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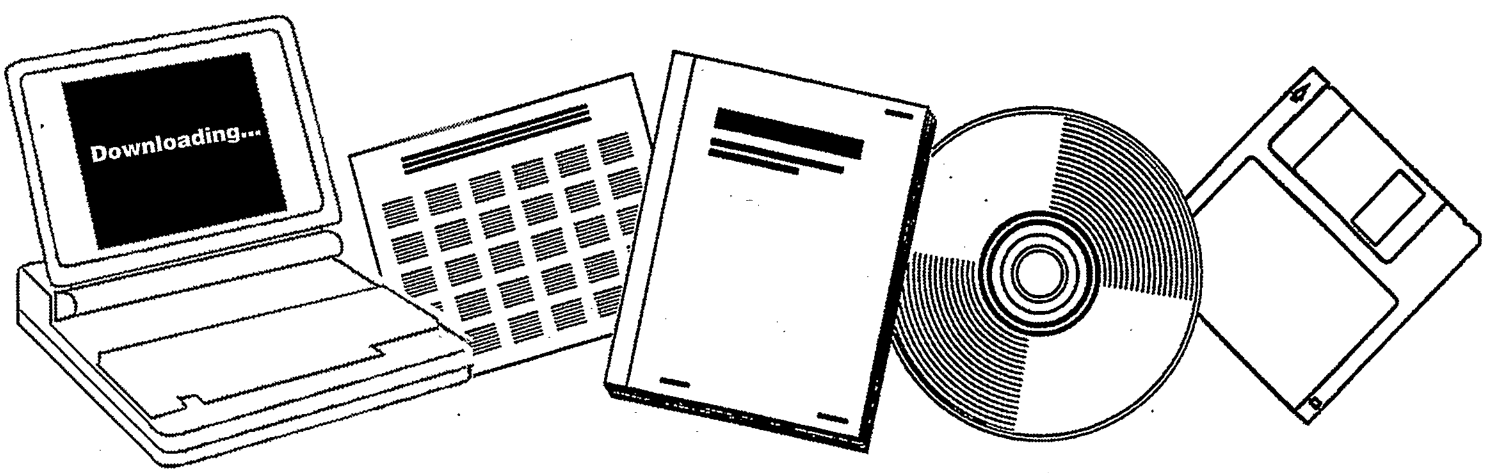
PRESTRESSED CONCRETE PRESSURE VESSELS: CONCEPTUAL DESIGN/ECONOMIC ANALYSIS. EXECUTIVE SUMMARY. R AND D REPORT NO. 114, INTERIM REPORT NO. 8

PARSONS (RALPH M.) CO.
PASADENA, CA

SEP 1978



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PRESTRESSED CONCRETE PRESSURE VESSELS CONCEPTUAL DESIGN/ECONOMIC ANALYSIS

R&D REPORT NO. 114, INTERIM REPORT NO. 8

EXECUTIVE SUMMARY

Prepared by:
THE RALPH M. PARSONS COMPANY
100 West Walnut Street
Pasadena, California 91124

September 1978

Under Contract No. EX-76-C-01-1775

Prepared for
DEPARTMENT OF ENERGY
OFFICE OF ASSISTANT SECRETARY FOR ENERGY TECHNOLOGY
DIVISION OF COAL CONVERSION
Washington, D.C. 20545

PREFACE

The U.S. Department of Energy is actively identifying and evaluating new technologies, as well as existing technologies in other fields, as they may be applied to improving the feasibility and economics of fossil fuel processing plants.

This study involves the conceptual design of commercial-sized prestressed concrete pressure vessels for coal conversion plant applications. The report addresses the design, constructibility and economics of these vessels compared with their steel counterparts.

Prestressed concrete pressure vessels (PCPV) are widely used today as storage tanks. PCPV design has been established and applied to some sixty (60) secondary containment vessels in use and under construction for nuclear power generating service.

While this work describes the benefits which may be obtained from prestressed concrete pressure vessels, such as:

- Benign failure characteristics
- Shorter construction schedules
- Minimum requirements for chromium and molybdenum
- More competitive procurements because thick steel plate is not required
- Less skilled labor for construction
- Lower capital investment than for steel vessels of comparable capacity

The report also addresses caveats in the further development of this technology, such as:

- Lack of design codes
- Lack of reliability analyses of cooling systems and refractory materials
- Lack of experience in thick-walled structural behavior of high temperature concrete pressure vessels

The following report increases the technology data base within the public domain and, it is hoped, stimulates interest in proceeding with further related research and development toward a more quantified assessment of prestressed concrete pressure vessels.

The contents of this report do not yet have the benefit of a detailed Department of Energy review.

David Garrett, P.E.
Technical Program Manager

TABLE OF CONTENTS

Figures

Tables

ABBREVIATIONS

Btu	British thermal units
FCI	fixed capital investment
ID	inside diameter
ksi	thousand pounds per square inch
MM	million
Parsons	The Ralph M. Parsons Company
PCPV	Prestressed Concrete Pressure Vessel
psig	pounds per square inch gauge
scf	standard cubic feet
TPD	tons per day

ABSTRACT

This report summarizes the results of a study which determined that the use of prestressed concrete pressure vessels (PCPV's) in coal conversion plants is technically feasible and offers potential economic advantages.

Four representative types of PCPV's were studied. Depending on the type of PCPV, it was found that reductions in fixed capital investment as high as 70 percent, amounting to as much as $300 million, are possible by the substitution of large PCPV's for steel vessels; the PCPV's would use state-of-the-art technology and proven construction methods and equipment.

Continued development of prestressed concrete pressure vessels is recommended.

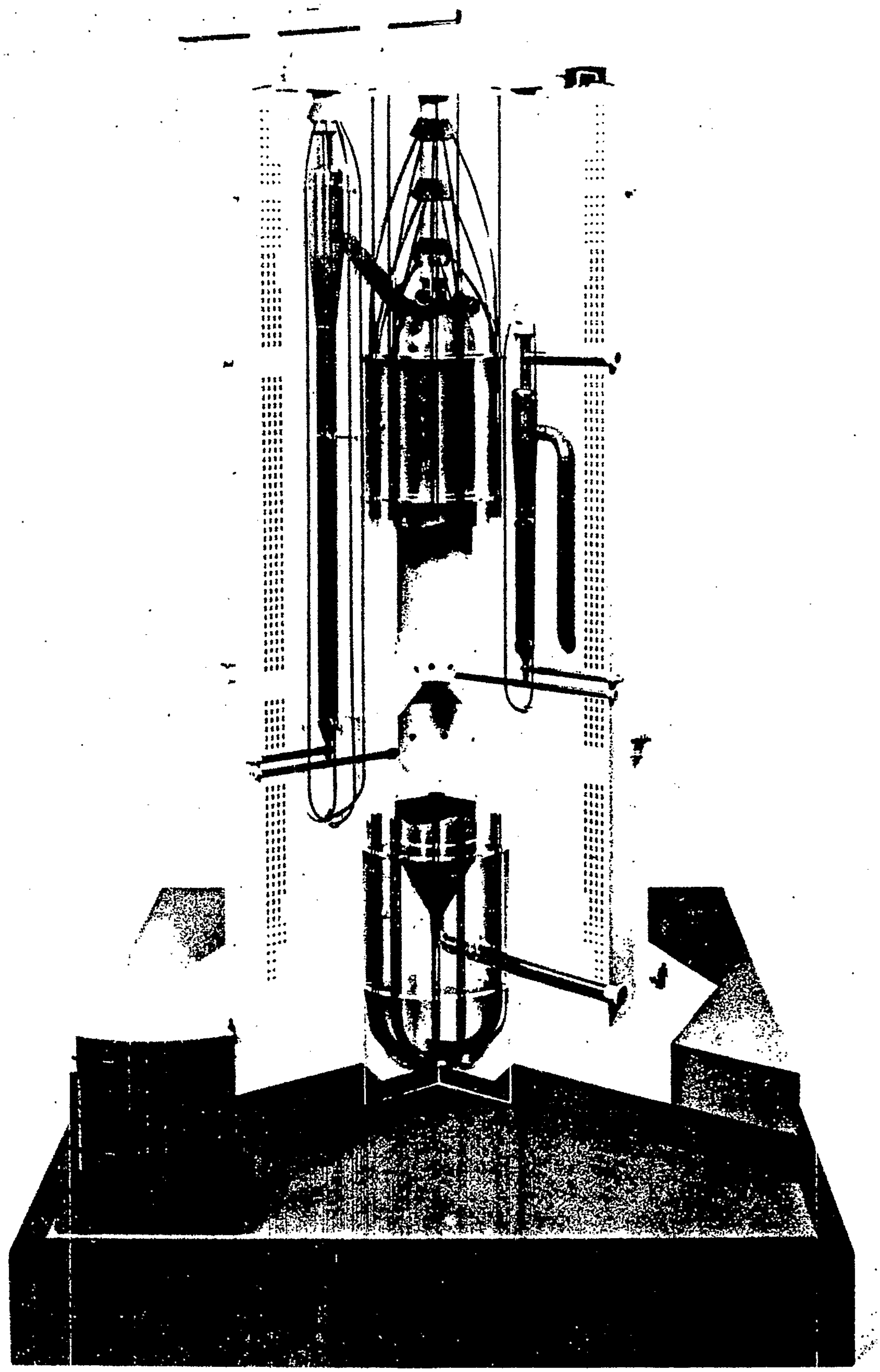


Figure 1 - Integrated Gasifier Vessel Model
Cross-Sectional View

SECTION 1

EXECUTIVE SYNOPSIS

A study of the conceptual design and projected economics of four types of prestressed concrete pressure vessels (PCPV's) for use in coal conversion plants has been completed under contract EX-76-01-1775 with the U.S. Department of Energy. The Ralph M. Parsons Company (Parsons) of Pasadena, California was the prime contractor and T. Y. Lin International of San Francisco, California served as subcontractor with responsibility for the structural design of the prestressed concrete pressure vessels.

The prime incentives for this study were:

- The development of PCPV's would permit the use of larger high pressure vessels than presently considered practical in steel construction.

- PCPV's would provide a competitive alternative to the use of steel vessels. This could be a major consideration if a number of coal conversion complexes were to be constructed simultaneously to meet national alternative energy supply goals as described in U.S. energy plans. This alternative is particularly important because of the limited U.S. capability to produce numerous large high pressure vessels simultaneously, and because of possible shortages of alloy materials for high strength steel alloys.

- PCPV's could reduce the fixed capital investment (FCI) of large coal conversion plants. The profitability of coal conversion plants is highly sensitive to the FCI; therefore a successful PCPV program would assist in making these plants economically viable.

