CONF-790802--42

FEASIBILITY STUDY OF PRESTRESSED CONCRETE PRESSURE VESSELS FOR COAL GASIFIERS*

C. B. Oland W. L. Greenstreet
J. P. Callahan

Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

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ABSTRACT

The use of prestressed concrete pressure vessels (PCPVs) for gasifiers in coal conversion systems has been examined by the Oak Ridge National Laboratory. Conceptual designs for commercial-sized vessels were developed based on an output of 2.64×10^8 MJ/day for the HYGAS process gasifier and 1.32×10^8 MJ/day for the Synthane process gasifier. Circular cylindrical configurations were employed for the single-cavity vessels. The geometry of the liners was essentially the same as proposed for the commercial steel vessel in both cases.

Although the geometry of the HYGAS gasifier vessel differs considerably from the Synthane PCPV the two vessels are quite similar from the conceptual standpoint. Consequently, only the reference design for the Synthane vessel will be described. The inside diameter of the steel liner for the Synthane gasifier is 9.75 m. The overall height of the structure is 46.63 m and its outer diameter is 16.76 m. A design pressure of 7.41 MPa was used together with a maximum process fluid temperature of 982°C.

The liners for both gasifiers are protected from the process temperature and the deleterious effects of the process media by refractory lining systems. Two liner designs were developed for each type of gasifier based on a hot-liner system and a cold-liner system. The hot-liner is designed to operate at a temperature above the dew point of the process fluid. Insulating concrete is used between the steel liner and the structural concrete. Anchorage is provided by steel anchor studs welded to the liner. The studs extend through the insulating concrete and are embedded into the structural concrete. The refractory is anchored by stainless steel to the inside of the steel liner. Finned tubes through which cooling water is circulated to remove excess heat are located between the insulating concrete and structural concrete. The cold liner, wich is restricted to temperatures below the dew point of the process fluid, was selected as the backup design.

The Synthane and HYGAS gasifiers both require numerous small penetrations. One large-diameter penetration is required in the top head. A removable multiplate steel structure serves as the closure for this large penetration. It is restrained by a series of short columns which provide for easy removal.

Each vessel is posttensioned by circumferential strand windings which are confined and anchored in steel-lined precast concrete channels on the outside surface of the PCPV. Linear tendon clusters which are housed in steel ducts provide the axial prestressing.

The results of these studies show that the use of prestressed concrete vessels in applications where large, heavy-walled, steel vessels are required is both technically and economically feasible. Further, the advantages of concrete over steel vessels for gasifiers are directly related to vessel size.

*Research sponsored by the Office of Fossil Energy Programs, U.S. Department of Energy under contract W-7405-eng-26 with the Union Carbide Corporation.

1. INTRODUCTION

An examination was made of the feasibility of using prestressed concrete pressure vessels (PCPVs) as gasifier vessels in coal conversion systems. Applications considered were those such as for the Synthane and HYGAS processes where large, thick-walled steel gasifier vessels would be required. Conceptual designs of pressure vessel and liner combinations for commercial-sized plants were developed and studied for assessment and guidance.

The impetus for consideration of PCPVs stems from at least two major factors. Steel gasifier vessels for commercial coal conversion plants are expected, in many cases, to be very large, heavy-walled structures that must be field fabricated. The requirements for such construction approach the limits of current steel production capability for plate thickness and related quality assurance, and field fabrication experience must be extended. In addition, there are important safety considerations associated with containment of the high temperature, high pressure process media, which present hostile environments for structural components.

Prestressed concrete pressure vessels offer a number of advantages which make them attractive for use in coal conversion plants where very large containment vessels are required. These advantages include field fabricability, nonrestrictive limitation on size, ease of fabrication, and use of readily available and relatively inexpensive materials. The vessels are made of reinforced concrete in conjunction with a posttensioning system consisting of vertical tendons and circumferential wire-strand windings. Conventional construction procedures are utilized for field fabrication of these structures, and the current technology required for design and analysis is advanced sufficiently to permit consideration of prestressed concrete vessels for coal conversion process applications. Moreover the approximately one-quarter of a century of satisfactory performance of prestressed concrete pressure vessels in nuclear applications provides considerable assurance of satisfactory performance.

