,900
Pumps and Drivers						
P-100 A, B; Bypass Loop Venturi Recirc. Pump	4,450	2	8,900	7,000	7,100	23,000
P-101 A, B; Flash Drum Bottoms Pump	1,050	2	2,100	1,700	1,700	5,500
P-102 A, B; Direct Contact Cooler Recirc. Pump	20,000	2	40,000	31,400	31,600	103,000
P-103 A, B; Sour Condensate Recirc. Pump	1,750	2	3,500	2,700	2,700	8,900
Total Pumps and Drivers		8	54,500	42,800	43,100	140,400

TABLE 5.9 COST WORKUP FOR ITEMIZED EQUIPMENT (Page 2 of 2)
All Costs in Fourth Quarter 1979 Dollars

<u>Item</u>	<u>Purchased Cost, Each</u>	<u>Number Required</u>	<u>Total Major Equipment Cost</u>	<u>Field Materials (Note 1)</u>	<u>Installation Labor</u>	<u>Total Direct Cost</u>
Mechanical Equipment						
ME-100 A, B, C; Venturi (Note 2)						
ME-101 A, B; Solids Addition Package	200,000	2	400,000	408,100	386,900	1,195,000
ME-102; Solids Receiving/Loading Package	61,000	1	61,000	89,900	72,200	223,100
ME-103 A, B; Stem Leakage Test Shroud	500	2	1,000	1,300	1,200	3,500
ME-104; Bypass Restriction Orifice	1,500	1	1,500	-	300	1,800
ME-105; Hot Gas Humidifier	2,000	1	2,000	2,800	2,400	7,200
ME-106; Gaseous Contaminant Makeup Package	2,000	1	2,000	2,800	2,400	7,200
ME-107; Flare	17,000	1	17,000	6,200	8,700	31,900
ME-108; Flash Gas Eductor	500	1	500	-	100	600
Total Mechanical Equipment		10	485,000	511,100	474,200	1,470,300
Total Major Equipment		30	2,433,300	1,307,300	1,034,500	4,775,100

NOTE: 1. Includes Instrumentation Materials as Specified by BDM Corporation
2. Included with V-100 A, B, C

Table 5.10 shows how the battery limits direct costs are built into a turnkey cost as described in Section 4.8. The total turnkey cost of \$9,774,700 is estimated to be accurate to about $\pm 30\%$. The direct offsites costs are 18.5% of the total direct facility costs. The largest single item in the offsite cost is an allowance for an electrical substation to serve the large electric motor on K-100. Again, reversion to a 50 psig operating plan for the HDGCV Test Facility would probably significantly reduce this cost, and in any event it should be the object of study in the next, detailed design phase of the project.

5.5.2 Operating Requirements and Costs

Table 5.11 has two parts. Part A gives operating requirements and costs for Case 1 (250 psig) operation while Part B gives the corresponding figures for Case 2 (50 psig) operation. The major difference between the operating requirements of the two cases is that for natural gas; this was alluded to in Section 5.5.1.

Ignoring other utility costs and assigning arbitrary unit costs to electricity and natural gas of, respectively, \$.03 per kWh and \$1.50 per 1000 scf, the annual utility costs attributable to these two items alone are approximately 1.3 million dollars for Case 1 and 0.6 million dollars for Case 2. Therefore, utility-related operating costs should be approximately the same order of magnitude as capital-related operating costs, for either case.

On the other hand, it is easily seen that even if the gas losses from the system were two to three times the values used to compute the tabulated costs, the cost of refilling the system with gas would still be small in comparison to other operating costs. On this basis it is possible to question the utility of the flash system. In Case 1 if the flash system were not used, the annual gas losses from the system, due to dissolution in the purge water, would be 1,248,000 SCF over and above the regular

TABLE 5.10 INVESTMENT SUMMARY
All Costs in Fourth Quarter 1979 Dollars

<u>Item</u>		<u>Cost</u>
Direct Costs for Major Equipment, From Table 5.9		4,775,100
Other Direct Costs		
Estimated Additional Cost of Refractory-Lined Piping	45,700	
Offsites Costs (Note 1)	<u>1,040,200</u>	<u>1,085,900</u>
Total Direct Costs		5,861,000
Indirect Costs		
Construction Overhead Costs (Note 2)	1,185,800	
Engineering Home Office Costs, Overhead, and Contractor's Fee	1,163,100	
Freight to Site	80,100	
Taxes and Insurance	<u>246,900</u>	<u>2,675,900</u>
Turnkey Cost Without Contingency		8,536,900
Contingency at 14.5% of Turnkey Cost (Note 3)		<u>1,237,800</u>
Total Turnkey Cost:		9,774,700

- NOTES:**
1. Offsites costs include cooling water distribution, fire loops and hydrants, fuel gas and oil distribution, plant air system extension, relief system, inert gas system extension, electrical distribution, steam tracing, general water piping and sewer system extensions, control building, yard lighting, and communications. Cost for hard ware for computer interface is included in instrumentation costs. Receiving and shipping facilities are not included.
 2. Construction overhead includes field supervision, temporary facilities, equipment rental, small tools, etc.
 3. Contingency is a weighted average percentage of turnkey cost. Weighting basis is the total direct cost. Contingency percentages are allocated to items as follows: Items H-100, K-100, ME-101 A, B = 20%; all other major equipment = 10%; offsites = 5%.

TABLE 5.11A OPERATING REQUIREMENTS AND COSTS - CASE 1
(250 psig Operation)

Item	Usage Rate	Units	Cost Per Unit, Dollars	Annual Units	Annual Cost 1979 Dollars	Remarks
Payroll						
Operating Labor, men/shift	1.0	M-H	9.00	8,760	78,800	8760 Hrs per Year Average 4.3% of Total Direct Cost
Maintenance Labor					150,900	
Supervision, men/shift	1.0	M-H	12.00	8,760	105,120	
Total Payroll					334,820	
General and Administrative Expense						
Operating and Maintenance Supplies					150,720	45% of Total Payroll See Section 4.8.6 3.2% of Turnkey Cost
Plant Insurance and Property Tax					124,200	
					312,820	
Subtotal Labor and Capital-Related Operating Expenses					922,520	
Utilities						
Process Water, gpm	85.4	1000 gallons	Not Provided	16,992	Not determined	Based on 81% efficiency, HHV, 1000 BTU/SCF Gas, 59.8 x 10 ⁶ BTU absorbed duty.
Cooling Water, gpm	26.7	1000 gallons	"	12,816	"	
Instrument Air, SCFM	50	1000 SCF	"	24,000	"	
Inert Gas, SCFM	30	1000 SCF	"	14,400	"	
Electric Power, KW						
2300 v:	1300	KWH	"	10,400,000	"	
460 v:	140	KWH	"	1,120,000	"	
110 v:	480	KWH	"	3,200,000	"	
Natural Gas, SCFM	1230	1000 SCF	"	590,400	"	
Catalyst and Chemical Makeups						
Contaminant Gases						1-Regular 2-Trailer Fill + 2 Unsched. 2-Trailer Fills Per Year
CCl ₄ + CO + H ₂ Tube Trailer, SCFH		SCF	.15	192,000	28,800	
CH ₄ , Cylinder, SCFH		SCF	.08	3 Cylinders, 1068 SCF	53	5 PPMW Dissolved in 35.4 GPM Purge Water
H ₂ S, Cylinder, SCFH		SCF	.10	15 Cylinders, 10,020 SCF	1,002	
N ₂ , Cylinder, SCFH		SCF	.08	3 Cylinders, 660 SCF	53	3 PPMW Dissolved in 35.4 GPM Purge Water 6 Days w/\$25 Per Day Plus 12 Months w/\$400 Per Month
CO ₂ , Cylinder, SCFH		SCF	.08	14 Cylinders, 4980 SCF	399	
Trailer Demurrage		Month	400.00		5,700	
Total					36,039	

TABLE 5.11B OPERATING REQUIREMENTS AND COSTS - CASE 2
(50 psig Operation)

Item	Usage Rate	Units	Cost Per Unit, Dollars	Annual Units	Annual Cost 1979 Dollars	Remarks
Payroll						
Operating Labor, men/shift	1.0	M-H	9.00	8,760	78,800	8760 Hrs per Year Average 4.3% of Total Direct Cost
Maintenance Labor					150,900	
Supervision, men/shift	1.0	M-H	12.00	8,760	105,120	
Total Payroll					334,820	
General and Administrative Expense					150,700	45% of Total Payroll See Section 4.8.6 3.2% of Turnkey Cost
Operating and Maintenance Supplies					124,200	
Plant Insurance and Property Tax					312,800	
Subtotal Labor and Capital-Related Operating Expenses					922,520	
Utilities						
Process Water, gpm	98.9	1000 gallons	Not provided	47,472	Not determined	
Cooling Water, gpm	186.7	1000 gallons	"	89,616	"	
Instrument Air, SCFM	50	1000 SCF	"	24,000	"	
Inert Gas, SCFM	30	1000 SCF	"	14,400	"	
Electric Power, KW						
2300 v:	1300	KWH	"	10,400,000	"	
460 v:	140	KWH	"	1,120,000	"	
110 v:	400	KWH	"	3,200,000	"	E-100 Fan Power may be lower
Natural Gas, SCFM	276	1000 SCF	"	132,300	"	Based on 81% efficiency, KWH, 1000 BTU/SCF gas, 13.4×10^6 BTU absorbed duty.
Catalyst and Chemical Makeup						
Contaminant Gases						
CO ₂ + CO + H ₂ Tube Trailer, SCFH		SCF	.15	192,000	28,800	1-Regular 2-Trailer Fill + 2 Unsched. 2-Trailer Fills Per Year
CH ₄ Cylinder, SCFH		SCF	.08	3 Cylinders, 1068 SCF	.85	
H ₂ S Cylinder, SCFH		SCF	.10	36 Cylinders, 24,050 SCF	2,405	Reg. Fills Plus 5 PPMW Dissolved in 98.9 GPM Purge ater
N ₂ Cylinder, SCFH		SCF	.08	3 Cylinders, 660 SCF	.53	
CO ₁ Cylinder, SCFH		SCF	.08	32 Cylinders, 11,390 SCF	.911	Reg. Fills Plus 3 PPMW Dissolved in 98.9 GPM Purge Water
Trailer Demurrage		Month	400.00		5,700	
Total					37,954	6 Days w/\$25 per day plus 12 mo. w/\$400 per month.

trailer fills due to planned maintenance and unscheduled shutdowns. At a cost of \$.08 per scf, the makeup costs due to these dissolution losses would be nearly 0.1 million dollars per year. Since the share of the total turnkey plant cost attributable to the flash system equipment is about 0.13 million dollars, the flash system has a simple payout of about 1.3 years, showing that it is an attractive design feature.

The other consequence of the smallness of the gas-makeup-related operating costs is that the inherent uncertainty in vapor-liquid equilibrium calculation methods for sour water systems will probably not have a large cost effect within the battery limits of the system. This of course is not necessarily true when consideration is given to possible odor and treating problems which could arise in METC water treating facilities due to the release of dissolved H_2S from the purge water. This is a potential problem which may need to be investigated in later study work.

5.6 SCHEDULES

5.6.1 Design and Construction Schedule

The design and construction schedule for the facility is presented in Figure 5.3. The schedule is based on the assumptions given in Section 3.2. The critical delivery equipment components are the Main Compressor K-100 and the Fired Heater H-100. Therefore, emphasis must be placed on ordering of these items as soon after release as possible.

In some more-or-less-standard process designs such as for ethylene plants, it is possible to place orders for long-lead-time compressors as little as three weeks after contract release. However, in a difficult and unique process service such as encountered here, Mittelhauser believes that the front-end design must be approached extremely carefully prior to a commitment to purchase these expensive equipment components. Therefore, Mittelhauser has allowed four months between job

FIGURE 5.3 DESIGN AND CONSTRUCTION SCHEDULE

release and the placement of the orders for the compressor. This time will be spent to:

- Define the process suction and discharge requirements.
- Review the requirements with METC.
- Prepare an inquiry specification and issue to vendors.
- Evaluate vendor offerings and select a unit for purchase.
- Review the vendor selection with METC.
- Prepare and issue a purchase order.

Other noncritical equipment components can be specified, evaluated, and orders placed over the next 3 months. All major equipment would be ordered by the end of the seventh month after release. Bulk materials (piping, steel, instruments, etc.) would be ordered not later than 12 months after release, about the same time as site preparation work began.

All major equipment items would be delivered to the site by the end of the twentieth month after release. The remainder of the construction work, including piping installation, insulation and paint, installation of instrumentation, and utility tie-ins, would be completed in another five months at most.

Mechanical checkout would begin in the twenty-fourth month and continue to the beginning of the startup period at the end of the twenty-sixth month after contract award.

It is emphasized that this schedule is preliminary and subject to revision, particularly in the area of equipment lead times. It may be possible to shorten the overall schedule by three to six months if equipment deliveries can be expedited. In terms of the overall test program,

this would be a very favorable development. Therefore preference should be given to vendors offering expedited delivery of these items in addition to compliance with all specifications, even if their price is not the lowest.

5.6.2 Operating Schedule

Figure 5.4 is an operating schedule for the HDGCV Test Facility. The schedule begins with a 90-day startup period which allows for the following items:

- Repair or replacement of malfunctioning or defective system components
- Component testing and integration
- Acceptance testing of the facility

During this startup period it is anticipated that the following general sequence of operations will be observed:

- Cure the refractory in the Fired Heater H-100.
- Partially fill pressure vessels and check pumps on cold circulation.
- Startup and testing of Main Compressor K-100 on total recycle through spillback loop.
- Insert pipe spool pieces in the valve test loops as "dummy valves" for checkout of the loops.
- Begin filling the remainder of the system with gas, using the compressor for circulation, but without solids addition, to cure the refractory in the hot piping system.
- Bring the entire HDGCV Test Facility to Case 1 operating conditions without solids addition. Then calibrate and check out all instruments.