The designs developed in this study were chosen to illustrate the potential of representative vessels selected from a large number of possible uses for PCPV's in coal conversion processes. The four PCPV's studied were: a dissolver-separator used to liquefy coal, an absorber used to purify gases, an integrated coal gasifier vessel and a coal gasifier vessel. The vessels studied range from a 23' 4" to a 33' 4" inside diameter. They were each designed to replace one or more conventional steel pressure vessels with no change in the process flow from conventional practice. Figure 1 illustrates the projected size and characteristics of one of the vessels - note the 6-foot man for size comparison.

The results of the study indicate:

- The design and construction of PCPV's was found to be generally within the present state of knowledge. Subscale testing should be performed to confirm some design judgements.

- The use of PCPV's can reduce the fixed capital investment (FCI) requirements. To illustrate, substitution of a single PCPV for as many as 18 steel vessels might reduce the FCI by approximately 70 percent, amounting to as much as $300 million. Replacement of a single steel vessel with a PCPV can reduce the FCI by approximately 10 percent.

    - Thus, there is a definite economic incentive to carry further the development of PCPV's to demonstrate their technical feasibility and economic viability.

- PCPV's offer an alternative for construction of large scale coal conversion plants.

- Improved vessel safety performance is expected because of the benign failure characteristics of PCPV's.

- PCPV's have the potential to be operational in a shorter schedule than steel vessels.

- At the time of this writing, supply projections indicate that the materials of construction for PCPV's can be readily available in the U.S. while the capacity to fabricate and install large numbers of large heavy walled steel pressure vessels was found to be currently limited by the number of suppliers and availability of fabrication facilities.

We recommend that a demonstration scale PCPV be designed, constructed and operated in a coal conversion plant and the results be used as a basis for commercial plant design.

SECTION 2
CONCLUSIONS AND RECOMMENDATIONS

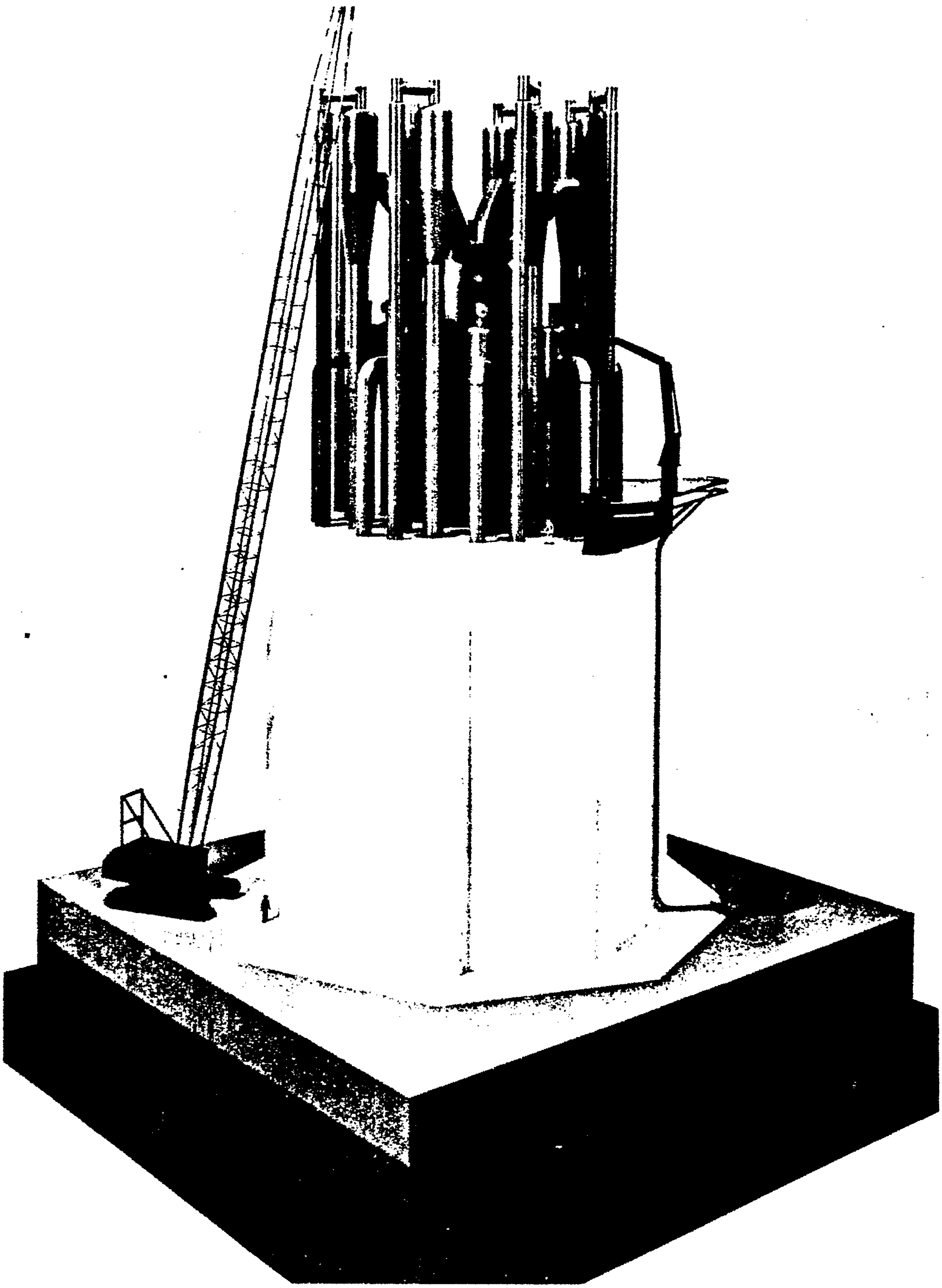


Figure 2 - Integrated Gasifier Vessel Model
During Construction

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

The conclusions of this study are:

- The fixed capital investment of a process unit can be reduced by as much as 70 percent by use of large PCPV's vis-a-vis multiple steel pressure vessels. For replacement of a single large steel pressure vessel with a PCPV, the reduction in investment can be approximately 10 percent.
    - Some of the savings are attributable to reductions in the cost of process equipment such as pumps, compressors, heaters and similar equipment because of use of fewer and larger equipment items with the large PCPV's.
- The design and construction of PCPV's was found to be technically feasible. The construction would use proven construction methods and presently available equipment and could require less time; Figure 2 is a model of a large PCPV during construction.
- PCPV's can be constructed in larger diameters for high pressure vessels than presently considered possible using steel construction.
- PCPV's will provide an attractive alternative to steel pressure vessels. The availability of large diameter heavy walled steel pressure vessels is limited by both the supply of heavy wall plate and the number of vessel fabricators.
- Subscale and laboratory testing should be conducted to confirm some design judgements used in the study.
- The maximum PCPV size will probably be determined by such factors as process safety, process scale-up capability, reliability, and the maximum economic single line capacity.
- PCPV's will conserve strategic materials such as chrome and molybdenum.

We recommend that a demonstration scale PCPV be designed, constructed and tested in a coal conversion plant. This work could be carried out in a program consisting of three parts as described below.

In the first part, the objectives are:

- Define total economic incentives for use of PCPV's in the U.S. coal conversion program.

- Determine minimum economic size of PCPV's.
- Define scale-up and design criteria.
- Define a program and schedule for a preferred demonstration plant test program.

The second part of the program provides confirmatory testing. We recommend that this part of the program:

- Define a confirmatory test program to provide further confidence in the designs for operational PCPV test vessels.
- Execute the test program to obtain necessary design data.
- Develop design criteria for operational PCPV test vessels.

The third part is an operational PCPV test vessel. We recommend that this part include:

- Design, construction, and operation of a demonstration scale PCPV in a DOE-sponsored coal conversion facility.
- Demonstrate the operational feasibility of a PCPV in a coal conversion plant.
- Develop criteria for future codes for use in the design and construction of commercial PCPV's.
- Obtain operational data for use in future design of commercial scale PCPV's.

The results of this third program part would provide the data necessary for the design and construction of multiple commercial PCPV's. It will also provide a basis for predicting the economics of use and demonstrate the viability of PCPV's in coal conversion processes.

Table 1 - Fixed Capital Investment Comparison

Vessel	Type of Construction	Number of Trains	Capacity per Train	Number of Major Vessels per Train	Total Number Of Major Vessels	FCI ($ Million)	Percent Reduction in FCI Compared to Steel Vessel
Dissolver-Separator	Steel	3	20,000 TPD of Coal	6	18	430	0
	PCPV	1	55,000 TPD of Coal	1	1	130	70
Absorber	Steel	3	23 million scf/hr	2	6	10	0
	PCPV	1	69 million scf/hr	1	1	4	60
Gasification	Steel	2	55,000 TPD of Coal	1	2	255	0
	PCPV-Gasifier Reactor only	2	55,000 TPD of Coal	1	2	225	12
	PCPV-Integrated Gasifier	2	55,000 TPD of Coal	1	2	230	10

Table 2 - Savings Using Prestressed Concrete Vs. Steel

Item	Dissolver-Separator		Absorber		Gasifier Only		Integrated Gasifier	
	Uniform Annual Cost ($ Million)	Feed Coal ($/MMBtu)	Uniform Annual Cost ($ Million)	Feed Gas ($/MMscf)	Uniform Annual Cost ($ Million)	Product Gas ($/MMBtu)	Uniform Annual Cost ($ Million)	Product Gas ($/MMBtu)
Operating Costs								
Operating Labor and Materials	-0.512	-	0.062	-	-	-	-	-
Maintenance	10.732	-	0.240	-	1.158	-	0.977	-
Utilities	-1.227	-	-	-	-0.025	-	-0.142	-
Plant Overhead	2.326	-	0.088	-	0.278	-	0.234	-
Property Tax and Insurance	7.381	-	0.165	-	0.796	-	0.671	-
G and A	0.293	-	0.008	-	0.033	-	0.027	-
Savings Subtotal	18.993	0.043	0.563	0.001	2.240	0.003	1.767	0.003
Capital Burden Costs								
Capital Investment	46.080	-	1.029	-	4.970	-	4.193	-
Working Capital	1.484	-	0.035	-	0.165	-	0.136	-
Income Taxes	26.062	-	0.585	-	2.815	-	2.374	-
Savings Subtotal	73.626	0.166	1.649	0.003	7.950	0.010	6.703	0.009
Total Savings	92.619	0.209	2.212	0.004	10.190	0.013	8.470	0.011

SECTION 3

ECONOMICS

Fixed capital investment (FCI) and operating costs were estimated for the four PCPV's and compared with equivalent economic parameters for steel pressure vessels in the same process service. The results are summarized here.

Process flow sheets, equipment sizes and equipment lists were prepared for each PCPV case. Equipment costs were obtained using either historical cost data or vendor-supplied information. The FCI's for the steel vessel cases were escalated to December 1977 values from those given in previous Parsons' studies.[1,2]

Table 1 summarizes the FCI comparison for the four types of PCPV's. The results indicate that very significant reductions in FCI can occur by the substitution of large PCPV's for several smaller steel vessels. The largest FCI reduction, $300 million or approximately 70 percent, was for the case of the dissolver-separator where one PCPV essentially replaced nine dissolvers and nine separators of conventional steel construction.