2. BACKGROUND

Gasifiers for the HYGAS and Synthane processes were selected for consideration [1]. Two-train plants were assumed for the two processes; the output of each train was 2.64×10^8 MJ/day (250×10^9 Btu/day) for the HYGAS gasifier and 1.32×10^8 MJ/day (125×10^9 Btu/day) for the Synthane gasifier. The design requirements for the vessels were based on conceptual design studies performed by C. F. Braun and Company with augmentations from other sources in the case of the Synthane gasifier vessel.

The PCPV conceptual design studies were limited to the pressure vessels; that is, the vessel internal structural members were not considered except as they would interact with the vessel. Connecting equipment was also not considered. Base supports for the vessels were included in the scope of the study, but the foundations were not. The loadings addressed were those for normal operating, startup, and shut-down conditions; seismic loadings were not considered.

In preparing the conceptual designs for the gasifier PCPVs, two alternatives were considered for the liner — a hot-liner and a cold-liner concept. For the first alternative, the operating temperature is above the dew point of the process media to minimize corrosive attack from condensation, while, for the second, the operating temperature is about the same as the temperature at the inner surface of the structural concrete. The hot-liner concept was used as the reference design since maintenance of the temperature at the dew point appears to be a most desirable feature. However, since all past operating experience with PCPVs has involved the cold-liner system, it was selected as the backup design. The reader is referred to Ref. [1] for further discussion of the cold-liner design.

Although the geometry of HYGAS gasifier vessel differs considerably from the Synthane PCPV, the two vessels are quite similar from the conceptual standpoint. Consequently, only the reference design for the Synthane vessel will be described in the following section.

3. DESCRIPTION OF THE SYNTHANE GASIFIER PCPV CONCEPTUAL DESIGN

The conceptual design [1] for a Synthane gasifier PCPV is illustrated in Figs. 1 and 2. This is the reference design which features the hot-liner concept. The design pressure is 7.41 MPa (1075 psi). The inside diameter of the steel liner is 9.75 m (32 ft). A 0.30-m (12-in.) refractory lining protects the 0.03-m steel liner from the 982°C process temperature. The PCPV rests on a base support which consists of four 52.5-deg concrete segments. The height of the vessel excluding its supporting structural head is 41.76 m (137 ft) and its outer diameter is 16.76 m (55 ft).

The lateral penetration design shown in Fig. 1 consists of a refractory-lined steel sleeve that extends through a circular radial opening in the concrete vessel. The sleeve is integrally attached to the liner and is actually an extension of this member. The pressure-tight seal for the larger penetration (manway) is provided by a cover plate, or blind flange, at the outside surface of the vessel.

Four 0.20-m-ID (8-in.) coal slurry inlet penetrations are located at 90-deg intervals around the vessel at elevation 25.22 m (82.75 ft). These inlet penetrations are refractory lined. A typical 0.05-m-diam (2-in.) instrumentation penetration is shown at elevation 20.65 m (67.75 ft); additional instrumentation penetrations will be required at unspecified locations. A manway is also located at elevation 20.65 m (67.75 ft) to provide access to the region of the vessel above the conical grid. A second manway passes through the bottom head of the concrete vessel to permit access to the region below the grid. Both manways are refractory lined, with the inside lining diameters being 0.91 m (36 in.) and are sealed at the external surface of the concrete by removable steel cover plates. A 0.61-m-ID (24 in.) refractory-lined grid outlet penetration is provided through the bottom concrete head at the vessel centerline. A 0.66-m-ID (26-in.) refractory-lined steam and oxygen inlet penetration also extends through the bottom concrete head. All of these penetrations have steel liners which derive their structural support from liner anchor studs and shear anchor assemblies that are embedded in the structural concrete.

The 2.74-m-ID (9-ft) penetration through the top concrete head is sealed by a removable steel closure plug shown in Figs. 3 and 4, which also supports the cyclone and cyclone downcomer. The gas enters the cyclone and passes out of the gasifier through a 0.91-m-ID (36-in.) opening in the center of the steel plug. Forty-eight 0.11-m-diam (4.25-in.) toggles secure the plug during operation of the vessel. These toggles are designed to permit easy removal of the closure plug and attached cyclone for maintenance. During vessel operation, the pressure loadings acting on the plug are transferred by the toggles to the 24 adjacent prestressing tendons. In addition to these 24 tendons, another 108 vertical prestressing as the temperature at the inner surface of the structural concrete. The hot-liner concept was used as the reference design since maintenance of the temperature at the dew point appears to be a most desirable feature. However, since all past operating experience with PCPVs has involved the cold-liner system, it was selected as the backup design. The reader is referred to Ref. [1] for further discussion of the cold-liner design.