FIGURE 5.4 HDGCV TEST FACILITY OPERATING SCHEDULE

- For each valve test loop in turn, activate and test the Solids Addition Packages ME-101 A, B and verify the particulate removal capability of the Venturis ME-100 A, B.
- Take Valve Test Loop A out of service, and install the first test valve.
- Take Valve Test Loop B out of service, and initiate the first-year valve test program with Valve 1 in Loop A.

The valve testing program is as shown in Figure 3.2 and described in Section 3. At the end of the first year's test program, a 31-day turnaround period is scheduled. In this connection, it is important to note that due to the initial startup period, many of the equipment components will operate for longer than the normal 8000 hours between maintenance turnarounds. These components must be carefully identified in the final design phase and provisions made for their increased reliability.

Valve Switching, Figure 5.5, is a schematic diagram of the operating procedures used to remove one valve from the test mode to the removal, disassembly and inspection mode as specified in METC/CR-79/10 and shown in Figure 3.1. Mittelhauser believes that the use of the bypass loop provides a safe, reliable way to accomplish this switching without interfering with smooth operation of either the Main Compressor K-100 or the Fired Heater H-100. The sequence tables shown in Figure 5.5 assume that another test valve is in the second test loop so that a smooth transition can be accomplished from one loop to the other. However, if the second test valve is not in place, or if a problem is encountered in either or both test loops during switching or normal operation, the bypass loop is designed to handle the full heater discharge flow.

5.6.3 Project Chronology

The overall project chronology, assuming contract release on July 1, 1980, is as follows:

FIGURE 5.5 VALVE TEST LOOP SWITCHING SEQUENCE

Example of testing to shut-down sequence.
Valve A has been out of loop for inspection/service.

SEQUENCE:

- 1) Normal testing of Test Valve B (TV-B).
- 2) Test Valve B, end of test.
- 3) Coming to no solids flow condition in Test Loop B. Loop A coming on stream.
- 4) Coming to cool down flow condition in Test Loop B.
- 5) Letdown of pressure in cooled Test Loop B.
- 6) Letdown of remaining pressure (above comp. suction) in cooled down Test Loop B.
- 7) Test Loop B cooled down, depressurized, out of service, & ready for valve removal for inspection/repair. Loop A ready for start of testing.

VALVE POSITIONS AT SEQUENCE #								
VALVE #	SEQUENCE #	1	2	3	4	5	6	7
CV-C1	OPEN	—	—	—	—	—	—	→
CV-B1	OPEN	—	—	—	—	→	CLOSED	CLOSED
CV-A1	CLOSED	CLOSED	OPEN	—	—	—	—	→
BV-C1	PART OPEN	—	—	—	—	—	—	→
BV-C2	CLOSED	—	—	—	—	—	—	→
BV-C3	OPEN	—	—	—	—	—	—	→
BV-B1	PART OPEN	—	—	—	→	—	CLOSED	CLOSED
BV-B2	CLOSED	—	—	—	→	—	OPEN	CLOSED
BV-B3	OPEN	OPEN	CLOSING	CLOSING	CLOSED	—	—	→
BV-B4	CLOSED	CLOSED	OPENING	OPEN	CLOSED	—	—	→
BV-A1	CLOSED	CLOSED	OPEN	—	—	—	—	→
BV-A2	CLOSED	—	—	—	—	—	—	→
BV-A3	CLOSED	CLOSED	OPENING	OPENING	OPEN	—	—	→
BV-A4	CLOSED	—	—	—	—	—	—	→
RV-B1	OPEN	OPEN	CLOSING	CLOSED	—	—	—	→
RV-A1	CLOSED	—	—	—	—	—	—	→
TV-A	NON-CYCLE	—	—	—	—	—	—	→
TV-B	CYCLING	CYCLING	NON-CYCLE	—	—	—	—	→

FLOW CONDITIONS AT SEQUENCE #							
(CONDITIONS SHOW: T(°F)/P(PSIG)/% TEST SECTION DESIGN FLOW)							
REF. PT. #	1	2	3	4	5	6	7
X-1	1650/250 125%	1650/250 125%	1650/250 125%	700/250 75%	700/250 25%	700/250 25%	700/250 25%
X-2	300/250 0%	0%	0%	0%	0%	0%	0%
B-1	550/250 100%	1650/250 100%	1650/250 100%	750/250 60%	300/150 =0%	300/0 =0%	100/0 0%
B-2	150/250 100%	150/250 100%	150/250 100%	150/250 60%	150/150 =0%	150/0 =0%	100/0 0%
B-3	150/150 100%	150/150 100%	150/150 100%	150/150 60%	150/150 =0%	150/150 0%	150/150 0%
C-1	1650/250 25%	1650/250 25%	1650/250 25%	700/250 25%	700/250 25%	700/250 25%	700/250 25%
C-2	150/250 25%	25%	25%	25%	25%	25%	25%
C-3	150/150 25%	25%	25%	25%	25%	25%	25%

July 1, 1980
September 1, 1982
November 30, 1982
November 30, 1987

Contract Release
HDGCV Test Facility Startup Begins
Begin Valve Test Program
Complete Valve Test Program

5.7 UNCERTAINTIES AND OPPORTUNITIES

5.7.1 Uncertainties

There are three basic categories of uncertainties which are included herein. The first category covers design uncertainties for equipment in the test facility. There are five points of design uncertainty for the overall test facility. These are, for simplicity, presented in table form in Table 5.12, along with their probable effects and means of resolution.

The second category is that of cost uncertainties. Since the requested accuracy of the overall cost estimate is 30% of the total value, and since contingencies are, in varying degrees, provided for major equipment cost estimates, it is believed that cost uncertainties will not drive the facility cost estimate beyond the requested accuracy scope. Primarily, any cost uncertainty would be directly tied to the facility design uncertainties and methods of solution shown in Table 5.12.

The third category of uncertainties is based on operational upsets. These uncertainties, and their probable effects, are presented in Table 5.13.

5.7.2 Opportunities

There are two possible points of opportunity which could be considered for the HDGCV Test Facility. The first would require a change in the facility design philosophy, but would result in significant facility cost reduction.

TABLE 5.12 DESIGN UNCERTAINTIES, EFFECTS, & RESOLUTIONS

<u>Uncertainty</u>	<u>Effect</u>	<u>Resolution</u>
Compressor may not be capable of handling up to 5 lbs/hr of solids 0.5 m and less.	Cost addition	Add additional gas cleanup step such as electrostatic precipitators.
Standard fired heater may not have sufficient turn-down to handle Case I and Case II operations.	Possible cost addition	Add more, smaller, burners or special high turndown burners.
Solids addition package not capable of providing stable, cyclic feed rate.	Delay of final valve testing	Full scale testing of solids addition package.
Required quality of process water not available.	Cost addition	Add process water treating/demineralizer package.
Process water effluent cannot go directly to METC ponds.	Cost addition	Add solids removal package.

TABLE 5.13 OPERATIONAL UNCERTAINTIES AND PROBABLE EFFECTS

<u>Uncertainty</u>	<u>Effect</u>
HDGCV test valve failure	Switch to second test loop or bypass loop.
Test loop pipe refractory failure	Pipe overtemperature. Switch to second loop or bypass loop. Remove and replace section. Program progress upset.
Heater tube failure	Facility shutdown. Loss of test gas charge. Possible damage to hot gas refractory lined pipe.
Venturi water failure	Loop can be brought to safe shutdown. Interruption of testing progress.
V-100C gas discharge control valve sticks open	Insufficient flow through test loop. Interruption of testing progress.
V-100C gas discharge control valve sticks closed	Pressure surges, with test valve cycling, to heater and compressor. Stop valve cycle, Interruption of testing progress.
Electric power failure	Testing stops. Safe shutdown of heater can be accomplished, but extended duration may cause hot gas pipe refractory failure.
Instrument air failure	Safe shutdown can be accomplished. Interruption of testing progress.
Pump failure	No effect. All pumps are 100% spared.
Solids feeder sticks wide open.	Solids feed rate will be 2 times required rate with valve in control position. May require loop shutdown for repair.

The second opportunity would be that of greatly expanded testing capabilities for the test facility. This would require only the expansion of the test loops themselves by possibly 15 or 20 feet.

These opportunities and their effects are presented in Table 5.14.

TABLE 5.14 OPPORTUNITIES & PROBABLE EFFECTS

<u>Opportunity</u>	<u>Effect</u>
Reduce maximum operating level of the test facility to the Case II, 50 psig 1650°F, level	Significant reduction in capital and operation cost. This would result from reduced material thickness at pressure and temperature, but primarily from the reduction of process duty rating as the required throughput of test gas for Case II is approximately 24.4% of that in Case I.
Increase test loop run length to accept the testing of equipment larger than valves. Could be done with or without the above mentioned change in maximum operating level.	<p>This would allow for the increased testing potential of the test facility to a scope beyond control valves, co-currently or after completion of valve testing. Some development work is currently awaiting the long term operation of a gasifier, while the test facility simulates this condition and could be used to test/develop the following equipment examples:</p> <ul style="list-style-type: none"> ● Hot gas cleanup electrostatic precipitators. ● Hot gas baghouse or filter media development. (Heater temperature can be trimmed) ● Humidifier nozzle designs. ● Miscellaneous materials of construction. ● High-temperature fuel gas desulfurization.

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7.0

APPENDICES

7.1

VENDOR CORRESPONDENCE

RECORD OF TELEPHONE QUOTATION
(BUDGET ESTIMATE)
GAS CHARGES

Project 231-C

Airco
City of Industry, Ca.
Phil Brown

High Pressure Tube Trailer

32,000 SCF of Mixed CO₂, CO, & H₂

At 2,000 PSI

1979 Dollars

($\approx$ \$0.15/SCF) $\rightarrow$ \$4,800.00

Demurrage on Trailer

\$25.00/Day to Max. of \$400.00/Month

Balance of Gases Required:

CH ₄	\$28.40 for 356 SCF Cylinder (2,200.psi)
H ₂ S	\$69.00 for 60 Lb. Cylinder (2,200.psi)
N ₂	\$18.00 for 220 SCF Cylinder (2,200.psi)

11/8/79

520 NORTH BROOKHURST • SUITE 206 • ANAHEIM, CALIFORNIA

LOS ANGELES SALES OFFICE
714/533-4700

November 15, 1979

Mittelhauser Corporation
Suite 802
22600-B Lambert
El Toro, California 92630

Attention: Mr. Scott Heffley

Subject : TEST LOOP COMPRESSOR ESTIMATE
DOE TEST FACILITY
MORGANTOWN, WEST VIRGINIA

Dear Mr. Heffley:

We are pleased to submit the following estimate for your consideration. We would offer:

One (1) Allis-Chalmers Model VT-205 "Centri-Stak" vertically split multi-stage centrifugal compressor lineup.
This lineup would consist of the following:

A. Compressor

1. Casing - cast steel
2. Impellers - 17-4 PH stainless steel
3. Shaft - carbon steel
4. Shaft seal - mechanical, oil contact
5. Bearings
 - a. Journal - pivoted shoe
 - b. Thrust - Kingsbury type
6. Vibration detectors
7. Bearing thermocouples

B. Couplings - flexible diaphragm type

C. Coupling guards - fabricated steel

D. Speed increaser gear

E. Electric drive motor - 2250 HP, 3/60/4000 V.
O.D.P., Sealed insulation

F. Baseplate - sized to accommodate the compressor, gear and motor

G. Lube and seal oil system - A-C standard sized to serve the compressor and gear. The system includes:

1. Reservoir - sized for 3 minute retention
2. Main oil pump - driven from the gear low speed shaft

Mr. Scott Heffley

- 2 -

November 15, 1979

3. Auxiliary oil pump - electric motor driven
4. Overhead seal tank
5. Trap console
6. Oil cooler
7. Two (2) oil filters - 10 micron
8. Three way selector valve
9. Various switches and controls for safe operation of the system

H. Oil headers in the confines of the base. Carbon steel.

I. Instrument panel - to monitor the following:

1. Oil pressure
2. Oil temperature
3. Vibration detectors
4. Bearing thermocouples

Approximate Price, F.O.B. Factory . . \$350,000.00

Shipment. Approximately 12 Months

Thank you for your interest in our products. If we may be of any service please contact us.

Sincerely,

ALLIS-CHALMERS CORPORATION

Elliott M. Frost
Assoc. Application Engineer
Compressor Division

EMF/and

Attachment

SPECIFICATION DATA

Purchaser Mittelhauser Corporation **User** D.O.E.
Destination Morgantown, West Virginia **Proposal/Contract No.** Estimate
Purch. Ref. **Purch. Item No.** **Date** November 15, 1979
Application Test Loop Compressor

PROCESS REQUIREMENTS

Item	.....
Gas handled	.....
Atmospheric pressure	psia
Operating condition	.....
Standard cfm (14.7 psia—60° F—Dry)	.....
Weight flow	lbs/min

1				
Flue Gas				
14.7				
Rated				
20976				
925				

INLET CONDITIONS

Pressure, at flange	psi	^a
Temperature	° F	
Relative humidity	%	
Molecular weight		
Ratio of specific heats, c_p/c_v	(k)	
Compressibility factor	(z)	
Inlet volume	acfm	

139.7				
150				
-				
16.7				
1.37				
1.0				
2590				

DISCHARGE CONDITIONS

Pressure, at flange psi a
 Temperature ° F

289.7				
340				

EXPECTED PERFORMANCE

Compressor type	.....	
Compressor designation	.....	
No. of stages	.....	
Pressure ratio	.....	
Rotational speed/Adiabatic head	.....	ft
Speed	.....	rpm
Impeller tip speed	.....	fps
Impeller diameter	.....	in
Hp req'd by compressor	.....	bhp

[illegible]

Performance curve no.