The projected annual and unit product cost savings using the PCPV when compared to steel vessels are shown in Table 2. Again, the largest saving was in the dissolver-separator case where a savings of about $0.20 per million Btu's of coal feed to the unit is projected; for a plant feeding 55,500 tons per day (TPD) of coal, this would result in a yearly savings of over $90 million. Approximately 80 percent of this savings is directly related to the predicted lower fixed capital investment.

The economic analyses were based on a 12 percent discounted cash flow rate of return on equity with a project structure using 65 percent debt borrowed at 9 percent interest, and a 20-year plant operating life at an operating rate of 330 stream days per year. Operating labor was based on a wage rate of $7.50 per hour with a payroll burden of 35 percent.

SECTION 4
TECHNICAL FEASIBILITY

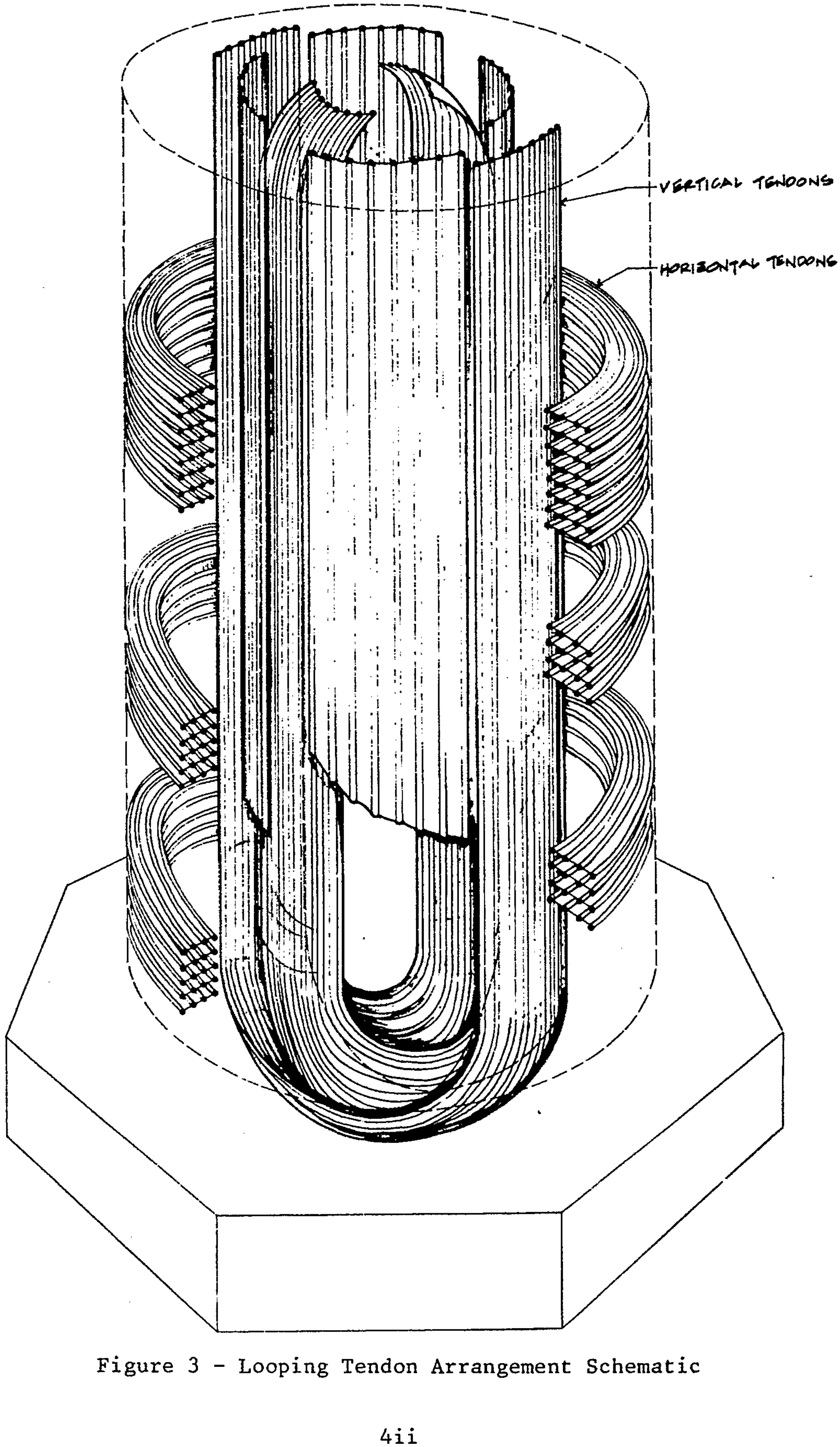


Figure 3 - Looping Tendon Arrangement Schematic

SECTION 4

TECHNICAL FEASIBILITY

A prestressed concrete pressure vessel (PCPV) is a structure wherein concrete, reinforcing steel, and high strength steel tendons are used to form the pressure containment shell. Well over 90 percent of the mass is concrete.

Prestressing means the intentional creation of permanent stresses in a concrete structure, for the purpose of improving its structural behavior under various load conditions. The prestressing forces can be applied by means of stressing the tendons. Figure 3 shows the general arrangement of the tendons in a PCPV. Similar to reinforced concrete, prestressed concrete involves combined action between the concrete and the prestressing steel tendons, and interaction between the internal prestressing force and the externally imposed loads. For PCPV's, the prestressing forces are applied by post-tensioning the steel tendons after the concrete has hardened. The post-tensioned tendons place the vessel in compression and enable it to resist the high operating pressures.

There are several additional elements required for a PCPV to perform successfully as a process pressure vessel. One of these is a metal membrane internal liner, which serves to prevent escape of process gases and liquids into the concrete structure. The metal membrane liner also serves as a form during concrete placement.

Another important element is a cooling system plus insulating concrete which is necessary to control the structural concrete temperature whenever the metal liner temperature exceeds 200^{o}F. Also, internal refractory is used when necessary to shield the metal membrane liner against very high temperature.

The general methods of PCPV design have been established. They are used routinely in the design of nuclear secondary containment vessels of which approximately 60 are under construction or in use today. These methods have also been applied in the design of vessels for storage of water, oil, LNG and coal. However, because of the higher operating temperatures and pressures, and the much thicker concrete walls for the coal conversion plant operations discussed here, some confirmatory tests should be performed to further substantiate the design.

The materials required for construction of large PCPV's are widely available in the United States. At present there is a temporary shortage of cement in the western states caused by the building boom. Indications are that structural concrete in the desired quantities and quality will be produced throughout the United States when needed. There are presently four U.S. companies that supply 270 ksi strength cable tendons required for this type of construction. Two other major U.S. firms have also produced this cable in the past.

Other required metal components are also readily available in the United States. In contrast, there are a very limited number of suppliers of large heavy-wall pressure vessel-grade steel plate in the United States. There is one company in the United States, one in Europe and one in Japan with capability to produce 12 to 15-inch thick plates which weigh up to 50 tons. There are a number of suppliers of pressure vessel-grade steel plate of lesser thickness.

The field fabrication of large heavy-walled pressure vessels has been limited in the United States to one firm. At least two other firms have organizations capable of the field fabrication of large heavy-walled pressure vessels. There are presently about 10 shops in the United States capable of building heavy walled pressure vessels of 10 to 12-inch wall thickness for all uses.

The method of construction of the PCPV's utilize well proven technology. The equipment for construction of the vessels is presently available and in use in construction of large concrete structures. The construction sequence of the integrated gasifier PCPV is shown in Figure 4.

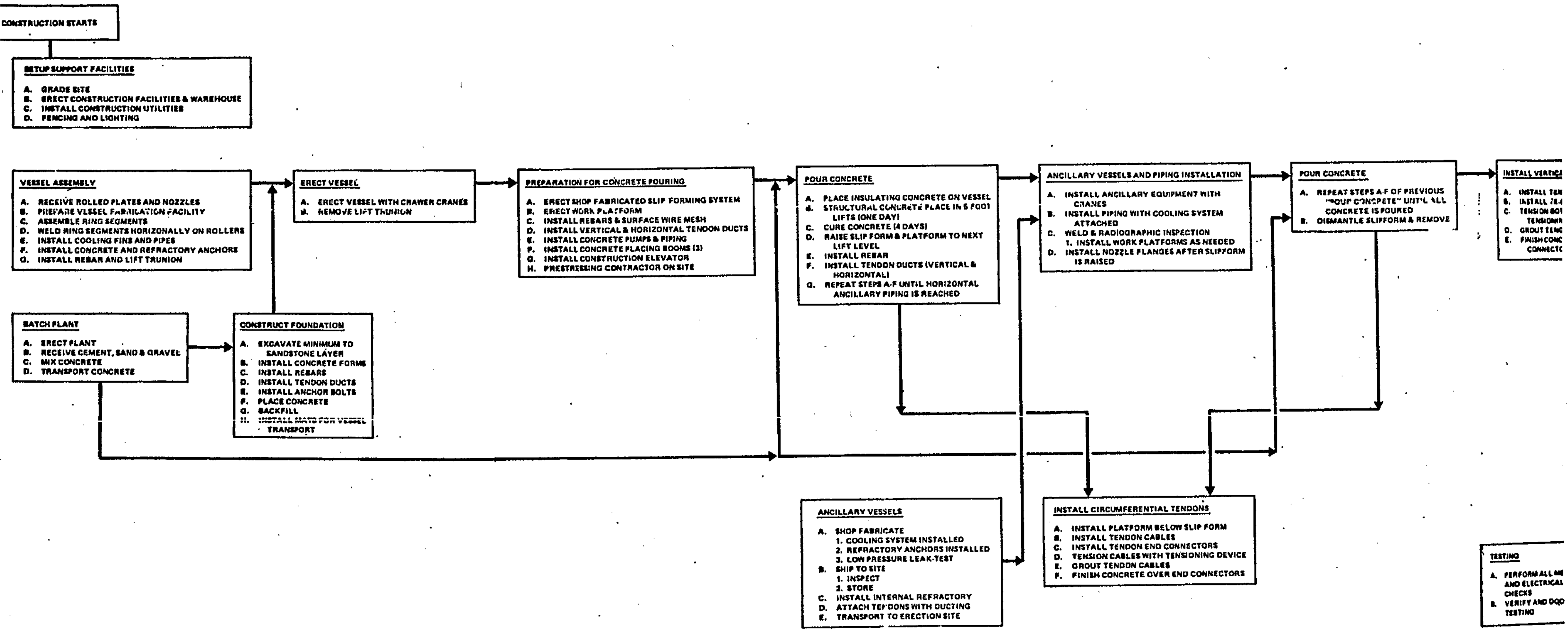
The operation of a PCPV process vessel will be generally similar to that of a conventional steel pressure vessel. For PCPV's with internal process temperatures over 200°F, a closed cycle cooling system will be required which will add some complexity to the system due to the addition of pumps, piping and heat exchange equipment.