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The circumferential prestressing consists of posttensioned strand windings, which are confined and anchored in steel-lined precast concrete channels on the outside surface of the PCPV. These channels also serve as formwork during concrete casting and support the waterproofed external insulation. The vessel requires 1.1×10^{-3} m^2 (1.7 $in.^2$) of high-strength prestressing steel per 0.025 m (1 in.) of vessel height based on ultimate strength considerations. Each of the 37 channels contain 890 wraps of 0.95×10^{-2}-m-diam (0.375-in.) strand. The strand is tensioned initially to about seven-tenths of the ultimate tensile strength. Bonded reinforcing bars are placed near the outside surface of the concrete walls in the circumferential and horizontal directions to provide crack control and added resistance to overpressurization.

The hot-liner system is shown in Fig. 5. A layer of insulating concrete is used between the steel liner and the structural concrete. Steel anchor studs, which are 0.38 m (15 in.) long and 0.02 m (0.75 in.) in diameter, are welded to the liner, extended through the insulating concrete and embedded in the structural concrete. These anchors are spaced on a 0.15-m (6-in.) square pitch. The refractory lining, which is placed on the inside of the steel liner, consists of a layer of insulating refractory and an inner layer of erosion-resistant dense alumina refractory, which is in direct contact with the process environment. Stainless steel anchors secure the refractory to the liner.

Finned tubes, through which cooling water is circulated to remove excess heat, are located between the insulating concrete and structural concrete. The cooling tubes are arranged into two discrete circuits in which tubes extend halfway around the vessel. Every other tube is supplied from an independent coolant source, with each of the two sources being capable of providing adequate vessel cooling. Each circuit is equipped with devices to measure coolant flow rates and inlet and exit temperatures; these devices are monitored to detect vessel hot spots and possible cooling system malfunctions.

The structural materials associated with the Synthane PCPV and estimated weight for the various items are listed in Table I.

Since the vessel is not contained in another structure or enclosure, the top of the PCPV must be protected from moisture and temperature extremes by an insulated and waterproofed roof system. It is anticipated that the roof will be a conventional-type structure which is supported by the PCPV and has no unique features; therefore, the details were not included in this study. A cellular foam-type material was selected for the external insulation. The insulation would be installed as blocks and held in place by stainless steel straps or other suitable means. The outer surfaces of the blocks are to be coated with a commercial waterproofing material.

4. CONCLUSIONS

In general, this study has shown that PCPVs are potentially both technically and economically feasible for gasifier applications. Since the requirements for gasifier vessels are probably the most stringent, it is expected that other uses in coal conversion systems could be readily accommodated.

Our conclusions on economics were based on cost studies for equivalent steel and concrete vessels for HYGAS gasifiers. For vessels of this size and complexity, the costs were estimated to be virtually the same. Interestingly, the amount of steel for the two vessels was also nearly the same. However, the PCPV generally uses less expensive lower-alloy steel. Thus, this study indicates that, for the case examined, the desirable attributes associated with PCPVs plus less demanding steel requirements can be had without economic penalty. In general, the relative economics favor PCPVs when the scale is large.

The technical conclusions reached must be confirmed by test work. In particular, the acceptable performance of the liner-thermal barrier system must be demonstrated for expected service-type conditions. Although these studies indicate that acceptable performance can be achieved, feasibility endorsement rests with demonstration of this aspect.

Other factors requiring examination are the influences of hydrogen-rich atmospheres on steel prestressing tendon behavior. Although no problems are suggested by available evidence, the possibility of adverse affects should be explored. There is an advantage here since possible detrimental effects can be mitigated by periodic tendon replacement. An experimental program to explore these and other questions is outlined in Ref. [1].

In total, the feasibility of the use of PCPVs as gasifier vessels in commercial coal conversion plants was examined with positive results. The next logical step is to complete the assessment by conducting test work to examine key issues, as identified.