**Guarantee and Warranty provisions will be as stated on the attached form.
Speeds and impeller diameters subject to change.**

A. P. GREEN REFRACTORIES CO.

MEXICO, MISSOURI 65265 U.S.A. PHONE: 314 473-3626 CABLE ADDRESS: "GREENCO"

December 11, 1979
4620 South Tripp Ave.
Chicago, Illinois 60632

Morgan Engineering Company
2500 Wisconsin Avenue
Downers Grove, Illinois 60515

Dear Mr. Miller,

As per our meeting on Tuesday November 27, 1979. We recommend that you use a 3" lining of VSL-50 Castable as the refractory material for the lining of the coal gasification valve test facility.

The Castable should be poured in sections, and because of the small diameter of the unit, anchors will not be needed.

I have enclosed technical information and pricing for your review.

The exact amount of material needed is unknown at this time.

If I can be of any further assistance, please feel free to contact me.

Sincerely,

A. P. GREEN REFRACTORIES CO.

Warren Orange

Warren Orange
Sales Representative

WO:as

CC: Mr. Mike Morgan
Mr. Ray Frazier

A. P. GREEN REFRACTORIES CO.

MEXICO, MISSOURI 65265 U.S.A.

Subsidiary of United States Gypsum Company

PRICING INFORMATION

<u>Product</u>	<u>Container</u>	<u>F.O.B. Points</u>	<u>Price MCL</u>	<u>Base Price</u> <u>Carload</u>
VSL-50	50 Lb Bag	Mexico-Thermo	455	450

Carload Prices - apply on individual shipments of any combination of speciality products which have a carload price lower than the mixed carload price.

Mixed Carload Price - apply on all other individual shipments amounting to at least 2500 equivalent of brick or 10 tons of any combination of products.

LTL Prices - Shipments smaller than the above are considered LTL and a special processing charge of 15% will be added to the carload selling price or minimum price at f.o.b. point unless otherwise indicated.

Minimum Invoicing Charge - of 100.00 will apply on all orders shipped from our manufacturing plants. This charge is based on the f.o.b. factory price from the origin of shipment.

Terms on all A. P. Green Sales - 30 days net.

TECHNICAL DATA

VSL-50

2300° F., Low Iron, Insulating Castable
 Manufactured at Mexico, Missouri

	Trowelled Or Poured	Gun Applied
MAXIMUM RECOMMENDED TEMPERATURE -----	2300° F.	2300° F.
POUNDS REQUIRED PER CUBIC FOOT - Net -----	50	60
POUNDS PER CUBIC FOOT IN PLACE		
Cured and Then Dried at 220° F. -----	51 - 57	62 - 68
Heated at 1500° F. -----	47 - 53	57 - 63
WATER REQUIRED FOR MIXING	Approximately	Added at
Gallons per 100 Pounds -----	6½	Nozzle
MAXIMUM TIME FROM ADDING WATER TO PLACING MATERIAL		
Minutes -----	30	
PERMANENT LINEAR CHANGE - A.S.T.M. C269		
Expansion or Shrinkage		
Cured and Then Dried at 220° F. -----	Nil	Nil
Heated at 1000° F. and Then Cooled ----	0.1 - 0.4% Shr.	0.1 - 0.4% Shr.
Heated at 1500° F. and Then Cooled ----	0.2 - 0.5% Shr.	0.2 - 0.5% Shr.
Heated at 2000° F. and Then Cooled ----	0.5 - 0.6% Shr.	0.2 - 0.6% Shr.
Heated at 2300° F. and Then Cooled ----	1.0 - 1.5% Shr.	0 - 1.0% Shr.
MODULUS OF RUPTURE - A.S.T.M. C268		
Cured and Then Dried at 220° F. -----	60 - 90 Psi	150 - 225 Psi.
Heated at 1000° F. and Then Cooled -----	35 - 55 Psi.	70 - 110 Psi.
Heated at 1500° F. and Then Cooled -----	35 - 55 Psi	70 - 110 Psi.
Heated at 2000° F. and Then Cooled -----	70 - 110 Psi	125 - 200 Psi.
COLD CRUSHING STRENGTH		
Cured and Then Dried at 220° F. -----	200 - 300 Psi.	400 - 600 Psi.
Heated at 1000° F. and Then Cooled -----	175 - 275 Psi.	300 - 450 Psi.
Heated at 1500° F. and Then Cooled -----	175 - 275 Psi.	300 - 450 Psi.
Heated at 2000° F. and Then Cooled -----	250 - 400 Psi.	300 - 450 Psi.
PARTICLE SIZE - A.S.T.M. C92		
Dry Analysis - Retained on 8 Mesh Tyler Screen		Less Than 1%

VSL-50

	Trowelled Or Poured	Gun Applied
THERMAL CONDUCTIVITY		
B.T.U./Sq.Ft./Hr./°F./In. Thickness		
at a Mean Temperature of		
400° F. -----	1.56	1.84
800° F. -----	1.79	2.11
1200° F. -----	1.87	2.20
1600° F. -----	1.89	2.21

CHEMICAL ANALYSIS

Calcined Basis

Silica - SiO_2 -----	53.0 - 56.0%
Alumina - Al_2O_3 -----	31.0 - 34.0%
Iron Oxide - Fe_2O_3 -----	0.6 - 0.9%
Lime - CaO -----	6.5 - 10.0%
Magnesia - MgO -----	0.1 - 0.6%
Titania - TiO_2 -----	0.5 - 1.0%
Alkalies - $Na_2O + K_2O$ -----	1.0 - 2.0%

These test data shown above are based on average results of control tests and are subject to normal variation on individual tests. These results cannot be taken as maximum or minimum requirements for specification purposes.

Date APR 1 1976

November 15, 1979

Mittelhauser Corporation
22600-B Lambert Street
Suite 802
El Toro, California 92630

Attention: Mr. Scott Heffley

Subject: Fired Gas Heater for Coal Gasifier Valve
Test Loop

Gentlemen:

I appreciated the opportunity of discussing with you the requirements that have been established by Mittelhauser for the Department of Energy's Morgantown test unit. In line with our discussions, I understand that the fired heater required will have a capacity of approximately 62.5 MM BTU/HR firing both natural gas and No. 2 fuel oil and heating a gas of the composition noted further on in this letter from 285° F to 1825° F.

As indicated, the flow rates will be 55,525 lbs/hr. of gas at the inlet and 65,735 lbs/hr. of gas plus water vapor at the outlet, subsequent to injection of 10,000 + lbs. of water at a point to be located somewhere in the lower portion of the convection section.

Since the unit will be in almost constant use for a period of about five years and in consideration of current fuel costs, it is recommended that this heater be designed for a reasonable efficiency in the order of 90% to 92% LHV.

We would point out here that the fuel savings alone for the heater of this size going from 90% to 92% efficiency with a heater operating at 8,000 hrs./year and an assumed fuel value of \$2.00 per MM BTU, would be equal to approximately \$120,000 over a five-year period.

...cont'd...

Since there is no specification delineating the requirements for this heater, but in consideration of the severity of the operation, particularly in the radiant section, we would recommend approaching the design in a fashion similar to other high temperature steam superheaters and the hundreds of proprietary cracking heaters that have been supplied by HTD.

While the inlet coil material can be low chrome, the material requirement would have to be increased substantially toward the shield portion of the convection section where stainless steel material would, in all likelihood, be employed. The radiant section configuration would be double fired at a maximum acceptable flux rate considering film temperature and material temperature and the material in the radiant section would, most probably, be supplied as centrifugally cast HK or HP alloy. At these temperatures, careful evaluation would have to be performed and analyses made of the coil expansion and support methods to assure that mechanical failure in operation would be avoided.

We estimate that for a heater of this capacity and these metallurgical requirements, the heater materials themselves can be supplied for approximately \$500,000. The unit could be supplied with a maximum degree of shop assembly and erection of the unit could cost upwards of \$200,000. We estimate that the plot space requirements for such a heater would be 20 ft. X 50 ft. approximately. The convection section, however, would be offset at an elevation of 40 ft. to 50 ft. above grade and the actual plot space required at grade would be approximately 12 ft. X 50 ft.

Instrumentation, electric lights, wiring, controls and all piping and equipment leading up to the heater as well as foundations, all of which are normally supplied by others, would have to be estimated separately.

The gas being fed to this heater at the inlet is

hydrogen	44.08 mol %
CO	25.38 mol %
CO2	25.5 mol %
CH4	.88 mol %
H2S	1.083 mol %
N2	.06 mol %

...cont'd...

Mittelhauser Corp.
page 3
Nov. 15, 1979

We trust that this information will be of assistance. If we can be of further service, please contact us.

Very truly yours,

THE LUMMUS COMPANY

G. F. Feldner
Sales Manager
Heat Transfer Division

GFF:hhl

M.H. DETRICK CO.

20 NORTH WACKER DRIVE • CHICAGO, ILLINOIS 60606 • PHONE 312/726-6974 •

January 9, 1980

Mr. Melvin Miller
Morgan Engineering
2500 Wisconsin Avenue
Downers Grove, IL 60515

Dear Melvin:

Here are estimated prices for a 10" Silicon Carbide (208) lined pipe per our phone conversation of 1/7/80. The lining is a 3/4" thick Silicon Carbide Clay Bonded and has excellent abrasion qualities. The Silicon Carbide grains have a hardness of 9 on the MOHS scale. Temperature limits for the material is 2600 deg. F.

Section 1

3 - 10" 30 foot run (2 - 15'-0")	\$1875.00 each
1 - 10" 25 foot run (1 - 15'-0")	1875.00 each
(1 - 10'-0")	1250.00 each
1 - 10" 16 foot run (1 - 10'-0")	1250.00 each
(1 - 6'-0")	750.00 each
1 - 10" 90 deg. Elbow - 4'-11" Radius	1153.00 each
2 - 10" Tees - 4'-0" Run 2'-0" Branch	1211.25 each

Section 2

2 - 10" 90 deg. Elbows - 4'-11" Radius	\$1153.00 each
1 - 35 foot section (1 - 15'-0")	1875.00 each
(2 - 10'-0")	1250.00 each
1 - 45 foot section (3 - 15'-0")	1875.00 each

Elbows and Tees to have fixed collars with rotating flanges.
All straight sections of pipe to have fixed flanges.

The Elbow price was based on a stock item. However the radius can be adjusted to fit your design. Also the prices for the Straight section of piping can also be adjusted to the exact linear footage required based on final design. We will submit an exact selling price based on a detailed drawing with exact bill of material which either you or we furnish.

I investigated gasket material and for temperatures up to 1700 deg. F., a 347 Stainless Steel Gasket would be suitable. Gaskets are .100 - .120 thick 10" x 16-1/2" - 12 holes 7/8" with a 15-9/16" bolt circle. Selling price is \$49.00 each.

Selling price for Hexagonal Head Nuts and Bolts:

3/4 - 10 x 3-1/2" are \$1.00 each

3/4 - 10 x 4-1/2" are \$1.50 each

Delivery for all materials can be within 12 to 16 weeks.

Melvin, the enclosed gradient shows an exterior temperature of 546 deg. F. The sketch shows a cross section of the lined pipe with an outside diameter of 12-3/4". On bottom portion of sketch is a table for thermal expansion.

After you have reviewed the pricing and gradient, please phone me so we can further discuss your project.

We appreciate your interest in our material and hope the information is of value to you.

Sincerely,

R. Favia

RF:gl

Encl.

November 6, 1979

Elliott
Company

Mittelhauser Corporation
22600-B Lambert Street
Suite 802
El Toro, California 92630

Attention: Mr. Scott Heffley

Subject: Compressor Performance Estimate for the
Morgan Town Energy Technology Center Study

Dear Mr. Heffley:

The following summarizes our phone conversation regarding the performance estimate for a 29M centrifugal compressor. For the conditions given we estimate a 29M5 compressor requiring 1700 HP at 10,830 RPM would be required. I have attached a typical drawing showing the overall dimensions for a similar unit with motor and gear. The total overall weight would be approximately 35,000 lbs. The lube and seal system for this service would be approximately 9 ft. x 19 ft. and weigh 16,000 lbs. dry.

The cost for the compressor, motor, gear, baseplate and the lube and seal system is \$490,000.00. This would include the basic requirements of API 617 and 614.

For your general information I have included a catalog showing equipment that Elliott builds for the process industries. I have also included Elliott's multi-stage compressor catalog bulletin P-25A. We appreciate your interest in Elliott Company equipment. Please feel free to contact us should you need any additional information regarding this particular application.

Very truly yours,

ELLIOTT COMPANY
A Division of Carrier Corporation

John A. Gegus
Senior Field Engineer

JAG/lp
Attachment

RECORD OF TELEPHONE QUOTATION
(BUDGET ESTIMATE)
PUMPS

Project 231-C

Goulds Pumps, Inc.
Whittier, Ca.
(213) 692-6901

All Pumps to Include: a) Pump
b) TEFC Motors
c) Base Plates
d) Falk Couplings
e) Durametallic Mech. Seals
f) All Flanged Connections

See Pump Summary Sheet for Additional Details of Pumps.

<u>Item No.</u>	<u>Unit Cost</u>	<u>No. of Units</u>	<u>Extended Cost</u>
P-100 A,B	\$ 4,450.00	x 2	\$ 8,900.
P-101 A,B	\$ 1,057.00	x 2	\$ 2,114.
P-102 A,B	\$19,980.00	x 2	\$39,960
P-103 A,B	\$ 1,739.00	x 2	\$ 3,478.
Total Extended Cost			<hr/> \$54,452.