The development of methods for operational inspection and monitoring of the vessel integrity will be required for some vessel elements. These elements include the external cooling system, the insulating concrete and the concrete to membrane wall attachments.

The maintenance of PCPV's is expected to be more difficult than steel vessels. This is due to the more difficult entrance into the vessel internals caused by very large and heavy closure plugs, the lack of accessibility to the embedded cooling coils, and the additional equipment maintenance for pumps and heat exchange equipment for the cooling systems. Further, it will be difficult to modify a PCPV because of the locations of tendons and reinforcing steel.

The inherent safety characteristics of a PCPV appear better than for a steel vessel. Tests conducted on PCPV's indicate that the concrete will crack and relieve excessive pressures, and after pressure relief, the steel tendons will again compress the concrete and seal the PCPV.

There are presently no commercial code criteria for PCPV's for coal conversion plants. The American Society of Mechanical Engineers Pressure Vessel Code, Section III, Division 2, covers the requirements for PCPV nuclear containment vessels and nuclear reactors. However, this code does not appear applicable to PCPV's for coal conversion processes because of the different characteristics required. It will be necessary to perform studies and tests to demonstrate their viability and to obtain data for design criteria for coal conversion PCPV's.



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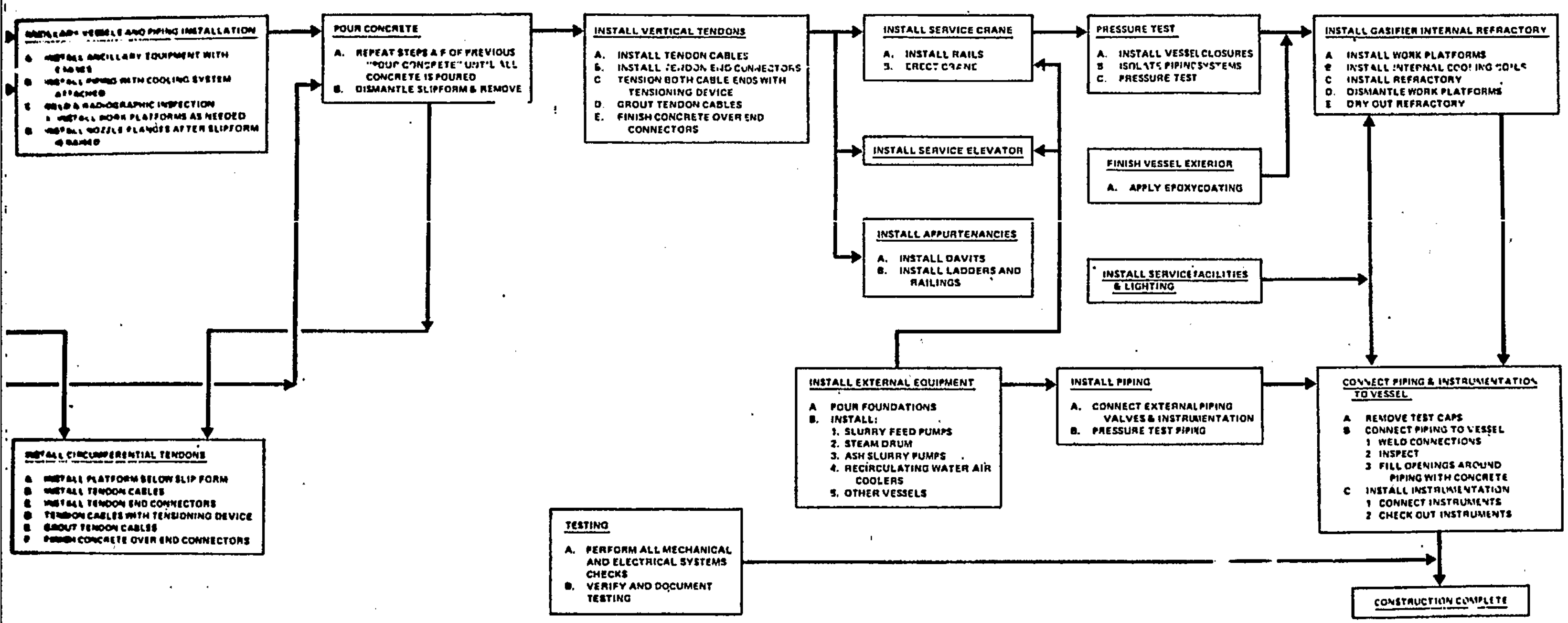
4-5 A