REFERENCE

[1] GREENSTREET, W. L., OLAND, C. B., CALLAHAN, J. P., and CANONICO, D. A., *Feasibility Study of Prestressed Concrete Pressure Vessels for Coal Gasifiers*, ORNL-5312, Oak Ridge National Laboratory (August 1977).

Table I. Estimated weight of structural materials for Synthane PCPV

Item description	Estimated weight [kg × 10^3 (ton)]
Concrete	18,228 (20,051)
Refractory	548 (603)
Circumferential prestressing	
Prestressing steel	731 (822)
Precast concrete channel steel liners	70 (73)
Anchorage assemblies	13 (14)
Vertical prestressing	
Bearing plates	55 (60)
Conduits	66 (73)
Prestressing steel	237 (261)
Anchorage assemblies	23 (25)
Liner, shear anchors, anchor studs, cover plates	381 (420)
Steel closure, toggles, bearing ring, anchorage, cyclone	82 (91)
Reinforcing steel	807 (888)

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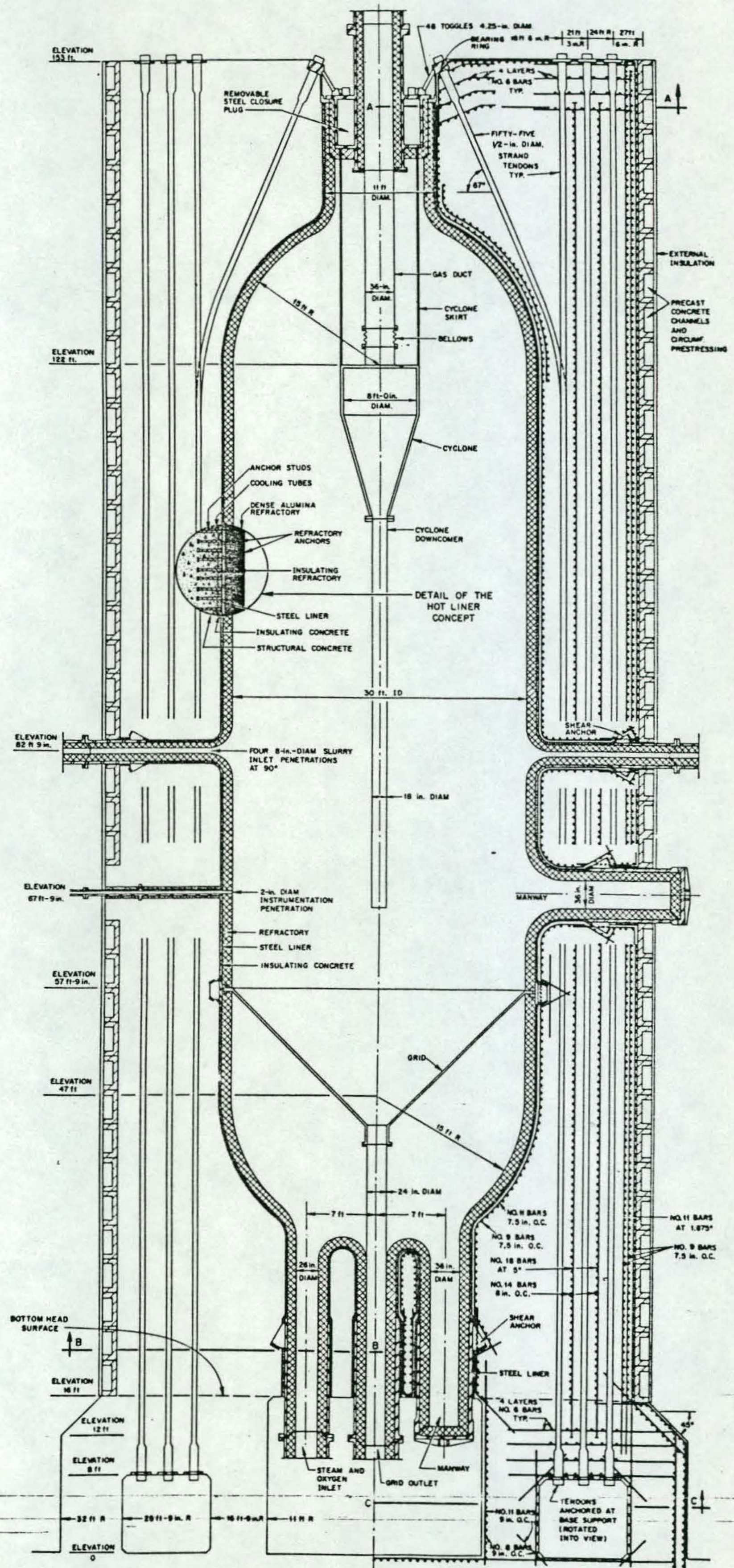