Delivery	P-100 A,B	-	16 Wks.
	P-101 A,B	-	8 Wks.
	P-102 A,B	-	18 Wks.
	P-103 A,B	-	14 Wks.

F.O.B. Shop, Southern California

Per Telephone Conversation with Goulds Sales Rep 12/18/79

HARBISON-WALKER REFRACTORIES

Division of Dresser Industries, Inc.,

2 Gateway Center, Pittsburgh, Pennsylvania 15222

JESS P. HUTCHINSON

PRODUCTS MANAGER - PROCESS MAINTENANCE & DEVELOPMENT
INDUSTRIAL MARKET

November 27, 1979

TELEPHONE 412 - 562 - 6606

Mr. Melvin Miller, Design Engineer
Morgan Engineering Company
2500 Wisconsin Avenue
Downers Grove, Illinois 60515

Dear Mr. Miller:

Thank you for your interest in Harbison-Walker. Since we have been actively involved in supplying refractories to the coal gasification field for many years now, we appreciate this opportunity to serve you.

For meeting the refractory conditions and requirements as outlined in your November 12 letter, we would suggest a 3" hot face lining of our CASTOLAST G high alumina castable, backed up by a 3" insulation of either H-W 40-64 or H-W LIGHTWEIGHT 26.

CASTOLAST G is a high strength, high purity calcium aluminate bonded tabular alumina castable. It resists severely abrasive conditions and maintains stability under reducing and hydrogen atmospheres. These products have performed well in transfer lines and vessels associated with second generation coal gasification pilot plant designs.

For your purposes, we thermally simulated a hydrogen atmosphere of 1650°F., containing 44% volume of hydrogen in a stainless steel pipe with an inside refractory diameter of 10". Using a 3" lining of CASTOLAST G backed by a 3" insulation of H-W LIGHTWEIGHT 26, we found that the outside temperature of the pipe would be approximately 225°F. Using the same hot face lining with H-W 40-64 as the back up, the temperature is closer to 281°F. You should note that both figures were arrived at using an ambient temperature of 70°F. with no wind velocity, and an emissivity of .95.

Again, we appreciate your interest in Harbison-Walker. For further assistance, please feel free to contact us at 412-562-6591.

Very truly yours,

Allen S. Johns
Products Analyst
Process Maintenance & Development

ASJ/jmp

HUDSON PRODUCTS CORPORATION

CABLE-HUPCO • TELEX-775404 • AREA CODE 713 785-4000

POST OFFICE BOX 36400
HOUSTON, TEXAS 77036

December 3, 1979

Mittelhauser Corporation
22600-B Lambert Street
Suite 802
El Toro, California 92630

REF: Contract 231-C
DOE/METC
FIN-FANS
HUDSON REF: 79-150

Attention: Mr. Scott Heffley

With reference to our telecon of November 30, 1979, we are pleased to submit estimates covering two (2) air cooled heat exchangers. The information is as follows:

Item	E-100	E-102
Fluid	Water	Water
Duty-MMBTU/Hr	56.0	2.3
Temperature-In/out F	318/140	228/140
Air Temperature F	98	98
Plot Area-Ft	33 x 33	7 x 11
Bare Surface	5300	310
Motors-HP	4-25	1-7.5
Materials	C. Stl	C. Stl
Est. Price FOB Factory	\$98,000	\$10,000
Add for AV Hubs	\$ 1,000 Ea.	\$ 1,000 Ea.
Approximate Weight	100,000#	7,500#

Freeze protection will be required, the extent will depend on alternate operating conditions. For complete winterization including steam coils and external recirculation, the addition would be 50-70 percent of the base price.

Please advise us if you require any additional information.

Yours very truly,

HUDSON PRODUCTS CORPORATION

Robert Reichhelm

RECORD OF TELEPHONE QUOTATION
(BUDGET ESTIMATE)
COMPRESSOR

Project 231-C

Ingersoll-Rand
Los Angeles, Ca.
Dan Tooter

Offered Recip. Machine

2 Cylinder: 19 In. Cyl. Dia. x 11 In. Stroke

1450 Machine HP Required

Electric Motor Driven w/ Speed Decreasing Gear to
Compressor 450 RPM Required

Motor HP = 1750

Compressor With; Gear, Motor, Lube System & Pulsation Bottles

\$450,000.00

Wt. $\approx$ 50,000. Lbs.

11/9/79

K . I

221 EAST WALNUT STREET • PASADENA, CALIF. 91101 • TELEPHONE (213) 577-1600 • CABLE ADDRESS: KINTECH

November 16, 1979

Mittelhauser Corporation
22660-B Lambert Street
Suite 802
El Toro, California 92630

Attention: Mr. Scott Heffley

Subject: Estimate for Department of Energy

Dear Sirs:

Confirming today's telephone conversation, the estimated price for one fired heater, 62.5 MM BTU/hr absorbed duty, 285°F @ 268 psig inlet, 1825°F outlet, processing a high-hydrogen gas, will be:

\$700,000 (Seven Hundred Thousand U. S. Dollars)*

Please note the accuracy of this estimate is $\pm 15\%$.

Thank you for considering KTI, and if we can be of further assistance, please advise.

Very truly yours

KTI CORPORATION

Bruce W. Fields
Furnace Division

BWF:sm

* KNOCKED DOWN, F.O.B. SHOP.

ADD \$50,000.-\$60,000. FOR INSTRUMENTS & CONTROLS.

November 20, 1979

Reply to:
REGIONAL OFFICE
SALES AND TECHNICAL SERVICES
SUITE NO. 1
6481 ORANGETHORPE AVE.
BUENA PARK, CALIFORNIA 90620
PHONE 714-739-8853

Mittlehauser Corp.
22600-B Lambert St. Ste. 80L
El Toro, Calif. 92630

Attn: Scott Hefley

Ref: D.O.E. Coal Gas Project - Morgantown, W. Va.
Koch Budgetary Proposal #79-CPE-132

Dear Sir:

In accordance with your request, we are pleased to submit budgetary price and design for a Koch Flexi-Venturi scrubbing system. Our proposal follows:

One (1) Koch Flexi-Venturi scrubber and Mist Eliminator separation in accordance with enclosed sketch. Material of construction will be 316L stainless steel. Vessels shall be provided with necessary connections for level control, and process stream nozzles. Pressure drop across the throat shall be manually controlled. Unit shall be supplied with legs for installation by customer on concrete foundation by others. Instrumentation, piping and pump are not included in this proposal.

Unit Price . . . \$56,720.00

Terms:

Revise to \$60,000.00 to cover missed design temp. Par Telephone

10% of contract price upon authorization to proceed. *w/ J. E. W. 12/6/79*
20% of contract price upon receipt of Koch approval drawings.
70% of contract price upon shipment of equipment.

All prices are F.O.B. fabrication point and are exclusive of sales, use, excise, personal property or similar taxes. Freight is not included in the price and will be billed collect.

Delivery: 8-12 weeks for submittal of approval drawings.
14-20 weeks after receipt of approval drawings.

The information provided in this proposal is to be used for budgetary purposes. Upon receipt of a written inquiry specification, we would welcome the opportunity of submitting

a firm quotation based upon the applicable project requirements.

Please call if you require additional information.

Very truly yours,

KOCH ENGINEERING COMPANY, INC.

Joseph O. Ewach
Western Regional Marketing Director

JOE/ak

encl: KAL-3, KPC-2, Sketch

cc: DSW
MM

DESIGN BASIS

Gas Stream = 8200 SCFM at 1750° F and 250 PSIG

- Composition:	N ₂	-	1.02% (by weight)
	H ₂ S	-	1.2 %
	H ₂	-	5.2 %
	H ₂ O	-	16.9 %
	CO	-	41.9 %
	CO ₂	-	32.9 %
	CH ₄	-	.84%

Inlet solids loading - 2 gr/SCFM

- Size distribution

10-60 microns	=	11% (by weight)
5-10 microns	=	40%
1-5 microns	=	39%
1-1 microns	=	9%
0.1 microns	=	1%

Scrubbing medium: water at 12-15 GPM

Pressure drop: 20 PSIG for 95+% removal efficiency.

HIGH ENERGY VENTURI SCRUBBER

RECORD OF TELEPHONE QUOTATION
(BUDGET ESTIMATE)

Project 231-C

FLARE SYSTEM

National Airoil Burner Co.
Philadelphia, Pa.
(215) 743-5300

Approx. 125.ACF Gas in a test loop at 250 psig & 1750°F.

$$= (125) \left(\frac{520}{2210} \right) \left(\frac{264.7}{14.7} \right) \left(\frac{16.96}{379.5} \right) \text{ Lbs.} = 23.67 \text{ Lbs.}$$

Blow down in 1 minute = 1,420.Lbs./Hr.

Gas Properties:

Component	Vol. %
-----------	--------

N ₂	0.06
H ₂ S	1.13
H ₂	44.03
H ₂ O	15.9
CO	25.34
CO ₂	12.66
CH ₄	0.88

Temp. = 1750°F
Press. = 250 psig.
M.W. = 16.96

Need: Non-smokeless Flare
Fluidic Seal
Self-Supporting Stack
Ignition Panel

Per Telephone w/ N.A.O. 12/20/79

Cost-----\$16,945. F.O.B. Phila., Pa.

Wt.-----2400 Lbs. Installed, 2800 Lbs. Ship.

Delivery----Dwgs.-4 Wks. A.R.O.; Equip.-
14 Wks. A.D.A.

Materials---(As Shown)

Support-----Self (As Shown): O.K. For
U.B.C. E/Q Zone I & 90 mph
Exposure Class C Wind.

PETROCARB, INC. 200 BROADACRES DRIVE, BLOOMFIELD, N.J. 07003

CABLE ADDRESS CABOCARB BLOOMFIELDNEWJERSEY

TELEPHONE (201) 893-0200

TELEX 642609

December 21, 1979

Morgan Engineering Company
2500 Wisconsin Avenue
Downers Grove, Illinois 60515

Attention: Mr. Melvin Miller, Design Engineer

Gentlemen:

This is in reference to your letter of November 14, 1979 and to confirm subsequent telephone conversation of December 3rd in which we indicated that we believe it could be a possible application for a Petrocarb Feed System, suitably engineered, to feed fly ash as outlined in your letter.

There are two major problem areas:

1. Flowability of the fly ash — A test sample would be required. We would also require the bulk density and particle density.
2. Variation of feed rate to correspond to gas flow in the test loop — Programmed modulation of the controls of the two basic characteristics of the Petrocarb system, variation of feed rate with a) differential pressure and b) injection (diluter) air (or gas) flow — see Figure No. 1 of the Petrocarb Pneumatic Feeding System sent you earlier this week — would have to be designed to provide the desired feed pattern.

per test loop S.T.N.

We would suggest a budget price of \$200,000.00 for a feed system to meet your requirements.

Should the project mature, we would appreciate hearing further from you.

Very truly yours,

PETROCARB, INC.

S. Lampert
Vice President

THE PETROCARB PNEUMATIC FEEDING SYSTEM

PETROCARB, INC.
200 Broadacres Drive
Bloomfield, New Jersey 07003

THE PETROCARB PNEUMATIC FEEDING SYSTEM

A. Historical Highlights

Pneumatic injection equipment and systems for the feeding of solids have been supplied by Petrocarb since 1959. Petrocarb has provided literally hundreds of injectors for use in feeding treating agents, such as graphite, into molten iron in foundries all over the world.

Petrocarb pioneered the first commercial sized blast furnace coal injection system at the Hanna Furnace Corporation No. 2 Furnace in 1961. The system fed minus 1/8" x 0 coal to each tuyere of the furnace. This was a merchant iron plant and economics unfortunately dictated the closing down of this furnace. The coal injection operation was described in a paper 1/ by Strassburger et al in 1962.

In 1963, the National Coal Board in England purchased a Petrocarb Coal Injection System which was installed at the Stanton & Staveley Ltd. No. 5 Blast Furnace. This system was operated successfully for about three years and was the subject of a paper 2/ by E.M. Summers entitled Engineering and Design Considerations of Coal Injection from which the following is quoted:

".....the original plant has operated continuously and completely automatically for a period of 14 weeks....."

* * *

".....we have demonstrated that the pneumatic system can be operated for very long periods completely automatically and that it can be regarded as a reliable ancillary part of blast furnace equipment."

Unfavorable economics resulting from the relative costs of coal and fuel oil at the time, plus the discovery of oil in the North Sea, prompted the discontinued operation of the coal injection system and abandonment of a plan to install coal injection systems on blast furnaces throughout the U.K. The injection unit was dismantled and moved to Leatherhead where it has been used in test operations by National Research Development Corporation, London, England, for feeding coal in a pressurized fluid bed combustor experimental program. A portion of this work was sponsored by the U.S. Office of Coal Research and the British Coal Utilization Research Association Ltd. (BCURA) and is covered in an OCR Report. 3/

Since 1967 two zinc slag fuming furnaces have been in substantially continuous operation at Port Pirie, South Australia, using the Petrocarb Injection System. The furnaces require dependable feeding of pulverized coal which serves a dual role of providing heat, and acting as a reducing agent in the process. Each of these two furnaces has thirty submerged tuyeres which are fed with coal from a single injection unit (one for each furnace). This operation was the subject of a paper by I.D. Brett. 4/

The United States Bureau of Mines purchased a Petrocarb Injector System which was used at Morgantown during the early 1960's. In a paper, Development of Coal Feeding Systems at the Morgantown Energy Research Center, Mr. John Mark Hobday, of the Morgantown Energy Research Center stated:

"The system had the capacity to feed coal at a rate of 60 TPH at pressures up to 100 psig. Since this is a sophisticated rate control system, it depends largely on instrumentation. The system performed satisfactorily for a complete series of tests which lasted about four months."