4-5 B



4-5 B

Figure 1 Construction Sequence - Integrated Gasifier Vessel

4-5 C

SECTION 5
VESSEL COMPARISONS

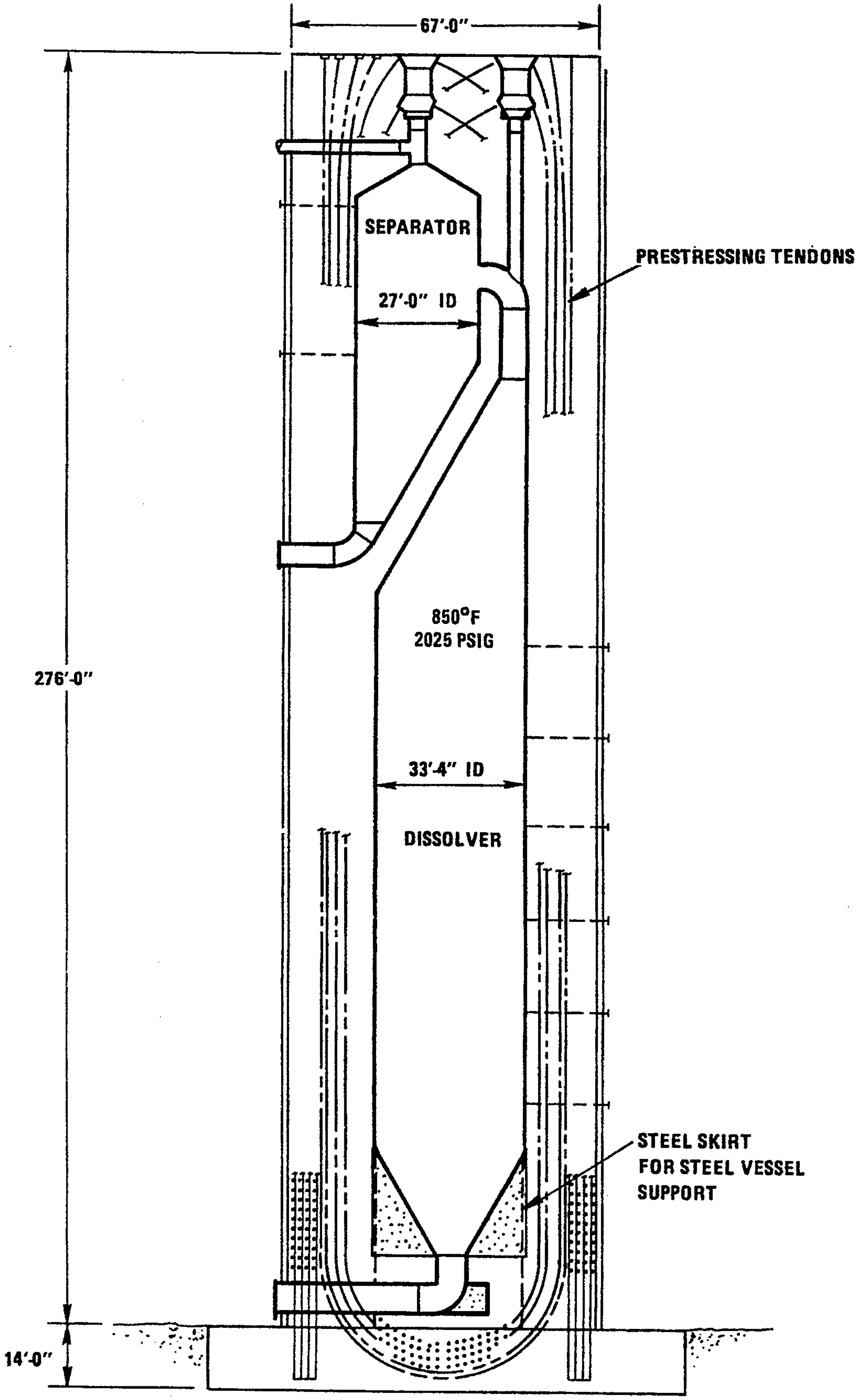


Figure 5 - Dissolver-Separator Vessel Sketch

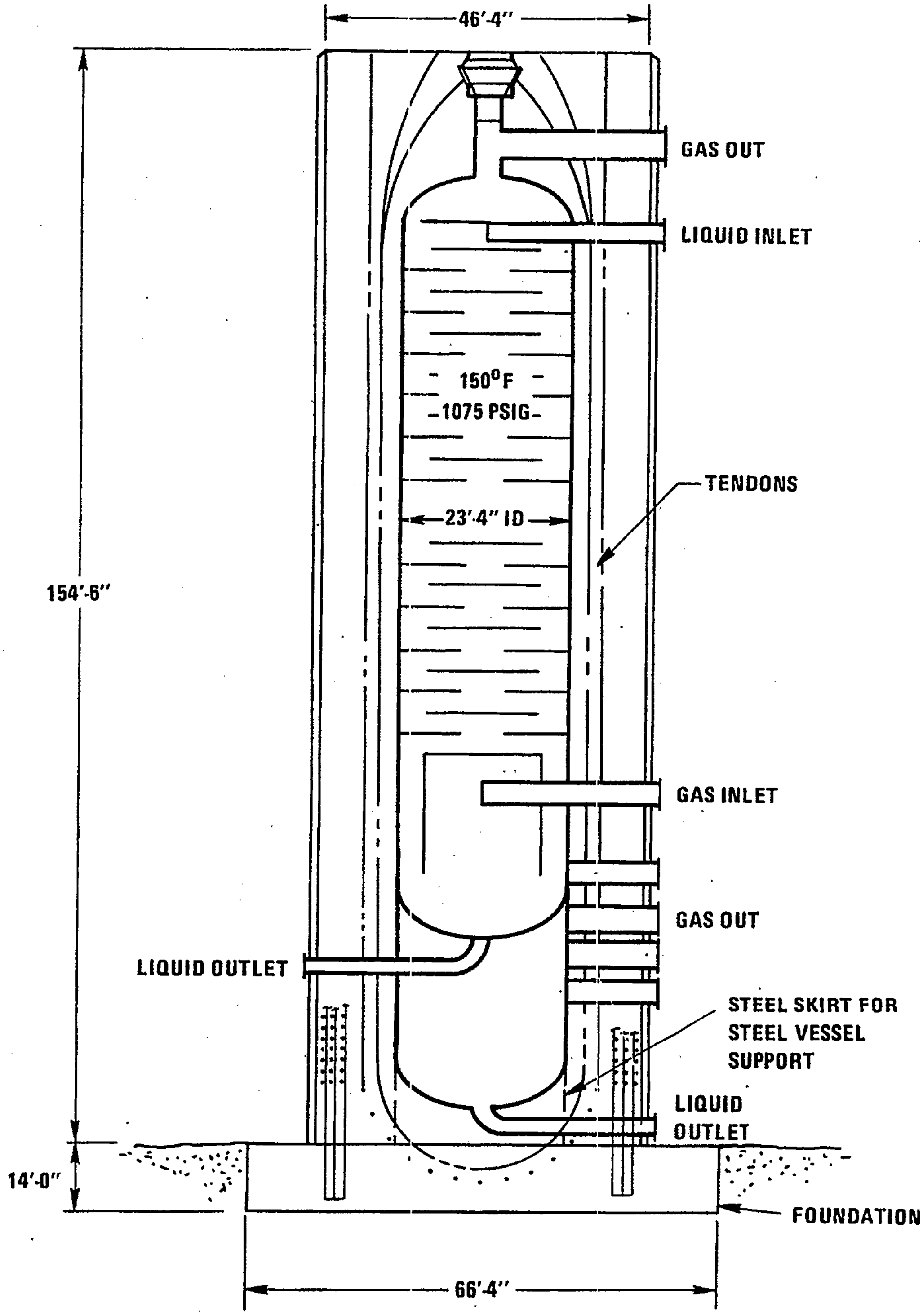


Figure 6 - Absorber Vessel Sketch

SECTION 5

VESSEL COMPARISONS

The three basic types of process pressure vessels — dissolver-separator, absorber and gasifier, were selected to be representative of those utilized in coal conversion plants. They cover a wide range of process requirements with regard to pressures, temperatures, process stream compositions, and configurations.

The PCPV's in this study were compared with steel pressure vessels for identical process duties. The steel pressure vessels had been investigated and reported in earlier studies made by Parsons.[1,2]

Dissolver-Separator

The dissolver-separator is a key vessel in coal hydroliquefation processing; a similar process is under development at the SRC pilot plant located at Fort Lewis, Washington for the U.S. Department of Energy.

Figure 5 is a simplified cross sectional view of this PCPV. Here, the main process elements, the dissolver-separator vessels, operate at 850^{o}F and 2,025 psig. The metal membrane wall is directly exposed to the process environment. A process flow diagram describing the process duties and conditions is shown in Figure 9 at the end of this section.

The estimated fixed capital investments are compared in Table 3. The results indicate that the PCPV system investment at about $130 million is approximately 30 percent of the predicted investment for eighteen steel vessels consisting of nine dissolvers and nine separators. The increase in size and reduction of numbers of pipelines and connecting process equipment items such as pumps, compressors and related equipment required for the PCPV case contributed to the significant reduction in fixed capital investment.

Table 3 - Dissolver-Separator Fixed Capital Investment Comparison ($ Million)

Costs	PCPV Dissolver-Separator	Steel Dissolver-Separator
Equipment		
Steel Vessels	7	155
Heat Exchangers and Heaters	27	55
Pumps	5	11
Compressors	13	15
Equipment Subtotal	52	236
Piping and Other Installed Costs	62	192
Concrete Containment Structure	14	-
Total Direct Construction Cost	128	428
Say	130	430

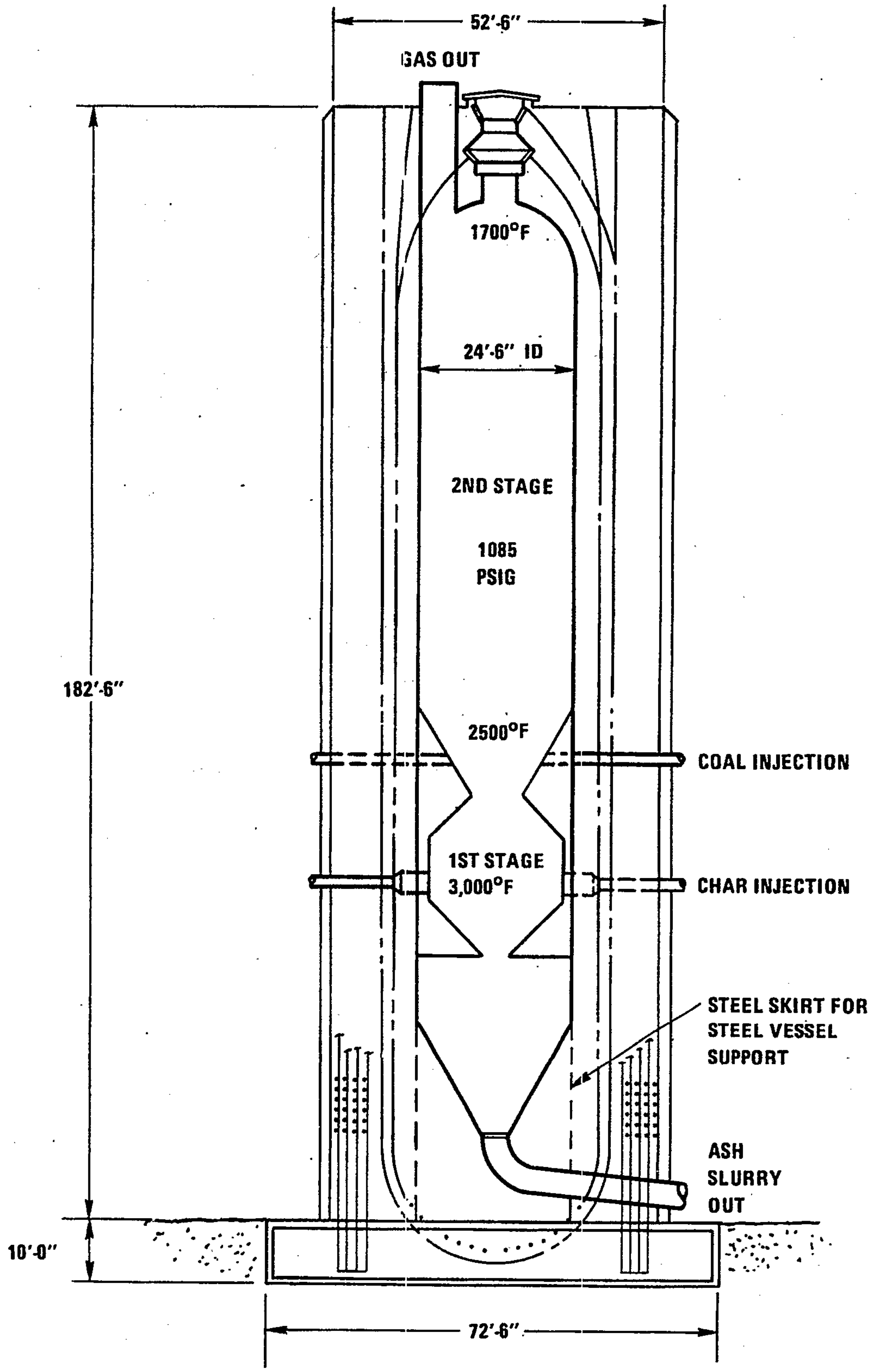


Figure 7 - Gasifier Vessel Sketch

Absorber

The process design for this acid gas removal contactor originated in an earlier conceptual design published by Parsons.[2] For this study only the absorber vessel was investigated.

A cross sectional view of this PCPV is shown in Figure 6. The vessel has internal trays and intermediate heads, which require carrying these loads into the concrete structure.

A process flow diagram is shown in Figure 10 at the end of this section.

A fixed capital investment comparison between the PCPV and six (6) steel vessels performing the same process duty is presented in Table 4. The results indicate that the large PCPV investment requirement would be approximately 40 percent of that of the steel vessels.

Table 4 - Absorber Fixed Capital Investment Comparison
($ Million)

Costs	PCPV Absorber	Steel Absorber
Vessels	1.3	9.8
Concrete	2.6	0.1
Total Cost	3.9	9.9
Say	4	10

Gasifiers

The gasification process flow scheme is the same for the gasifier and the integrated gasifier vessel. The process scope covers from the point of feeding a coal-water slurry to the gasifier to the discharge of solids-free gas for further downstream processing. The process design is based on a two-stage entrained gasification process. A typical similar process would be the Bi-Gas process being developed at Homer City, Pennsylvania for the U.S. Department of Energy; the first stage of the gasifier operates at 3,000^{o}F, at a pressure of 1,085 psig.

A process flow diagram showing the process conditions and major equipment items is shown in Figure 11 at the end of this section. The key gasifier vessels operate in a severe process environment with temperatures ranging from 1,700 to 3,000^{o}F at a pressure of 1,085 psig. Further, they have a complex internal geometry. Two types of possible gasifier configurations were investigated. For the first type, only the gasifier reactor is contained in the concrete structure. Figure 7 is a simplified cross sectional view of this vessel. The second type is referred to as an integrated gasifier vessel. This unit, shown in Figures 1, 2 and 8 on the following page, has the closely associated ancillary equipment - coal and char cyclones, flash dryers, and coal and char eductors embedded in the concrete structure.

A fixed capital investment comparison for the gasifiers is shown in Table 5. The results indicate that the required investment may be approximately 10 percent less for PCPV's than for steel vessels; they also show that there is no economic incentive to use the integrated gasifier PCPV vis-a-vis the case of a PCPV gasifier as depicted in Figure 7.