Fig. 9.1. Synthane gasifier PCPV cross section.

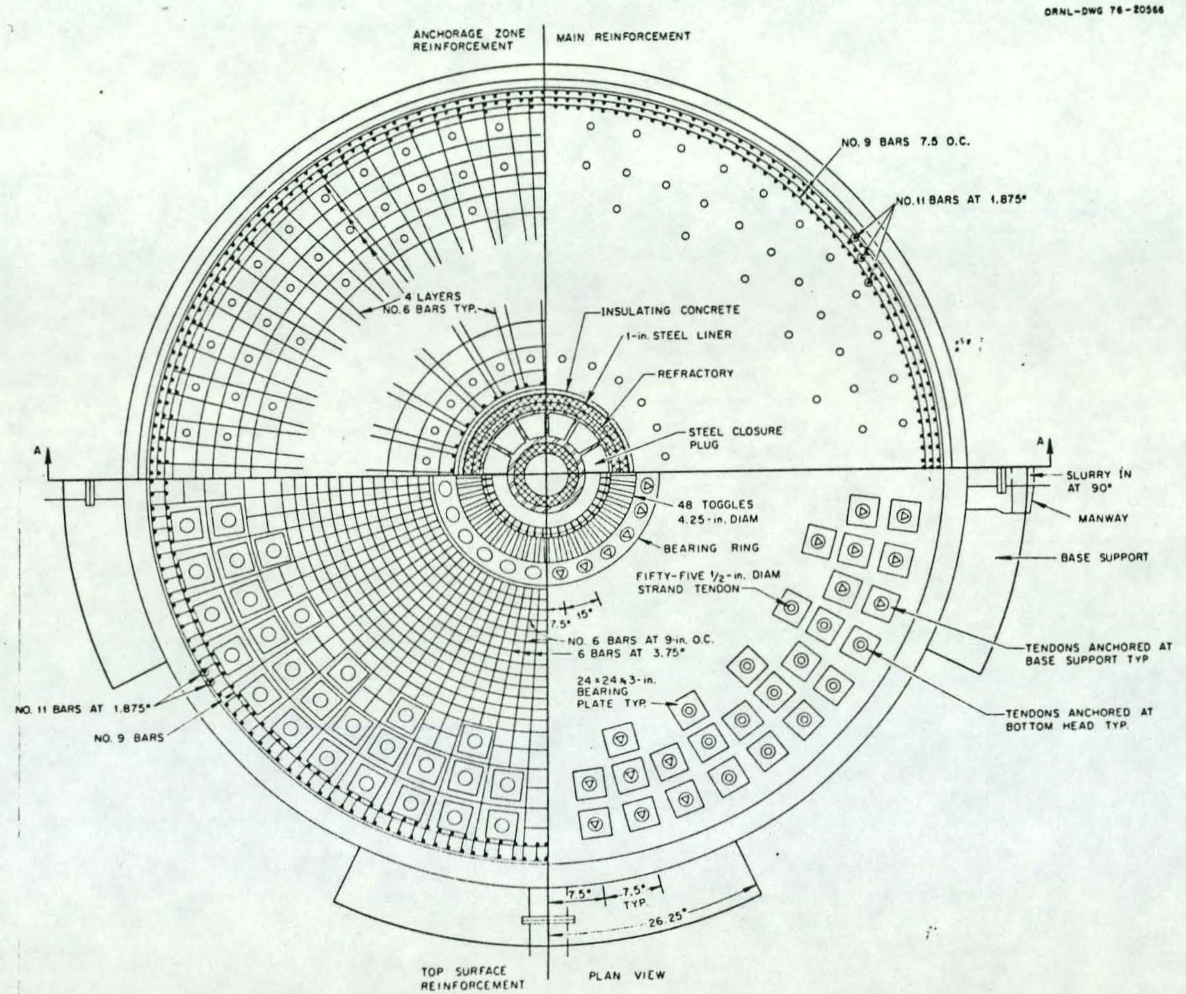

Fig. ●.2. Synthane gasifier PCPV, top view.