Petrocarb's Injection System is used in a modern copper-nickel plant located in Botswana which uses the Outokumpu Flash Smelting Process. Pulverized coal is being fed to multiple burners to produce heat for the process. It is essential that the coal injection equipment used to feed coal into the burners provide smooth, steady flow and uniform distribution among the burners. In this facility, the coal feed rate is automatically controlled by a single rate-setting on the control panel. The rate control instrumentation automatically adjusts the instrument primarily responsible for the delivery rate of coal. The net weight of coal in the Primary Injector is continuously recorded on a strip-chart so that the operator has visual evidence of the performance of the feeding system.

A copper and nickel smelter complex being constructed in Russia, which also uses the Outokumpu Flash Smelting Process, will utilize Petrocarb Injection Systems for feeding pulverized coal to the process. This application is interesting in that the coal is to be used as a reducing agent for converting sulfur dioxide in the high temperature exit gas from each of two smelters (one copper and the other nickel) to elemental sulfur which will be condensed and recovered in waste heat boilers.

The application of Petrocarb Injection Units for high feed rates has been fully demonstrated in a multiple unit installation in Venezuela where very abrasive iron ore is fed at the rate of about 77 tons per hour in each unit against a pressure of three atmospheres. In a paper by R.T. Whitehead in 1974 ^{6/} reference is made to the units in Venezuela as the reason for the selection of the Petrocarb System by The Lummus Company for use on the Synthane Coal Gasification Project.

Unfortunately the operation of the Synthane Plant has been discontinued. However, a paper ^{7/} entitled The Synthane Process - A Technical and Economic Assessment by A.J. Weiss, C-E Lummus, Bloomfield, New Jersey (published December 1977 - prepared for the United States Department of Energy and the International Conference on Alternative Energy Sources) states that

"A major requirement for coal gasification plants operating under an elevated pressure is a system that can feed the coal at controlled rates in a continuous reliable manner. Such a system was developed for the Synthane Process in cooperation with Petrocarb, Inc. of New York."

* * *

"Its operation has been fully satisfactory and it can now be used in the design of large scale coal gasification plants."

* * *

"The dry coal feed system operating at pressure of 600 psig has been demonstrated for continuous troublefree service."

A description of the feed system is available in a paper, The Petrocarb Pneumatic Feeding System as Applied to the Feeding of Coal in the Synthane Coal Gasification and MHD Power Generation Processes, by Harold Reintjes, President of Petrocarb, Inc., which was presented at the American Institute of Chemical Engineers 70th Annual Meeting in New York City, New York on November 16, 1977.

Petrocarb has supplied many other feeding systems for coal, dolomite, and the like, and is involved with major pilot plant projects on such processes as:

- a) Pressurized fluid bed combustor development, and
- b) MHD reactor development.

A more complete list of Petrocarb's principal sales in this field is shown in Appendix A.

B. Feeding Systems Characteristics

Some of the principal characteristics are:

- a) The capability of feeding continuously at constant and reproducible flow rates for long periods of time
- b) An ability to feed against high back pressure
- c) The system can be scaled up from feed rates of a few pounds per minute for pilot plant operation to several thousand pounds per minute for commercial application
- d) The system can be easily and quickly stopped and started
- e) It can operate with high solids to gas ratios at minimum transport velocities
- f) It can feed materials having a wide range of particle sizes from about 1/4" x 0 down to boiler grind coal. However, the particle size and feed rates must be compatible
- g) It can be fully automated to hold a predetermined set-rate or made to follow a modulating feed rate demanded by the downstream process.

3. Description of Petrocarb Injection System

A simplified flow diagram of a typical system for feeding against intermediate pressures is shown in Figure No. 1. Modifications of this system are used depending on the particular application. The Petrocarb Injection System provides continuous and automatic injection of prepared solids into a process reactor at any designated rate. The Primary Injector is the heart of the system. This unit is a pressure vessel of proprietary design. It can be supplied with multiple feed outlets, one for each injection nozzle of a reactor, or with a single feed outlet. In our preferred arrangement using multiple feed points, each of the feed outlets from the Primary Injector has an individual injection air line equipped with both gas and solids flow indicating instruments. After initial adjustments are completed substantially equal quantities of solids will be delivered to each nozzle.

The total injection rate is a direct function of the differential pressure between the continuously pressurized Primary Injector and the point of delivery of the solids. The characteristic is stable, smooth, and repeatable, thereby providing a means of controlling solids feed rate without the use of moving mechanical parts, with their attendant problems. The Primary Injector is usually mounted on load cells which provide necessary signals for a weight rate control system.

Above the Primary Injector is the Storage Injector, which automatically replenishes the solids fed from the Primary Injector without interrupting or disturbing the injection process. This functions as a lock hopper. Lock hoppers, traditionally, have been somewhat unreliable for the same reasons that one cannot assume that a vessel or storage bin, provided with an inlet and outlet, assures that solids will flow from the vessel when the outlet valve is opened. Petrocarb's Storage Injector overcomes such problems, and is a dependable, integral part of the system. When the Storage Injector is emptied of material, it is automatically depressurized and refilled either by a feed injector located at grade level below a prepared materials storage bin, or from an elevated storage bin. When a feed injector is used, material from the storage bin is fed and conveyed to a receiver-filter above the Storage Injector where the solids and conveying gas are separated. Solids flow is by gravity into the Storage Injector and the filtered transport gas is discharged to the atmosphere.

The size of the solids batch, mechanical equipment, valves, and time increment for each function are all designed and coordinated to provide feed to the process, up to the maximum design rate, while maintaining a reserve capability in the Primary Injector. All operations are automatic, being controlled by a specially designed logic system. Solids flow in any feed line can be stopped or started by the manual operation of a remote switch for that line. Also the flow can be stopped automatically in an individual line or any desired multiple thereof by programmed process requirements or system safeguards. The feed rate can be commanded to follow a downstream process signal such as temperature, bed level, or production rate.

A section from a strip chart recorder showing the net weight of coal being fed from a Primary Injector mounted on load cells, with the system functioning in the equivalent of the manual mode, is shown in Figure No. 2. Note the smooth line with only one irregularity which was caused by automatic stopping of coal feed for a brief period because of a process requirement.

In some applications, for example where the solids preparation facility is located a substantial distance from the injection facility, or where a headroom problem prevents the installation of an elevated storage bin, it is advisable to integrate a "feed injector" into the system. Such a system is illustrated in Figure No. 3 which applies to the feeding of coal for a Department of Energy (DOE) MHD test facility in Butte, Montana.

The process and plant layout requirements must be examined and the most effective system designed for each installation.

R E F E R E N C E S

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3. National Research Development Corporation, London, England (NRDC) "Pressurized Fluidised Bed Combustion, R & D Report No. 85, Interim No. 1", for the Office of Coal Research (OCR), U.S. Department of the Interior - 1974
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6. Whitehead, Richard T., "The Synthane Coal Gasification Process of Coal Feeding and Char Removal Systems", AIChE Annual Meeting 1974
7. Weiss, A.J., "The Synthane Process - A Technical and Economic Assessment", Prepared for U.S. Department of Energy and The International Conference on Alternative Energy Sources, Miami Beach - 1977

PETROCARB CONTINUOUS INJECTION SYSTEM

Figure No. 1 - Simplified Flow Diagram of a Typical Petrocarb System for feeding against intermediate pressures.

Figure No. 2 - Section from a strip chart recorder showing the net weight of coal being fed from a Primary Injector mounted on load cells.

PETROCARB COAL FEED SYSTEM FOR MHD TEST FACILITY

Figure No. 3

A P P E N D I X A

PRINCIPAL PETROCARB INJECTION SALES

A. ENGINEERED INJECTION EQUIPMENT

<u>Project</u>	<u>Date</u>	<u>Customer</u>	<u>Purpose</u>
E-201	1960	Hanna Furnace Co. Buffalo, N. Y.	Coal Injection into Blast Furnace
E-209	1961	United States Steel Corp. Fairless Hills, Pa.	Ore and Limestone Injection into Open Hearth Furnace
E-213	1962	National Coal Board, England	Coal Injection into Blast Furnace
E-288	1967	Broken Hill Associated Smelters, Australia	Zinc Fuming Furnaces
E-302	1964	U.S. Bureau of Mines Morgantown, W. Virginia	Coal Transport - Test Installation
E-309	1970	Orinoco Mining Co., Venezuela	Iron Ore Injection into Pressurized Reactor
E-314	1965	Republic Steel Company Gadsden, Alabama	Lime Injection into Basic Oxygen Furnace
E-324	1964	Bethlehem Steel Company Bethlehem, Pa.	Feed System for Experimental Iron Oxide Treater
E-329	1967	United States Steel Corp. Universal, Pa.	Coal Injection into Experimental Blast Furnace
E-333	1968	United States Steel Corp. Chicago, Ill.	Coal Injection into Blast Furnace
E-413	1973	Bamangwato Concessions Ltd., Botswana	Coal Injection into Outokumpu Flash Copper/Nickel Smelter
E-434	1973	Esso Research & Engineering Linden, N. J.	Coal and Dolomite Feeders
E-438	1974	U.S. Department of Energy (DOE), Bruceton, Pa. (Customer: The Lummus Co.)	Coal Feed System for Synthane Gasification Pilot Plant

Principal Petrocarb Injection Sales

Project	Date	Customer	Purpose
E-454	1972	IMC Corporation Des Plaines, Ill.	Limestone Feeding System for Pressurized Reactor
E-458	1977 1978	Rauma-Repola Oy Helsinki, Finland	Coal Preparation and Injection Systems for Copper and Nickel Smelters in Norilsk, USSR
E-459	1972	U.S. Department of Energy (DOE) (Bureau of Mines) Bruceton, Pa.	Coal Feeding System for MHD Reactor Pilot Plant
E-533	1977	Curtiss-Wright Corporation Wood-Ridge, N. J.	Coal and Dolomite Feed Systems for Pressurized Fluid Bed Combustor Pilot Plant
E-593	1978	National Coal Board (IEA Services Ltd., U. K.) (Co-sponsors: USA & West Germany)	Coal and Dolomite Feed System for Pressurized Fluid Bed Combustor Pilot Plant
E-618	1978	Kaiser Engineers for U.S. Department of Energy (DOE) Butte, Mont.	Coal Feed System for MHD Test Facility
E-660	1979	Kaiser Engineers for U.S. Department of Energy (DOE) Butte, Mont.	Fly Ash/Seed Material Feed System for MHD Test Facility
E-690	1979	Avco Everett Research Laboratory, Inc. Everett, Mass.	System for Injection of Granular Potassium Carbonate into MHD Combustor
E-559	1979	Italimpianti Genova, Italy	Ore Feeding System for Iron Sponge Pilot Plant
E-640	1979	Curtiss-Wright Corporation Wood Ridge, New Jersey	Coal and Dolomite Feed Systems for Pressurized Fluidized Bed Pilot Plant

Principal Petrocarb Injection Sales

B. INDUSTRIAL MATERIALS DIVISION - INJECTION EQUIPMENT AND SYSTEMS SALES

Project	Date	Customer	Purpose
M-447	1972	Chevrolet Motor Division General Motors Corporation Saginaw-Grey Iron Foundry	Graphite Transfer and Injection System
M-573	1977	General Motors of Canada Ltd. St. Catharines, Ontario, Canada	Coke Transport and Injection System
M-619	1978	The Dalton Foundries, Inc. Warsaw, Indiana	Tuyere (Coke) Injection System
M-624	1977	Central Foundry Division General Motors Corporation Defiance Plant	Calcium Carbide Desulfurization System
M-630	1978	Planet Corporation Saginaw, Michigan	Automated Coke Fines and Calcium Carbide Feeding Systems for Chevrolet Grey Iron Casting Plant
M-636	1978	Central Foundry Division General Motors Corporation Defiance, Ohio	Coke Fines Injection System
M-639	1978	Central Foundry Division General Motors Corporation	Automated Coke Injection System
M-653	1978	Central Foundry Division General Motors Corporation Defiance, Ohio	Coke Fines Injection System
M-662	1979	Ford Motor Company	Coke Fines Injection System at Cleveland Castings Plant
M-675	1979	Gurmendi Sociedad Anonima Buenos Aires, Argentina	Special Injector for Automated Injection System
M-685	1979	Caterpillar Tractor Co. Mapleton, Illinois	Injection Unit for Nodularization and Desulfurization
M-693	1979	Ford Motor Company Michigan Casting Plant Flat Rock, Michigan	Calcium Carbide Pneumatic Conveying System

Principal Petrocarb Injection Sales

C. PETROCARB INJECTOR EQUIPMENT

Following is a sample list of customers using Petrocarb Injector Equipment for the purpose of injecting carbon into electric arc furnaces.