Table 5 - Gasifiers Fixed Capital Investment Comparison
($ Million)

Costs	PCPV Integrated Gasifier	PCPV Gasifier Only	Steel Gasifier
Major Equipment			
Steel Vessels	4	12	12
Heat Exchangers	26	26	25
Pumps	18	17	17
Separation Equipment	47	53	55
Reactors	9	9	37
Major Equipment Subtotal	104	117	146
Material			
Concrete	24	7	1
Piping	63	59	69
Structural Steel		3	7
Other Bulk Materials	9	10	1
Material Subtotal	96	79	78
Field Indirects	29	28	29
Total Construction Cost	229	224	253
Say	230	225	255

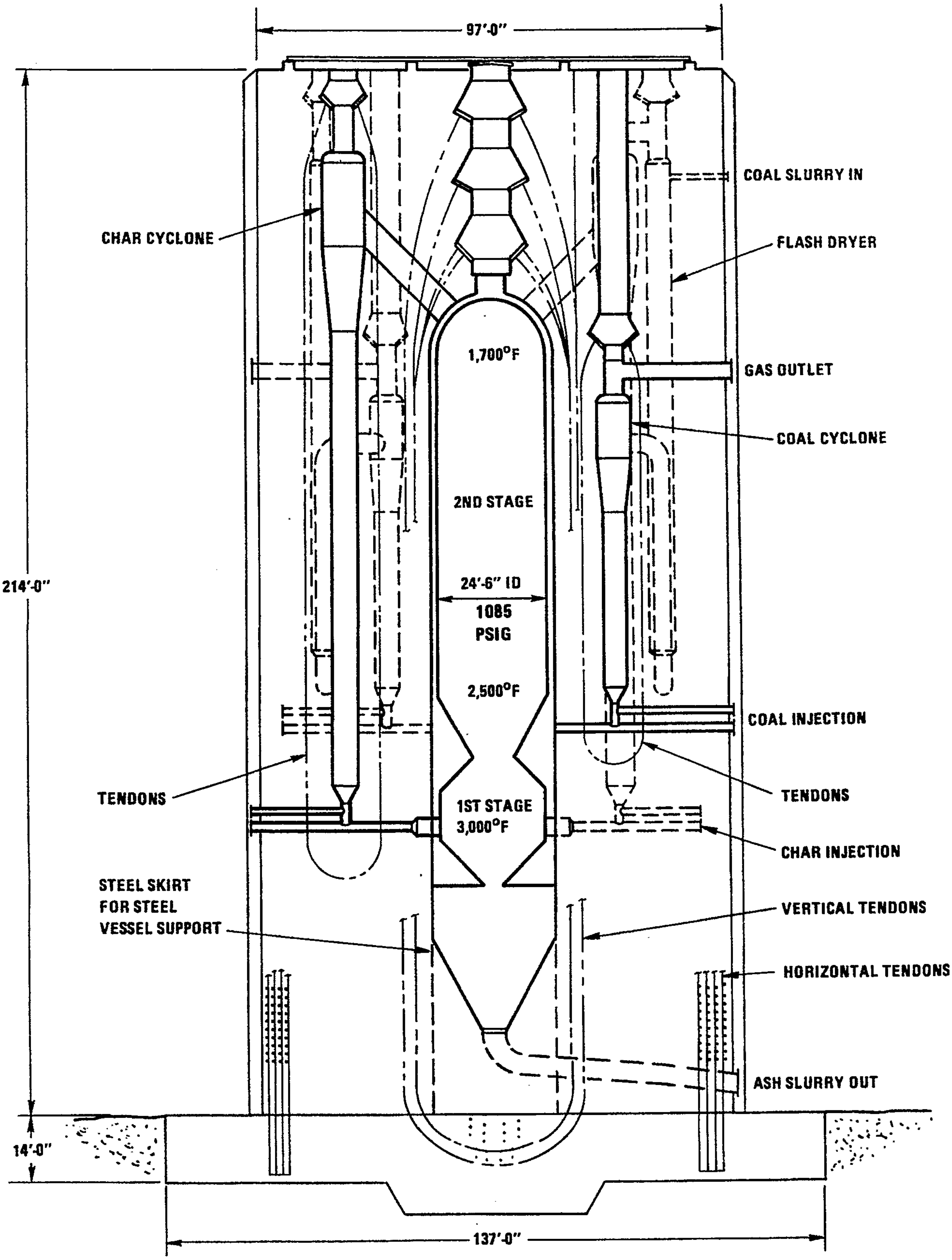
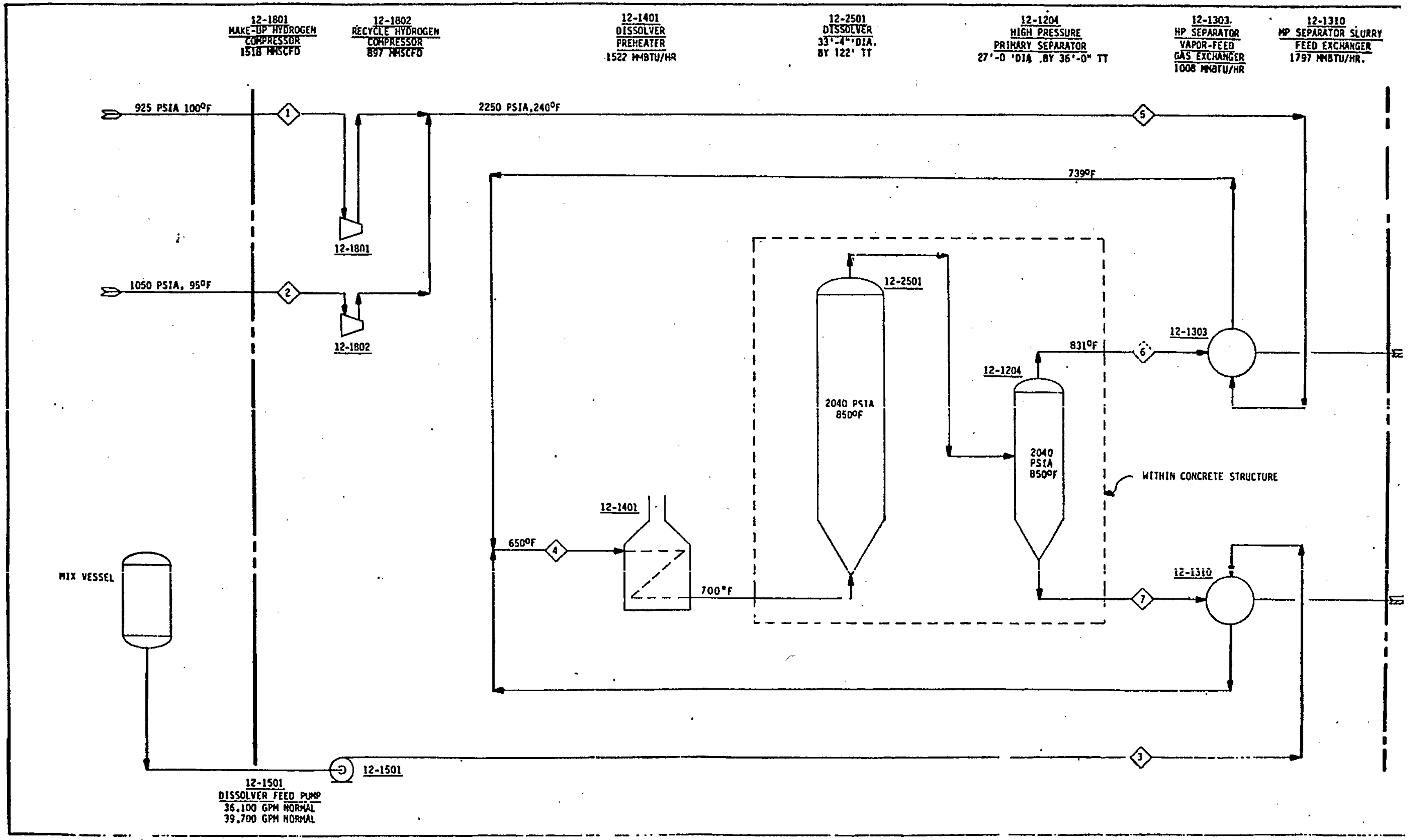
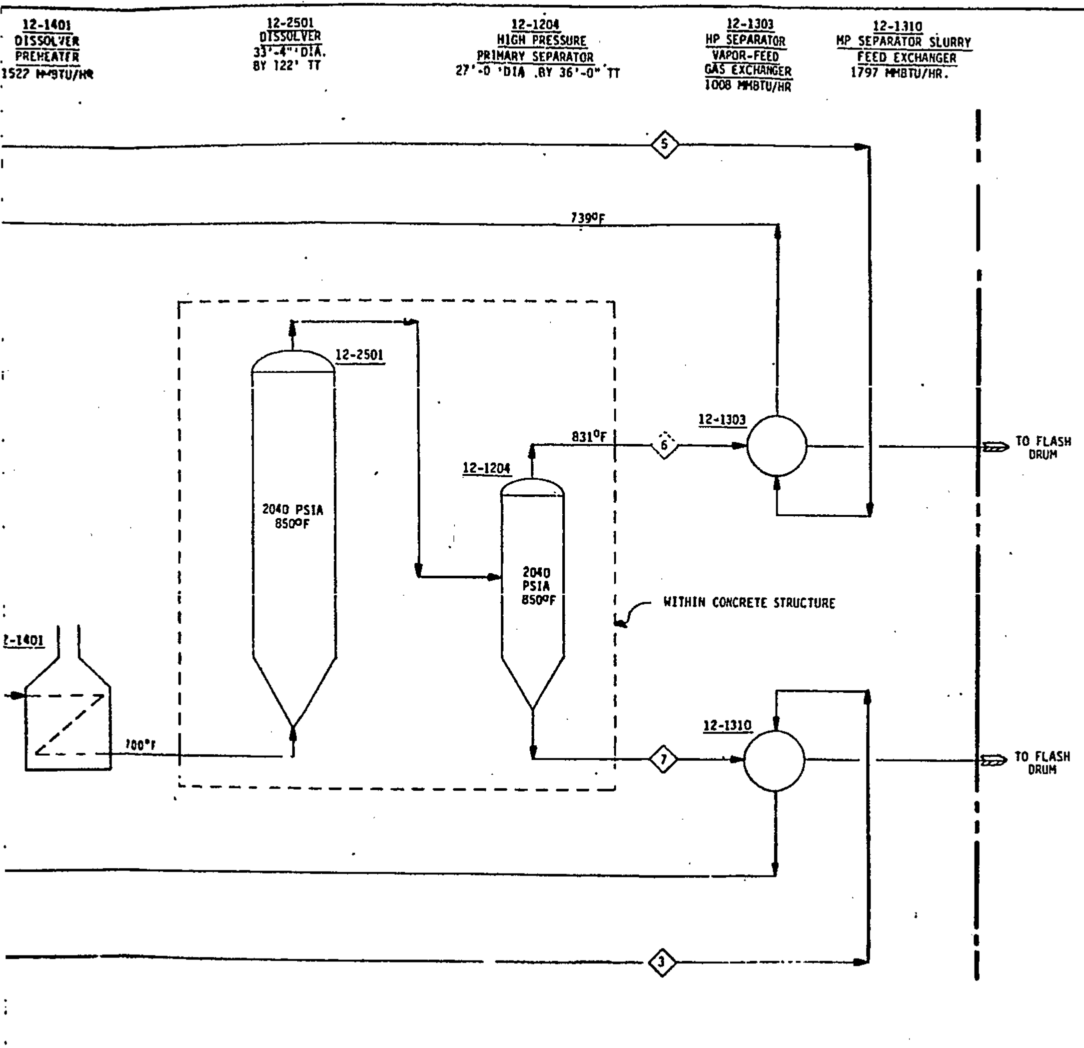