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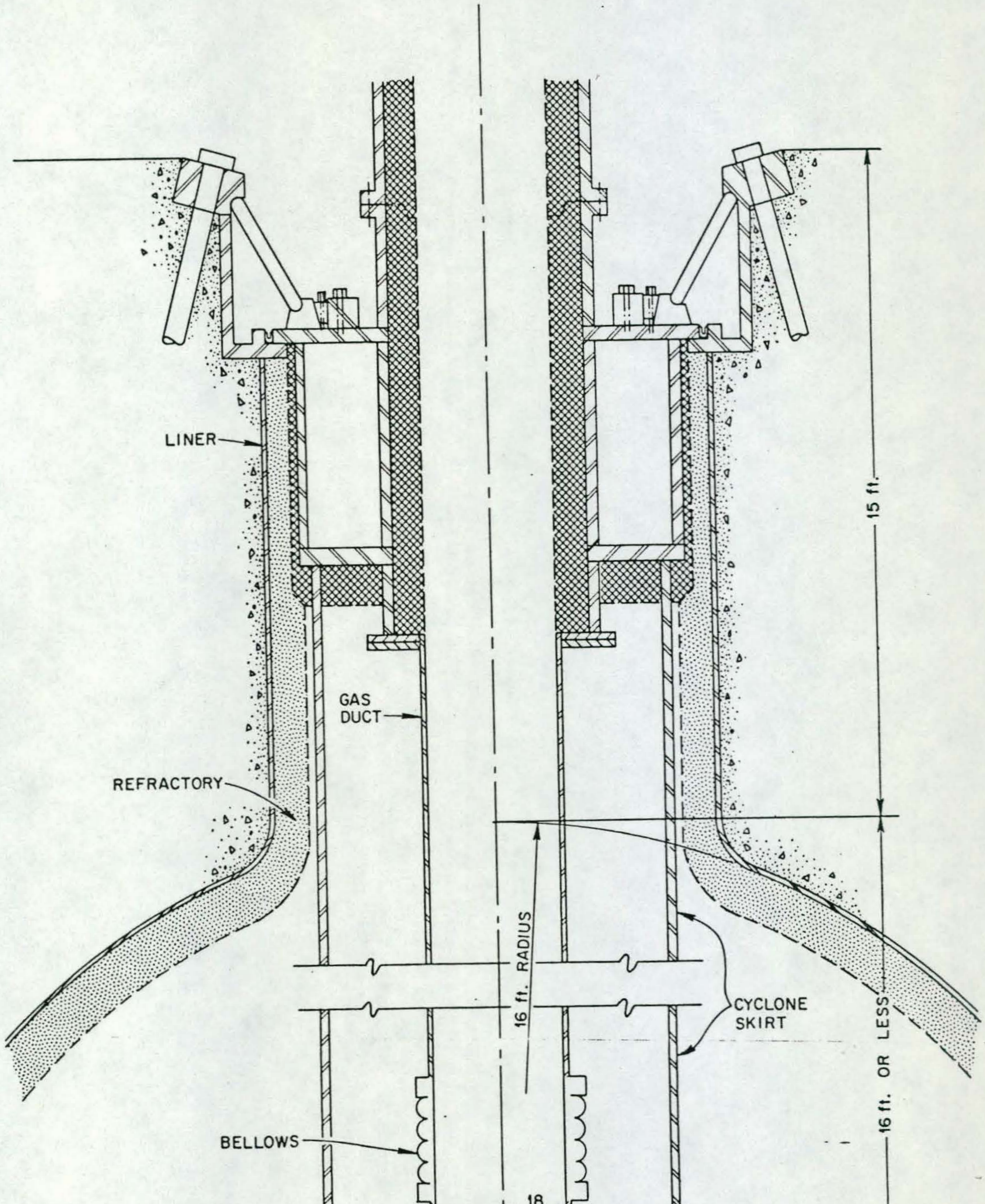

Fig. 3Ø. Removable steel closure plug for Synthane PCPV.