Keystone Steel and Wire Company Peoria, Illinois	Two 150 Ton Capacity Furnaces
Armco Steel Company Kansas City, Missouri	150 Ton Capacity Furnaces
Hoeganaes Division Interlake Corporation Riverton, New Jersey	30 Ton Furnace
Bethlehem Steel Co. Los Angeles, California	100 and 75 Ton Furnaces
Ford Motor Co. Iron Casting Center Flat Rock, Michigan (Swindell-Dressler)	Four 80 Ton Furnaces
Kama River Project USSR (Swindell-Dressler)	Eight Furnaces melting gray iron, each equipped with Carbon Injector
Carpenter Steel Co. Bridgeport, Connecticut	40 Ton Furnace
Hinduston Steel Ltd. West Bengal, India	
Metalexport Poland (Swindell-Dressler)	Melting Cast Iron
Companhia Siderurgica Nacional Brazil	Open Hearth and Electric Arc Furnaces
U. S. Steel Corp. Johnston, Pennsylvania	Steel Foundry
Blaw-Knox Co. East Chicago, Indiana	30 Ton Furnace
Calumet Steel Calumet City, Illinois	30 Ton Furnace

Principal Petrocarb Injection Sales

Union Carbide Corporation
New York, New York

Special injector to demonstrate desulfurization of blast furnace metal by injecting ultra fine ground calcium carbide. Feed rates range up to 600 pounds per minute

Algoma Steel Company
Sault Ste. Marie, Ontario, Canada

Injection of magnesium alloy in electric arc furnace. Injection of deoxidizing and desulfurizing reagents into 100 ton ladles of BOF steel

Armco Steel Co.
Middletown, Ohio

Injector for desulfurizing blast furnace iron by injecting magnesium and lime mixtures at maximum depths in 200 ton capacity hot metal cars

Warren Pipe Division
McWane Cast Iron Pipe
Phillipsburg, New Jersey

Continuous carbon injection into cupola melted iron

Stellite Division
Cabot Corporation
Kokomo, Indiana

Inject magnesium powder and lime mixture to desulfurize super alloy steel in 20 ton arc furnace

U. S. Steel Corporation
Provo, Utah

Full scale facility for desulfurizing blast furnace iron by the injection of calcium carbide

Principal Petrocarb Injection Sales

Mesta Corporation
West Homestead, Pennsylvania

40 Ton Furnace

National Roll Div.
General Steel Industries
Avonmore, Pennsylvania

40 Ton Furnace

John Deere Tractor Works
Waterloo, Iowa

Four 16 Ton Furnaces served by a Petrocarb Automated Carbon Storage Transfer and Injection System. Distance of transfer from Storage Injector to the most remote Primary Injector at the Furnace location is in excess of 200 feet

Ohio Steel Foundry Co.
Lima, Ohio

35 Ton Furnace

Following is a partial list of customers who use Petrocarb Equipment in various other applications of the Injection Process.

Quebec Iron and Titanium Company
Sorel, Quebec, Canada

Carburizing and desulfurizing electrically smelted iron. Annual production rate: 600,000 tons of commercial pig iron

Fuller Company
Manheim, Pennsylvania

Carbon injection into channel injection furnace melting gray iron

Chevrolet Division
General Motors Corporation
Experimental Foundry

Automated continuous injection of carbon into a 20 ton/hour horizontal coreless induction furnace. The Petrocarb System provides automatic refilling of the Primary Injector by transfer from a Storage Injector located some distance away from the furnace area

Sydney Steel Company
Sydney, Nova Scotia, Canada

Special injectors for desulfurizing blast furnace iron. These units can handle granular magnesium powder as well as ultra fine ground lime and calcium carbide

December 11, 1979

MORGAN ENGINEERING CO.
2500 Wisconsin Avenue
Downers Grove, ILL 60515

Attn: Mr. Melvin Miller
Design Engineer

Subj: Fly Ash Feed System for testing coal gasification valve

Dear Mr. Miller:

We have reviewed your letter of November 16 describing the requirements for the fly ash feed system and we feel such a system is, certainly within the capabilities of our organization.

Although considerable engineering and design work would be required, we are proposing a system similar to the one shown on the attached flow diagram.

An outline of our system is as follows:

- ITEM NO. 1 Smoot Pressure Pot (vessel) to allow pressurization of the fly ash pot to a pressure equal to or slightly higher than the estimated 250 psia in your convey line. This is necessary to feed the fly ash into the convey line and to minimize the pressure drop across the rotary airlock feeder. This pressure pot will be operated on a cyclic basis to allow depressurization of fly ash pot when it is necessary to fill pot with fly ash. The pressure pot will be an ASME coded vessel and be complete with level control, inlet valve, fluidizing pads and all necessary controls.
- ITEM NO. 2 Smoot Rotary Airlock Feeder with SCR controlled variable speed drive. Airlock will be designed to withstand system pressure and be of abrasion-resistant design. The abrasive action of fly ash on this feeder is greatly reduced because of the equalization of the pressure across it.
- ITEM NO. 3 Butterfly valve with air cylinder operator.
- ITEM NO. 4 Expansion joint.

- ITEM NO. 5 Transition from expansion joint to 10 in. convey line.
- ITEM NO. 6 Restricting orifice to maintain the pressure pot at a higher pressure than the convey line; or, by some other means to provide clean, unheated gas at a pressure in excess of the pressure in 10 in. test line.
- ITEM NO. 7 Air piping and valves for operation of fly ash feed system.
- ITEM NO. 8 Fly ash feed system control panel.

The above is based on the test loop conditioned outlined in your letter (i.e., 250 psia and 1750°F). Higher operating pressures and temperatures may be feasible, however, we would like the opportunity to reconsider our design under such conditions. For the purpose of our estimate, we are assuming design conditions of the major components to be as follows:

	<u>PRESSURE</u>	<u>TEMPERATURE</u>
PRESSURE POT	325 psig	150°F
ROTARY FEEDER	325 psig	250°F
EXPANSION JOINT	300 psig	1750°F

We are very interested in working with you on this project and will be glad to discuss our concept at your convenience. Certainly, this system will have to be tailored to your specific needs. However, the estimated cost for a system similar to the one outlined above is \$50,000 to \$75,000.

Thank you for your interest in Smoot Co. and we will look forward to hearing from you.

Good luck on your project.

Very truly yours,
SMOOT CO.

David K. Smoot
President

DKS/kc

DETAIL NO.	NO. REQ'D	PART NO.	STOCK	SIZE	MATERIAL	SOURCE
SMOOT COMPANY KANSAS CITY, KANSAS						
FLOW DIAGRAM MORGAN ENGINEERING CO.						
REVISIONS	DATE	ENG. NO.	DATE: 12-11-74			
REMARKS	DATE	ENG. NO.	DWG. NO. 1000			
10" CONVEY LINE (BY MORGAN)			SCALE: 1" = 10'			
10" CONVEY LINE (BY MORGAN)			APPROVED: [Signature]			

RECORD OF TELEPHONE QUOTATION
(BUDGET ESTIMATE)
LARGE MOTORS

Project 231-C

U.S. Motors, Div. of Emerson Electric
Orange, Ca.
(714) 639-9752

3Ø/60 Hz 3600 R.P.M.

Horsepower	Open Drip Proof Cost	
	<u>2300V</u>	<u>4160V</u>

1500	\$33,333.	+10%
1750	\$35,941.	+10%
2000	\$56,100.	+7.5%
2250	\$58,400.	+7.5%

TEFC Cost

Only go up to
500 H.P.
on T.E.F.C.

(List Prices as of 11/16/79; O.E.M. Purchasers, -19%)

General Electric
Alhambra, Ca.
(213) 572-5200

2300V/3Ø/60 Hz, 3600 R.P.M.

Horsepower	Open Drip Proof Cost	TEFC Cost
1500	\$25,000.	\$50,000.
1750	\$26,000.	\$52,000.
2000	\$41,000.	\$82,000.
2250	\$43,000.	\$86,000.

frame
size charge

Note: Custom vessel fabricators did not want to participate in response to telephone inquiries as they did not feel accuracy could be maintained.

From Process Plant Estimating, Evaluation & Control,
Kenneth M. Guthrie, c 1974, (Mid-1970\$, Escalate to End 1979)
(Used 2.16X Escalation Factor)

See Vessel Data/Summary for Additional Information.

V-101:	Base Cost	- \$12,000.	(6½'Ø x 26'T/T)
	Shell Mat'l.	- x 2.3	(304 S.S. Clad)
	Pressure Factor	- x 2.0	(300 psi)
	Escalation	- x 2.16	
	Total Vessel Cost	- \$119,200.	
	Valve Trays	- \$1,300.	
	(10 trays,		
	24" spacing)	x { 1.0	(24" spacing)
		+0.3	(Valve trays)
		+1.5	(S.S. Mat'ls.)
		x 2.16	
	Total Cost Trays	\$7,860.	(Installed)
	Total Cost V-101	= <u>\$127,060.</u>	
V-102:	Base Cost	- \$1,600.	(2½'Ø x 7-3/4'T/T)
	Shell Mat'l.	- x 1.0	(C.S.)
	Pressure	- x 1.55	(175 psi. for Corr. Allow.)
	Escalation	- x 2.16	
	Total Vessel Cost	\$5,360.	
	Sieve Trays	\$100.	
	(3 trays,		
	24" spacing)	x { 1.0	(24" spacing)
		+0.0	(Sieve trays)
		+0.0	(C.S.)
		x 2.16	
	Total Cost Trays	\$216.	(Installed)
	Total Cost V-102	= <u>\$5,576.</u>	

(Cont.)

12/18/79

BUDGET ESTIMATE
VESSELS (Page 2 of 2)

Project 231-C

V-103:	Base Cost	-	\$3,000.	(3½'Ø x 10' T/T)
	Shell Mat'l.	- x	1.0	(C.S.)
	Pressure	- x	2.8	(500 psi. for Corr. Allow.)
	Escalation	- x	2.16	
	Total Vessel Cost		\$18,100.	

Total Cost V-103 = \$18,100.

V-104:	Base Cost	-	\$ 700.	(1½'Ø x 4½' T/T)
	Shell Mat'l.	- x	1.0	(C.S.)
	Pressure	- x	2.0	(250 psi. for Corr. Allow.)
	Escalation	- x	2.16	
	Total Vessel Cost		\$3,025.	

Total Cost V-104 = \$3,025.

12/18/79

BUDGET ESTIMATE

Project 231-C SHELL & TUBE EXCHANGER E-101

From Process Plant Estimating, Evaluation & Control,
Kenneth M. Guthrie, c 1974, (Mid-1970\$, Escalate to End 1979)
(Used 2.16X Escalation Factor)

From Exchanger Size Estimate:

1090.FT², U-Tube, Carb. Stl. w/ 1/4" Corrosion Allowance

Prob. S.S. Tubes., 12' Tubes.

Base Cost	- \$10,000.	(1970 \$'s)
Design Factors - x	<div style="display: inline-block; vertical-align: middle;"> <div style="font-size: 3em; vertical-align: middle;">{</div> <div style="display: inline-block; vertical-align: middle;"> 0.842 +0.042 +0.10 </div> </div>	(U-Tube) (200 psi. tube) (634 psi shell w/ corr. allow.) (S/T Mat'l. C.S./S.S.)
Material	- x 2.2	
Escalation	- x <u>2.16</u>	
Total Cost E-101	= \$46,760.	

12/19/79

7.2 EQUIPMENT AND PIPING SPECIFICATIONS

7-51

PUMP SUMMARY

MITTELHAUSER
corporation

PROJECT NO. 231-C CLIENT MORGANTOWN ENERGY TECHNOLOGY CENTER

PAGE 1 OF 1 PAGES

UNIT Hot Dirty Gas Control Valve Test Facility

DONE BY S.E.Heffley REVISION NO. 0 DATE 12/12/79

ITEM NO.	P-100A, B	P-101A, B	P-102A, B	P-103A, B		
SERVICE	BYPASS LOOP VENTURI RECIRC.	FLASH DRUM BOTTOMS.	DIRECT. CON- TACT COOLER RECIRC.	SOUR CONDENSATE RECIRC.		
NUMBER SERVICE	ONE	ONE	ONE	ONE		
NUMBER SPARE	ONE	ONE	ONE	ONE		
LIQUID PUMPED	H ₂ O	H ₂ O+ SOLIDS	H ₂ O	H ₂ O		
TEMPERATURE °F	318	228	318	140		
SP.GR. @ P.T.	0.908	0.952	0.908	0.984		
VISC. @ P.T.	CP					
GPM PER PUMP @ P.T., SERVICE	11.	37.2	746.6	9.		
GPM PER PUMP @ P.T., DESIGN						
PRESSURE DISCHARGE PSIG	335.	35.	344.	346.5		
SUCTION PSIG	156.25	2.2	123.8	16.6		
DIFFERENTIAL PSI	178.75	32.8	220.2	329.9		
DIFFERENTIAL FT.	455.	80	560.	775.		
NPSH AVAILABLE FT.	397.5	5.4	315.	39.		
NPSH REQ'D. @ RATING	7.5	4.75	19.5	2.		
HYDRAULIC H.P. @ RATING	1.15	0.72	95.9	1.73		
B.H.P. @ RATING	3.4	1.35	133.	3.9		
MAX. B.H.P. @ DESIGN SP.GR.						
PUMP MANUFACTURER	GOULDS	GOULDS	GOULDS	GOULDS		
MFGRS.: MODEL	3935	3199	3316	3333		
SIZE	BP20-18	1x1½-6	4x6-11	CB10-35		
SUPPT. (C.L., FOOT, BRACKET, VERT.)						
OVERHUNG IMPELLER (YES/NO)						
NO. OF STAGES	18	1	2	35		
SPEED R.P.M.	3500	3500	3550	3500		
MATERIALS: CASE	S.S.	C.S.	304 S.S.	C.S.		
IMPELLER	S.S.	C.S.	304 S.S.	C.S.		
COUPLING	FALK	FALK	FALK	FALK		
WATER COOLED: BEARINGS	-	-	YES	-		
STUFF. BOX	YES	YES	YES	NO		
PEDESTAL	-	-	-	-		
DRIVER (MOTOR, TURB., ENGINE)	MOTOR	MOTOR	MOTOR	MOTOR		
MANUFACTURER			-	-		
TYPE						
ENCLOSURE	TEFC	TEFC	TEFC	TEFC		
B.H.P./R.P.M.	5/3600	1.5/3600	150/3600	5/3600		
ELECT. VOLTS/PH./CYC.	460/3/60	460/3/60	2300/3/60	160/3/60		
STEAM: SUPPLY PRESS. PSIG	N/A	N/A	N/A	N/A		
SUPPLY TEMP. °F	"	"	"	"		
EXHAUST PRESS. PSIG	"	"	"	"		
CONSUMPTION KW						
SHIPPING WT., PUMP & DRIVER						