Figure 8 - Integrated Gasifier Vessel Sketch



12-1801
MAKE-UP HYDROGEN COMPRESSOR
1518 MMSCFD
12-1802
RECYCLE HYDROGEN COMPRESSOR
897 MMSCFD
12-1401
DISSOLVER PREHEATER
1522 MMBTU/HR
12-2501
DISSOLVER
33'-4" DIA. BY 122' TT
12-1204
HIGH PRESSURE PRIMARY SEPARATOR
27'-0 'DIA .BY 36'-0" TT
12-1303
HP SEPARATOR VAPOR-FEED GAS EXCHANGER
1008 MMBTU/HR
12-1310
HP SEPARATOR SLURRY FEED EXCHANGER
1797 MMBTU/HR.
925 PSIA 100°F
1050 PSIA, 95°F
2250 PSIA,240°F
739°F
831°F
650°F
700°F
2040 PSIA 850°F
2040 PSIA 850°F
WITHIN CONCRETE STRUCTURE
MIX VESSEL
12-1801
12-1802
12-1401
12-2501
12-1204
12-1303
12-1310
12-1501
12-1501
DISSOLVER FEED PUMP
36,100 GPM NORMAL
39,700 GPM NORMAL

5-7 A



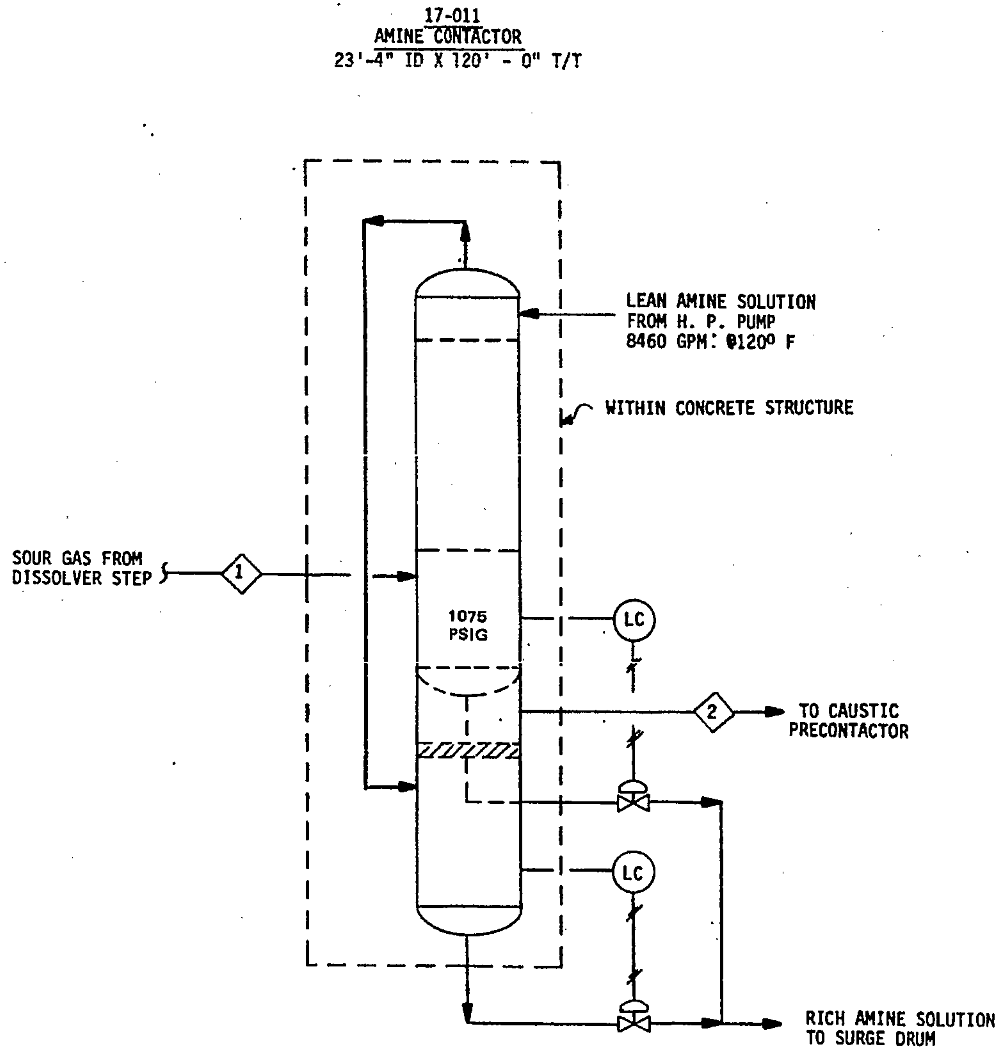
COMPONENT	① MAKE-UP HYDROGEN	② RECYCLE HYDROGEN	③ SLURRY TO DISSOLVER	④ SLURRY & GAS TO FURNACE	⑤ TOTAL HYDROGEN GAS	⑥ HP SEPARATOR VAPOR	⑦ HP SEPARATOR SLURRY
H_2 MOLES/HR.	132,590	94,308	---	226,898	226,898	103,460	9,989
N_2	1,027	345	---	2,772	2,772	1,681	1,090
CO	5,582	2,422	---	8,004	8,004	5,396	2,608
CO_2	166	---	---	166	166	1,142	199
NH_3	---	---	---	---	---	594	67
H_2S	86	---	---	86	86	3,451	423
H_2O	127	---	105	229	229	7,298	155
C_1	26,317	768	---	27,085	27,085	36,846	4,496
C_2	---	---	---	---	---	3,855	949
C_3	---	---	---	---	---	3,534	732
NC_4	---	---	---	---	---	1,274	333
IBP-200	---	---	---	---	---	310	95
200-400	---	---	---	---	---	1,791	1,38[illegible]
400-450	---	---	---	---	---	388	533
450-500	---	---	---	---	---	285	509
500-600	---	---	285	285	---	566	1,68[illegible]
650+	---	---	34,507	34,507	---	1,412	38,6[illegible]
RESIDUE	---	---	37	37	---	---	70
ASH	---	---	126	126	---	---	126
COAL (MAF)	---	---	427	427	---	---	---
TOTAL MOLES/HR	166,696	98,442	35,488	300,626	265,138	172,135	63,3[illegible]
LB/HR	909,536	296,750	19,866,890	21,073,176	1,206,286	2,491,344	18,551,83[illegible]
BPD	---	---	1,097,886	---	---	---	1,100,31[illegible]
MMSCD	1,518.213	896.589	---	---	2,414.8	1,578.8	---
MW	5.456	3.014	559.82	---	4.55	14.37	29[illegible]
LB/GAL	---	---	10.340	---	---	---	9.650

Figure 9

PROCESS FLOW DIAGRAM
DISSOLVER - SEPARATOR
PRESTRESSED CONCRETE
PRESSURE VESSEL

THE RALPH M. PARSONS COMPANY
R-1-15-2

7 A 5-7 B C



COMPONENT	① GAS TO CONTACTOR	② GAS FROM CONTACTOR
H_2 Mols/Hr	113,756	113,598
N_2	2,803	2,798
CO	8,004	7,997
CO_2	1,173	---
NH_3	16	---
H_2S	3,371	---
H_2O	148	148
CH_4	41,650	41,587
C_2H_6	4,798	4,791
C_3H_8	4,285	4,280
C_4H_{10}	1,417	1,415
IBP-200°F	259	258
200-300°F	88	88
300-350°F	5	5
350-400°F	1	1
400-450°F	---	---
TOTAL MOLS/HR	181,773	176,966
LB/HR	1,816,392	1,647,375
MSCFH	69,078	67,158
M.W.	9,993	9,309