PROJECT NO. 231-C CLIENT MORGANTOWN ENERGY TECHNOLOGY CENTER PAGE 1 OF 1
UNIT HOT DIRTY GAS CONTROL VALVE TEST FACILITY
DONE BY S. E. HEFFLEY REVISION NO. 0 DATE 12/12/79 PAGES

ITEM NO.	E-100	E-102			
SERVICE	DIRECT CONTACT COOLER RECIRCULATION	SOUR FLASH GAS CONDENSER			
DUTY, 10 ⁶ BTU/HR.	56.	2.3			
TOTAL SURFACE, SQ. FT. PER BAY BARE	2650	310			
TYPE (OPEN SECT., FIN TUBE)	FIN	FIN			
NO. OF BAYS PER UNIT	2	1			
TUBE SIDE: FLUID (V OR L)					
LBS/HR. TOTAL	282,000	2,211			
LBS/HR. COND. OR VAP.	-	2,200			
TEMP. INLET °F	318	228			
TEMP. OUTLET °F	140	140			
DESIGN TEMP. °F	350	350			
PRESS. DROP PSI	2	2			
OPER. PRESS PSIG	335	5.3			
DESIGN PRESS PSIG	380	30			
CORR. ALLOW. IN.					
NO. OF PASSES					
FAN SIDE					
LBS/HR. AIR FLOW					
FORCED/INDUCED DRAFT	FORCED	FORCED			
AIR TEMP. INLET °F	98	98			
AIR TEMP. OUTLET °F					
FANS PER BAY	2	1			
HP PER FAN	25	7.5			
BELT OR GEAR DRIVE	BELT	BELT			
TOTAL NO. BAYS FOR SERVICE	2	1			
TOTAL HP FOR SERVICE	100	7.5			
TRANSFER COEF., CLEAN					
TRANSFER COEF., SERVICE					
FOULING RESISTANCE					
TUBE LGTH., FEET	32	10			
TUBE O.D., IN. x GAUGE	1 x 14	1 x 14			
TUBE PITCH & LAYOUT	2½"Δ	2½"Δ			
MATERIALS:					
HEADERS	S.S.	S.S.			
TUBES	S.S.	S.S.			
CODE REQUIREMENTS					
WINTERIZING	YES	YES			
MANUFACTURER					
MFGRS. DESIGNATION					
TOTAL WEIGHT, DRY.	100,000 lbs	7500 lbs			

PROJECT NO. 231-C CLIENT MORGANTOWN ENERGY TECHNOLOGY CENTER

PAGE 1 OF 1 PAGES

UNIT HOT DIRTY GAS CONTROL VALVE TEST FACILITY

DONE BY S.E. HEFFLEY REVISION NO. 0 DATE 12/18/79

ITEM NO.	K-100	K-100
SERVICE	CASE I TEST GAS	CASE II TEST GAS
STAGE	5	5
NUMBER SERVICE	1	1
NUMBER SPARE	0	0
GAS HANDLED	TEST GAS	TEST GAS
MOLECULAR WEIGHT	16.747	16.747
WEIGHT FLOW Lb/HR	61,160	15,620
INLET CONDITIONS		
PRESSURE, PSIA	164	40
TEMPERATURE °F	149	141
Cp/Cv	1.374	1.374
COMPRESSIBILITY	1.	1.
SUCTION VOLUME, ACFM	2430	2505
DISCHARGE CONDITIONS		
PRESSURE, PSIA	292	85
TEMPERATURE, °F	284	330
Cp/Cv		
COMPRESSIBILITY	1.0	1.0
B.H.P. @ SERVICE	1700	550
MAX. B.H.P. @ DESIGN (% OF SERVICE)		
EFFICIENCY AT SERVICE	0.75	-
EFFICIENCY AT DESIGN		
MFGRS. SIZE AND MODEL		
TYPE: (CENT., RECIP., P.D., AXIAL)	CENT.	CENT.
MATERIALS: CASE OR CYLINDERS	CAST. STL	CAST. STL
BLADES OR PISTONS (STAINLESS STEEL)	17-4 P.H.	17-4 P.H.
COUPLING		
DRIVER (MOTOR, TURB., ENGINE)	ELEC. MTR	ELEC. MTR
MANUFACTURER		
TYPE	INDUCTION	INDUCTION
ENCLOSURE	TEFC	TEFC
B.H.P./R.P.M.	1750/3600	1750/3600
ELECT., VOLTS/PH./CYC.	2300/3/60	2300/3/60
STEAM: SUPPLY PRESS. PSIG	N/A	N/A
SUPPLY TEMP. °F	N/A	N/A
EXHAUST PRESS. PSIG	N/A	N/A
CONSUMPTION KW OR LBS/HR	N/A	N/A
SHIPPING WT., WITH DRIVER		
REFERENCE FOR GAS		
COMPOSITION:		

PROJECT NO. 231-C CLIENT MORGANTOWN ENERGY TECHNOLOGY CENTER
UNIT HOT DIRTY GAS CONTROL VALVE TEST FACILITY
DONE BY S.C. HEFFLEY REVISION NO. 0 DATE 12/27/79

PAGE 1 OF 6 PAGES

ITEM NO.		V-100A,B,C	V-101	V-102	V-103	V-104	
SERVICE		VENTURI SCRUBBER SEPARATOR	DIRECT CONTACT COOLER	PURGE WATER FLASH DRUM	COMPRESSOR SUCTION DRUM	SOUR COND. KNOCK OUT DRUM	
POSITION(HORIZ.OR VERT.)		VERT.	VERT.	VERT.	VERT.	VERT.	
INSIDE DIAMETER,	IN.	42	78	30	42	18	
LENGTH(TANG.TO TANG.)	FT. & IN.	6'-0"	26'-0"	7'-9"	10'-0"	4'-6"	
NO. OF TRAYS: BUBBLE CAP							
CHIMNEY				1			
OTHER		MIST PAD	10-VALVE	2-VALVE	MIST PAD		
TRAY SPACING,	IN.	-	24	24	-	-	
NORMAL OPER. PRESS.,	PSIG	245	195	5	164	2	
NORMAL OPER. TEMP.,	°F	331	318	228	149	140	
DESIGN PRESSURE	PSIG	305	305	30	305	30	
DESIGN TEMP.,	°F	1750	350	350	300	300	
SHELL	REQ. THICK.,	IN.					
	CORR. ALLOW.,	IN.	0	0	1/8	1/4	1/8
	TOTAL THICK.,	IN.					
TOP HEAD	TYPE						
	REQ. THICK.,	IN.					
	CORR. ALLOW.,	IN.	0	0	1/8	1/4	1/8
	TOTAL THICK.,	IN.					
BOTTOM HEAD	TYPE						
	REQ. THICK.,	IN.					
	CORR. ALLOW.,	IN.	0	0	1/8	1/4	1/8
	TOTAL THICK.,	IN.					
SUPPORTS	SKIRT.	HT./THK.					
	SADDLES						
MATLS.	SHELL & HEADS	316L S.S.	304L CLAD	CARB. STL.	CARB. STL.	CARB. STL.	
	SKIRT OR SADDLES						
	TRAYS		304L S.S.	CARB. STL.			
	LINING						
RADIOGRAPHED	YES OR NO						
STRESS RELIEVED	YES OR NO						
CODE STAMP							
OTHER SPECS.							
		WITH ME-100 A,B,C					
INSULATION	YES OR NO						
SHOP COAT PRIMER	YES OR NO						
WEIGHT LESS INTERNALS							
WEIGHT WITH INTERNALS							
REFERENCE DWGS.							

V-100 A,B,C with ME - 100 A,B,C.

Design Pressure
= 305 psig.

Design Temperature
= 1750°F

Material:
All 316L S.S.

V-101

Design Pressure
= 305 psig.

Design Temperature
= 350°F

Materials:

Vessel & Nozzles
304L or
304L Clad
on C.S.

Internals
304L

V-102

Design Pressure
= 30 psig.

Design Temperature
= 350°F

Materials:

Vessel & Nozzles
C.S. w/ 1/8" C.A.

Internals
C.S. or S.S.

V-103

Design Pressure
= 305 psig.

Design Temperature
= 300°F

Materials:
C.S. w/ $\frac{1}{4}$ " C.A.

V-104

Design Pressure
= 30 psig.

Design Temperature
= 350°F

Materials:
C.S. w/ 1/8" C.A.

ME-102

SOLIDS RECEIVING & LOADING PACKAGE

MORGAN ENGINEERING CO.

Mittelhauser Project #231-C
Morgantown Valve Test Facility Design

Refractory Lined Pipe

Summary of findings from: M.H. Detrick, Gray Tool Co., Illinois
Pipe Supply, Johnson Pipe Supply, and Southern Technical Service

Description of pipe runs:

1. I sent an inquiry to M.H. Detrick Co. for their specification and estimated cost for a piping system as required for the Morgantown test facility. In a letter dated Jan. 9, 1980 Mr. Favia from Detrick gave me a quotation on the cost of pipe as I described.
2. At the time I contacted Detrick Co., there was no physical layout of the facility. The lengths of the pipe runs were not accurately sized, although the directions of the pipe runs and fittings required were known.

3. The quotation Mr. Favia gave me was based on using carbon steel pipe as an outer shell with flanged connections and stainless steel gaskets.
4. After discussions with Bill Seward concerning flanged connections and the unsuitability of flanged connections with a high hydrogen atmosphere, I got the following information from Mr. Frank Lindberg a representative of Gray Tool pertaining to the cost of Grayloc connections:

Nominal pipe size	Item description	Cost
12"	Hub	\$2,600.00 for 316 S.S.
12"	Clamp & Bolts	\$1,000.00 for Carbon Steel
12"	Seal Ring	\$480.00 for 316 S.S.
20"	Hub	\$5,100.00 for 316 S.S.
20"	Clamp & Bolts	\$2,600.00 for Carbon Steel
20"	Seal Ring	\$1,500.00 for 316 S.S.
24"	Hub	\$6,000.00 for 316 S.S.
24"	Clamp & Bolts	\$3,800.00 for Carbon Steel
24"	Seal Ring	\$2,200.00 for 316 S.S.

Larry Hovey had recommended A.I.S.I. 310 stainless steel for the piping material. I had asked Mr. Lindberg for prices of connectors made out of the 310 material but he gave the prices for the 316 material because that was readily available information and according to Mr. Lindberg connectors in the sizes we are talking about are not shelf items. The prices for a connector made out of 310 stainless steel instead of 316 stainless steel is not much different because the connectors would have to be made per order in either case. The prices listed for 20" diameter and 24" diameter connectors are a result of a conversation with Mr. Dick Roberts of Southern Technical Service. Mr. Roberts had said that he didn't have time for a complete cost analysis for the piping system but instructed me to gather information on 20" and 24" diameter pipe and fittings and he would supply costs for refractory lining that size pipe.

5. Mr. Favia provided me with a cost of \$111.29 per ft. for 12" schedule 40 316 stainless steel pipe. The carbon steel pipe used in the original quotation for the lined pipe costs from \$8.00 to \$10.00 per foot. The cost for the refractory lined pipe will increase by at least \$100.00 per foot due to the increased cost of the material. The price will in fact be even more because of the increased cost of fabricating (mounting the hubs for the "Grayloc" connectors) stainless steel pipe. So, I would estimate the cost of the pipe as follows:

Original cost from Detrick Quote: (1) 15'-0" length = \$1875.00
or \$125.00 per foot

Cost of Stainless Steel Pipe: \$125.00 per foot plus approximately \$111.00 per foot for
Stainless Steel = \$236.00 per foot

6. I would estimate the total cost of the piping as follows:

Section 1 45'-0" less 10'-0" (Mr. Favia listed a 10" elbow as having a 4'-11" radius) or 35'-0" with Grayloc connectors at either end and one in the center.

Cost is: Pipe = 35 X \$236.00 = \$8,260.00
Connectors = 3 X \$6680.00 = \$20,040.00

Total \$28,300.00

Section 2 33½ ft. less 5 ft. for an elbow and 2 ft. for a tee (also information provided by Mr. Favia) and (3) connectors.

Cost is: Pipe = 26.5 X \$236.00 = \$6,254.00
Connectors = 3 X \$6680.00 = \$20,040.00

Total \$26,294.00

Section 3 28 ft. less 4 ft. for (2) elbows and (3) connectors.

Cost is: Pipe = 24 X \$236.00 = \$5,664.00
Connectors = 3 X \$6680.00 = \$20,040.00

Total \$25,704.00

Section 4 12½ ft. less 2 ft. for (1) tee and 5 ft. for (1) elbow and (2) connectors

Cost is: Pipe = 5½ X \$236.00 = \$1,298.00
 Connectors = 2 X \$6680.00 = \$13,360.00

Total \$14,658.00

Section 5 24 ft. less 2 ft. for (1) tee (since there are three similar lines the cost will be three times the cost of one pipe)

Cost is: Pipe = 24 X \$236.00 = \$5,664.00
 Connectors = 2 X \$6680.00 = \$13,360.00

Total X (3) \$57,072.00

Section 6 5½ ft. plus two connectors (since there are three similar lines the cost will be three times the cost of one pipe)

Cost is: Pipe = 5.5 X \$236.00 = \$1,298.00
 Connectors = 2 X \$6680.00 = \$13,360.00

Total X (3) \$43,974.00

Tee's There are two required at an estimated cost of \$2543.00 each.

Cost is: Tee's = 2 X \$2543.00 = \$5,086.00

Elbows There are three required at an estimated cost of \$2460.00 each.

Cost is: Elbows = 3 X \$2460.00 = \$7,382.00

Total estimated price for entire refractory pipe installation would be \$208,470.00.

7. I never did hear from Mr. Roberts from Southern Technical Service. Everytime I called Mr. Roberts, he was either out of office or busy and he would call me back.

TYPICAL CROSS SECTION OF
REFRACTORY LINED PIPE

TYPICAL PIPE COUPLING
GRAYLOC COUPLING OR EQUIVALENT

MORGAN ENGINEERING CO.

7.3 INSTRUMENTATION ISSUES

7.3.1 Programmable Controller

The use of a programmable controller may be desirable for this facility because:

- The use of local pneumatic control loops results in different control loops not being directly related. Implementation of a central programmable controller would allow total system integration.
- The ability to perform control operations remotely from a central control board provides redundancy of control for increased system reliability.
- A central controller can also aid the operator in the control room monitor to overall system performance. This is especially important while changing test valves.
- A programmable controller has the capability of providing automatic sequencing for system shut down or start up. This can be of vital importance in an emergency situation.

In keeping with the aforementioned philosophy, the Tenor Model 716 PC was recommended in Table 5.8 for use as an optional controller, timer and cycle generator. The Tenor is an industrial oriented, rugged, flexible and versatile device ideally suited for service in the HDGCV Test Facility. Although it is anticipated that data manipulations will be performed by the METC data acquisition system, the controller can be programmed to do that as well.

7.3.2 Mass Spectrometry

Mass spectrometry has the advantages of speed over gas chromatography of speed (the entire 7 component analysis can be done in less than 0.1 seconds), analysis of virtually any combination of substances and the ability to detect unspecified foreign impurities. However, the cost can be higher than gas chromatography. Both methods have high reliability, extreme accuracy (down to ppb), and extensive application in the

process industry. The choice depends on those characteristics of the particular analyzer that are most appropriate for the user application.

Given below are data on two different mass spectrometers.

Anacon/Aero Vac

The first analyzer system to be discussed is the Anacon Aero Vac Model 180-730 mass spectrometer with the scanning electromagnet option. The Model 180-730 allows the operator to select up to seven different mass ranges, one for each gas one wishes to monitor. The scanning electromagnet allows the monitoring of the 1-100 amu mass range without changing magnets. The cost of the mass spectrometer with the scanning electromagnetic option is estimated at around \$15,000.

The elevated temperature and pressure in the process stream would require a series of pressure reduction areas in order to properly sample the steam. A heated sampling line would be furnished to ensure that all components remain gaseous during sampling and subsequent analysis. A fast loop sampling line would allow a fast response time to rapidly detect any changes in the stream. A rough cost estimate for this sampling system is \$12-15,000.

Anacon/Aero Vac does not provide a computer for data analysis, although the output from the mass spectrometer can be linked into a computer. Anacon/Aero Vac has installations at G.E. Waterford and IBM where this method is used.

CVC Superspec 600

An analyzer system which comes complete with software is the CVC Superspec 600 Microprocessor Controlled Process Mass Spectrometer System. The Superspec 600 has been engineered for durability and ruggedness so as to tolerate the abuse of harsh process plant conditions. It has been

sold for application in coal gasification to a good number of customers. Some basic inherent operating features include:

- 1-600 amu mass range
- Good resolution affords quantitative resolution of adjacent gas peaks without crosstalk interference
- Easily maintained contaminant-resistant analyzer
- Non-degradable and easily cleaned detector
- Fast analyzer response time, analyze six or more gases in typically less than one second
- Capable of handling several process gas lines/points (with inlet options)
- Analog oscilloscope and scanner output
- Portable system, self-contained in caster mounted cabinet.

With the addition of the CVC software and data acquisition package, interfaced to the mass spectrometer, results in a "turnkey" process mass spectrometer. The microprocessor has total control of the mass spectrometer operation, mass spectral acquisition, data processing, and readout. The CVC system provides direct percent concentration readings for each gas. Using a 19" color CRT display (one color for each component for easy reading), the system includes a keyboard input terminal for operator usage. The cost of the entire system is \$87,750. An itemized cost summary is provided in Table 7.1.

TABLE 7.1 ITEMIZED COST SUMMARY FOR THE CVC SUPERSPEC
600 MICROPROCESSOR CONTROLLED MASS SPECTROMETER
SYSTEM

Item No.	Quantity	Description	Total Price	Estimated Delivery
		CVC Superspec 600 Microprocessor Controlled Process Mass Spectro- meter System		
1	1	CVC Superspec 600 Process Mass Spectrometer Gas Analyzer System Including: a) Vacuum System Consisting of Balzers TPH-100 Turbomolecular Pumping System b) Separate Electronics Control Chassis Including a CVC MA-010 Analog Scanner c) CVC MA-018 Ambient Temperature Continuous Atmospheric Inlet (Via Capillary Tube) for On-Line Gas Analysis.	\$47,050	ARO 22-26 Weeks
2	1	CVC Superspec 600 Data Acquisition and Reduction System with Software. Features Include: a) Microprocessor Based Hardware b) 19" Color CRT with Data Input Terminal c) Software Package to Contain Matrix Programming (Up to 16 x 16 Matrix), Mass and Gas Trend Displays, and Mass Scanning Routines d) Complete User Manual and System Documentation e) This Data System will be Fully Interfaced to the CVC Superspec 600 (Item 1 Above) f) Data System Installation and Checkout Optional Item	\$38,750	ARO 22-26 Weeks
3	1	Teletype Printer (For Item 2) Including Cables, Manual, and Software Driver	\$ 1,950	
		TOTAL PRICE WITH OPTION	\$87,750	
		Installation Available by CVC at a Daily Rate of \$250 Plus Serviceman Cost of Transportation		

7.4 DRAWINGS

INSTRUMENT IDENTIFICATION

VARIABLE FROM LIST BELOW

INSTRUMENT NUMBER

LOOP FUNCTION AND/OR MODIFIER FROM LIST BELOW

EXAMPLE

FIRST LETTER-PROCESS VARIABLE OR ACTUATION

A ANALYSIS	L LEVEL
B BURNER/FLAME	P PRESSURE/PURGE
D DRAFT	R RATIO/REMOTE/RESTRICTION
E VOLTAGE (EMF)/ELECT/EMERGENCY	S SPEED/FREQUENCY
F FLOW RATE	T TEMPERATURE
H HAND (MANUALLY)	U MULTIVARIABLE
I CURRENT/AMPS	W WEIGHT/FORCE
J POWER/WATTS	X UNCLASSIFIED
K TIME	Z POSITION/LIMIT

INSTRUMENT FUNCTION OR MODIFIER

A ALARM	L LOW
B BLOCK	M METAL
C CONTROLLER/CONTROL	O ORIFICE
(C1) CUT IN	Q INTEGRATOR
(CO) CUT OUT	R RECORDER/RECORDING/RELIEF
D DIAL/DUAL	S SWITCH/SAFETY/SHUTDOWN
d DIFFERENTIAL	T TRANSMITTER
E ELEMENT OR PROBE	V VALVE
F RATIO (FRACTION)	W WELL
G GLASS/GAUGE	X BACKUP
H HIGH	Y RELAY
(H) HAND	Z POSITION
I INDICATING/INDICATOR	SO (SWITCH OPEN)
J MULTIPLEX	SC (SWITCH CLOSED)

GROUP CODED INSTRUMENTATION WILL BE DIFFERENTIATED BY LISTING THE PROCESS VARIABLE & MODIFIER ALPHA-CHARACTERS ON ONE LINE FOLLOWED, ON THE SECOND LINE, BY THE ASSIGNED NUMERICAL SEQUENCE NUMBER.

FUNCTION TO DATA ACQUISITION

COMPUTER INPUT OR FUNCTION

COMPUTER FUNCTION WHERE NO HARDWARE DEVICE EXISTS

COMPUTER INPUT OR FUNCTION - WITH CONTROL BACKUP IN CONTROL CENTER

COMPUTER INPUT OR FUNCTION - WITH CONTROL BACKUP ON LOCAL PANEL

PANEL/CONSOLE MOUNTED INSTRUMENT

LOCAL PANEL MOUNTED INSTRUMENT

LOCAL MOUNTED INSTRUMENT

INSTRUMENT WITH TWO SERVICES OR FUNCTIONS

IDENTIFICATION ONLY - NO HARDWARE EXISTS

SEE FIRST LETTER-PROCESS VARIABLE OR ACTUATION FROM LIST ABOVE

HIGH ALARM WITH COMPUTER INPUT

LOW ALARM WITH COMPUTER INPUT

CUT OUT ALARM

CUT OUT OR TRIP

LOCAL DEVICE WITH DEDICATED INDICATOR

DEDICATED CONSOLE MOUNTED DEVICE

TREND RECORDER

TRANSMITTER

SHUTDOWN SWITCH

RESISTANCE (BULB) TEMPERATURE DETECTOR

PURGE - IBFW-250, BFW-850, CW, IA, N₂, OIL, PA, PG, PW, RW, OR UA.

LIGHT-CLEAR (COLOR: R-RED, G-GREEN)

CONTROL STATION

CONTROL STATION SINGLE FUNCTION

SELECTOR SWITCH (MULTI-POSITION)

DESIGNATION	SIGNAL
E	VOLTAGE
I	CURRENT
H	HYDRAULIC
O	ELECTROMAGNETIC
P	SONIC SIGNAL OR
R	LIGHT BEAM
	PNEUMATIC
	RESISTANCE

MANUALLY OPERATED VALVES

BY ADDING AN ACTUATOR TO BASIC VALVE SYMBOL, VALVE BECOMES A CONTROL VALVE.

OTHER VALVES

INDICATE PROPER ABBREVIATION UNDER VALVE

EXAMPLE: TS

CONTROL VALVES

LINE AND PIPING SYMBOLS IDENTIFICATION

LOCATION OF IDENTIFICATION CODES ON VALVE SYMBOLS

HAND VALVES AND MOV'S

VALVE DETAILS:

CO - CHAIN OPERATED
CSC - CAR SEALED CLOSED
CSO - CAR SEALED OPEN
FP - FULL PORT
FPRF - FIREPROOFED
GO - GEAR OPERATED
TS - TIGHT SHUTOFF
FOR GATE VALVES (ONLY):

CONTROL VALVES

VALVE SERVICES:

EMERGENCY ISOLATION BLOCK VALVES (ONLY)
EBV - EMERGENCY BLOCK VALVE (TYPE A,B,C,D)
HBV - HAND OPERATED BLOCK VALVE
SHOW (TYPE A) OR (TYPE B)
RBV - REMOTE OPERATED BLOCK VALVE
W/HANDWHEEL SHOW (TYPE C) OR (TYPE D)
CONTROL VALVES (ONLY):
FS - FLASHING SERVICE

VALVE POSITION AND FUNCTION:

FC - FAIL CLOSE
FO - FAIL OPEN
FCS - FAIL CLOSE, STATIONARY.
FOS - FAIL OPEN, STATIONARY.
FCR - FAIL CLOSE, LOCKUP WITH LOCAL MANUAL RESET.
FOR - FAIL OPEN, LOCKUP WITH LOCAL MANUAL RESET.
FCRP - FAIL CLOSE, LOCKUP WITH PANEL MANUAL RESET.
FORP - FAIL OPEN, LOCKUP WITH PANEL MANUAL RESET.
RCV - REMOTE OPERATED CONTROL STATION.

MISCELLANEOUS

MORGAN ENGINEERING CO.
7500 Wisconsin Ave. • Olney, MD 20815
(301) 863-0445
CONSULTING ENGINEERS

MITTELHAUSER
corporation
312/864-6164

HDGCV TEST FACILITY
PROJECT 231-C
MORGANTOWN ENERGY TECHNOLOGY CENTER
P&ID INDEX

MATERIAL'S LIST			NO. REQ'D		MATERIAL SPEC.	ZONE
NOTE	PART NO.	DESCRIPTION	GR.1	GR.2

7-78

REV		ZONE	DATE	DESCRIPTION	BY	CHK	APVD
1		0		REPORT ISSUE ISSUED FOR REVIEW			
United States Department of Energy MORGANTOWN ENERGY TECHNOLOGY CENTER Morgantown, WV							
DRWG TYPE		TITLE: PRELIMINARY DESIGN					
DRWG SIZE		HOT DIRTY GAS CONTROL VALVE					
REF. DRWG NO.		TEST FACILITY					
		PIPING AND INSTRUMENT DIAGRAM					
		GAS COOLING AND RECIRCULATION					
DRAFTSMEC		DATE	PROJ. ENG.	DATE			
DESIGNER		DATE	BRANCH	DATE			
PROJ. NO.(S)		CHECKED BY	DATE				
CODE IDENT. NO.		SCALE	DRWG. NO.	SHT. 2 OF 3	REV 1		
		NONE	231-C-102

1	25 JAN 1980	REPORT ISSUE	MECO	W.H.	W.H.
0	14 DEC 1979	ISSUED FOR REVIEW	MECO	W.H.	W.H.
REV	ZONE	DATE	DESCRIPTION	BY	CHK
<div style="display: flex; justify-content: space-between;"> <div> MITTELHAUSER corporation 312/854-8184 MORGAN ENGINEERING CO. 1500 Mountain Ave. • Columbia, S.C. 29203 </div> <div> United States Department of Energy MORGANTOWN ENERGY TECHNOLOGY CENTER Morgantown, WV </div> </div>					
DRAWG TYPE DRAWG SIZE REF. DRAWG NO.		TITLE: PRELIMINARY DESIGN HOT DIRTY GAS CONTROL VALVE TEST FACILITY PIPING AND INSTRUMENT DIAGRAM BY PASS LOOP			
DRAFTS MECO DATE 14 DEC 79 DESIGNER MITTELHAUSER CHECKED BY F		PROJ. ENG. J.F. GARDNER DATE 14 JAN 80			
PROJ. NO.(S) CODE IDENT. NO.		SCALE NONE DRAWG NO. 231-C-103 SHT 3 OF 3 REV 1			