Figure 10

REV NO	CUST APPR.	DATE	REVISION	BY	PROC ENGR	CHECK	CHIEF PROC. ENGR.	CHIEF OPER. ENGR.	PROC. DIR.
0				SRO					

PROCESS FLOW DIAGRAM
ABSORBER
PRESTRESSED CONCRETE
PRESSURE VESSEL

THE RALPH M. PARSONS COMPANY
PASADENA, CALIFORNIA

JOB NO. 5435-6 | DWG NO. R-1-FS-3 | REV. 0

DC- DT-

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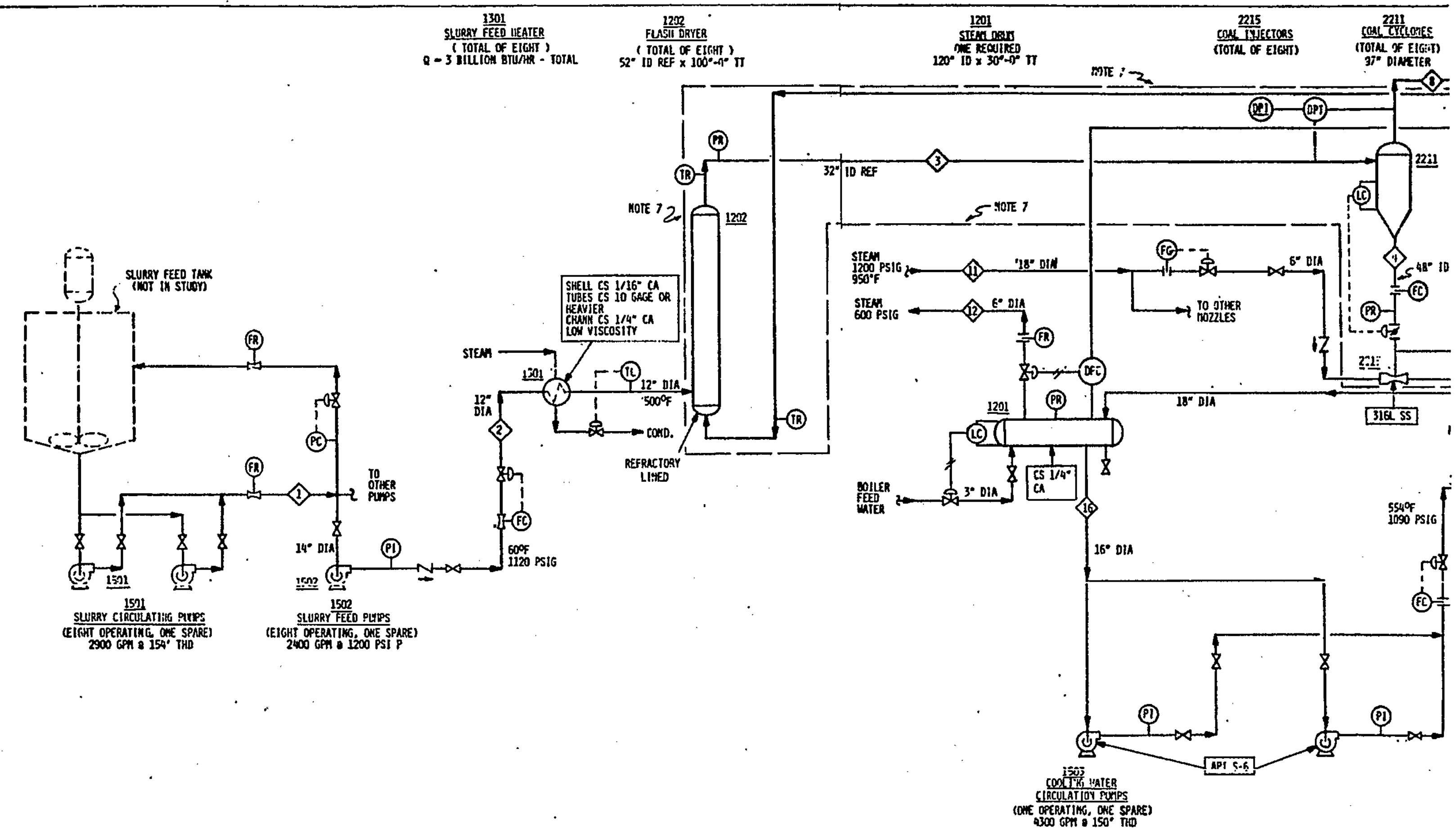
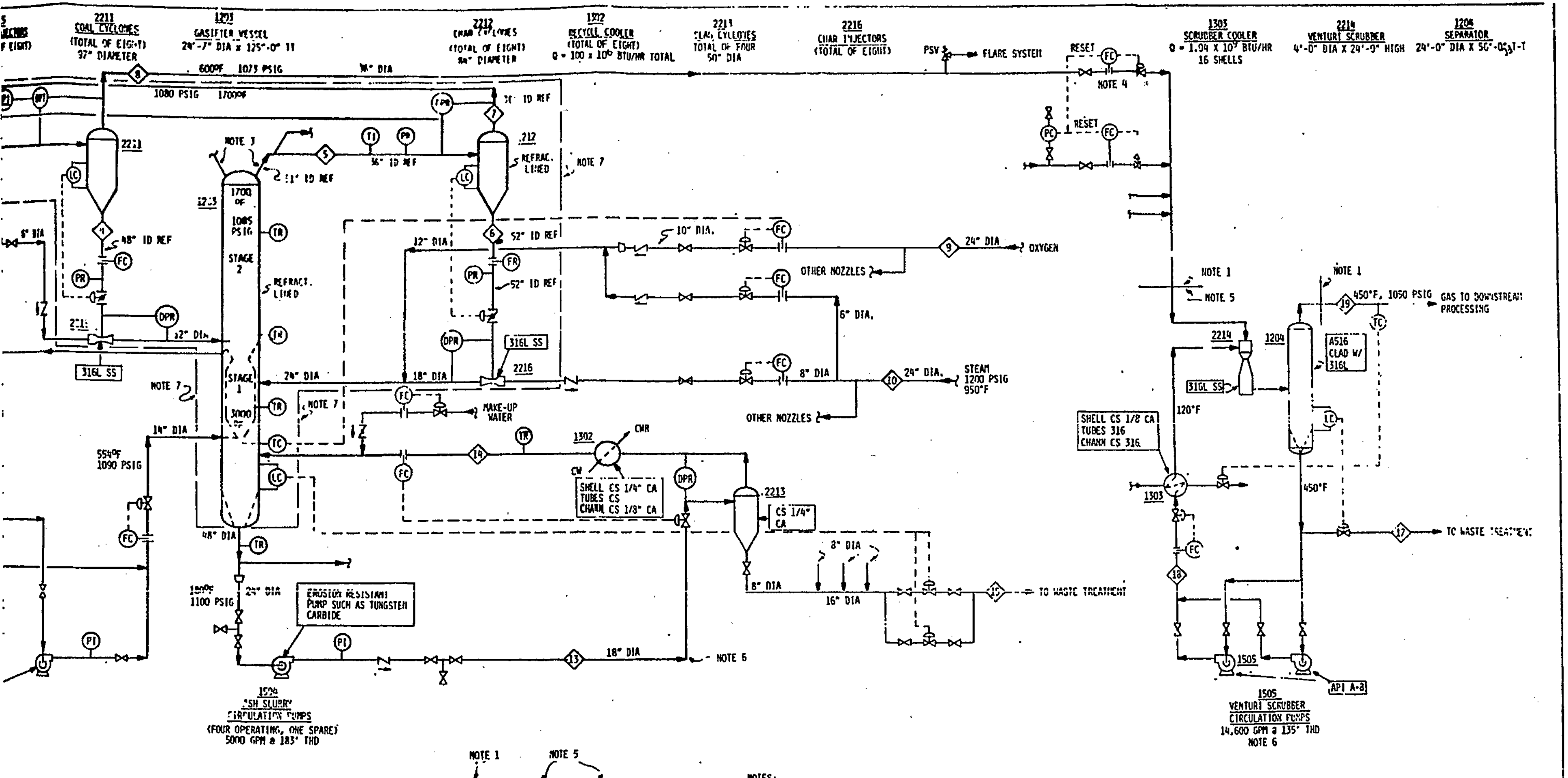


STREAM NO.	1	2	3	4	5	6	7	8	9	10	11
GASES MOLS/HR											
H_2	-	-	113,310	-	113,310	-	113,310	113,310	-	-	-
CH_4	-	-	51,230	-	51,230	-	51,230	51,230	-	-	-
CO	-	-	132,460	-	132,460	-	132,460	132,460	-	-	-
CO_2	-	-	72,070	-	72,070	-	72,070	72,070	-	-	-
H_2O	-	-	408,880	-	87,950	-	87,950	408,880	-	101,760	50
H_2S	-	-	5,270	-	5,270	-	5,270	5,270	-	-	-
NH_3	-	-	4,200	-	4,200	-	4,200	4,200	-	-	-
N_2	-	-	1,320	-	1,320	-	1,320	1,320	1,320	-	-
O_2	-	-	-	-	-	-	-	-	64,570	-	-
Total Mols	-	-	788,740	-	467,810	-	467,810	788,740	65,490	101,760	50
Total Lbs	-	-	15.58×10^6	-	9.80×10^6	-	9.80×10^6	15.58×10^6	2.10×10^6	1.33×10^6	0.92 x
SOLIDS AND LIQUIDS LBS/HR											
C	3.96×10^6	3.28×10^6	3.50×10^6	3.30×10^6	3.50×10^6	3.29×10^6	220,000	196,600	-	-	-
H	$.27 \times 10^6$	0.22×10^6	0.22×10^6	0.21×10^6	-	-	-	13,400	-	-	-
O	$.52 \times 10^6$	0.43×10^6	0.43×10^6	0.40×10^6		-	-	25,500	-	-	-
N	$.07 \times 10^6$	0.06×10^6	0.06×10^6	0.06×10^6		-	-	3,800	-	-	-
S	$.22 \times 10^6$	0.18×10^6	0.18×10^6	0.17×10^6	-	-	-	10,900	-	-	-
Ash	$.72 \times 10^6$	0.60×10^6	0.66×10^6	0.62×10^6	1.08×10^6	1.02×10^6	60,000	35,800	-	-	-
H_2O	7.15×10^6	5.92×10^6	0.14×10^6	0.13×10^6	-	-	-	8,200	-	-	-
Total	12.91×10^6	10.69×10^6	5.19×10^6	4.89×10^6	4.58×10^6	4.31×10^6	270,000	294,700	-	-	-
Total Lb/Hr	12.91×10^6	10.69×10^6	20.77×10^6	4.89×10^6	14.38×10^6	4.31×10^6	10.07×10^6	15.87×10^6	2.10×10^6	1.33×10^6	0.92 x

5-11 A

5-1 B



9	10	11	12	13	14	15	16 (NOTE 1)	17 (NOTE 5)	18 (NOTE 5)	19
-	-	-	-	Note 2	Note 2	Note 2	-	Note 2	Note 2	113,310
-	-	-	-				-			51,230
-	-	-	-				-			132,460
-	-	-	-				-			72,070
-	101,700	50,880	1,940				-			247,470
-	-	-	-				-			5,270
-	-	-	-				-			4,200
1,320	-	-	-				-			1,320
66,170	-	-	-				-			-
[illegible]	101,760	50,880	1,940				-			627,330
7.10×10^6	1.33×10^6	0.92×10^6	35,000				-			12.67×10^6
-	-	-	-	32,600	1,600	31,000	-	97,300	378,000	2,000
-	-	-	-	-	-	-	-	6,600	25,800	130
-	-	-	-	-	-	-	-	12,600	49,200	250
-	-	-	-	-	-	-	-	1,900	7,300	60
-	-	-	-	-	-	-	-	5,400	21,000	110
-	-	-	-	549,300	28,500	540,800	-	17,700	69,000	340
-	-	-	-	8.92×10^6	7.60×10^6	1.26×10^6	1.57×10^6	1,458,000	5,677,400	80
-	-	-	-	9.52×10^6	7.60×10^6	1.83×10^6	1.57×10^6	1.60×10^6	6.21×10^6	2,970
7.10×10^6	1.33×10^6	0.92×10^6	35,000	9.52×10^6	7.60×10^6	1.83×10^6	1.57×10^6	1.60×10^6	6.21×10^6	12.68×10^6

NOTES:

1. ALL FLOW RATES TOTAL FOR TRAIN, TWO TRAINS REQUIRED.
2. DISSOLVED GASES ARE NOT INCLUDED AS THEY ARE RECOMPRESSED INTO MAIN GAS STREAM.
3. FOUR NOZZLES ON GASIFIER VESSEL TWO PARALLEL BRANCH LOOPS FROM EACH NOZZLE.
4. PRESSURE CONTROLLER TO RESET FLOW CONTROLLERS FOR EIGHT PARALLEL PATHS.
5. FOUR PARALLEL TRAINS TO HANDLE GAS FROM TOTAL PLANTS (BOTH TRAINS).
6. ONE LOOP SHOWN, FOUR LOOPS TOTAL.
7. ALL EQUIPMENT WITHIN THIS AREA TO BE IN PRESTRESSED CONCRETE PRESSURE VESSEL.

Figure 11

0	INITIAL ISSUE	

PROCESS FLOW DIAGRAM
25 FOOT DIA. GASIFICATION REACTOR
PRESTRESSED CONCRETE CONCEPT

THE RALPH M PARSONS COMPANY
PASADENA, CALIFORNIA

R-1-FS-1

5-11 D

5-11 B

5-11 C

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SECTION 6

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APPENDIX A

TABLE OF CONTENTS OF MAIN REPORT

APPENDIX A REFRACTORY CHARACTERISTICS

APPENDIX B COOLDOWN RATE

APPENDIX C EFFECT OF REFRACTORY AND COOLING WATER FAILURES

APPENDIX D BRIEF SPECIFICATIONS FOR THE CONCRETE STRUCTURE OF A PCPV

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