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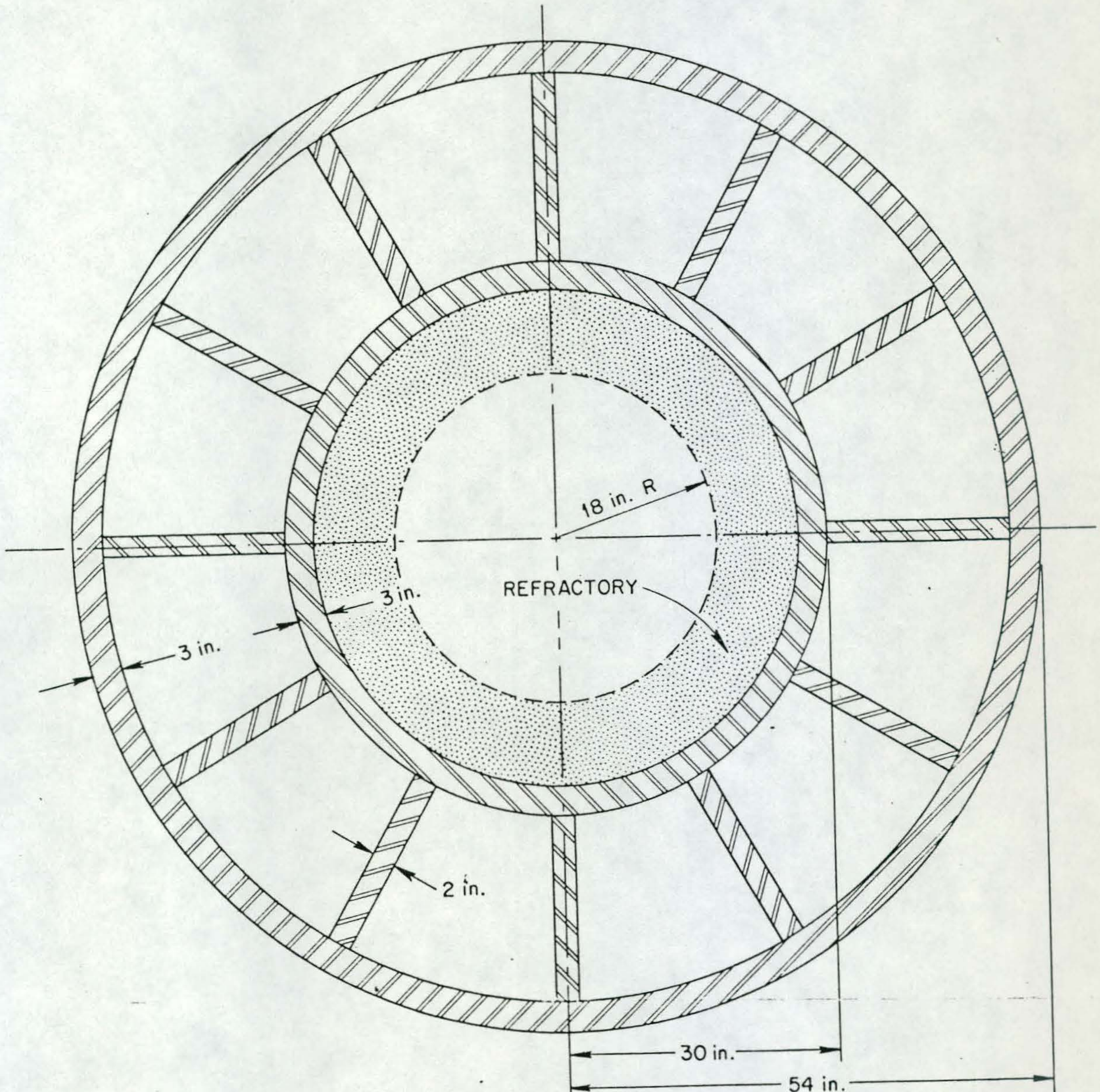

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Fig. 3.9. Cross section of removable steel closure plug for Synthane PCPV.

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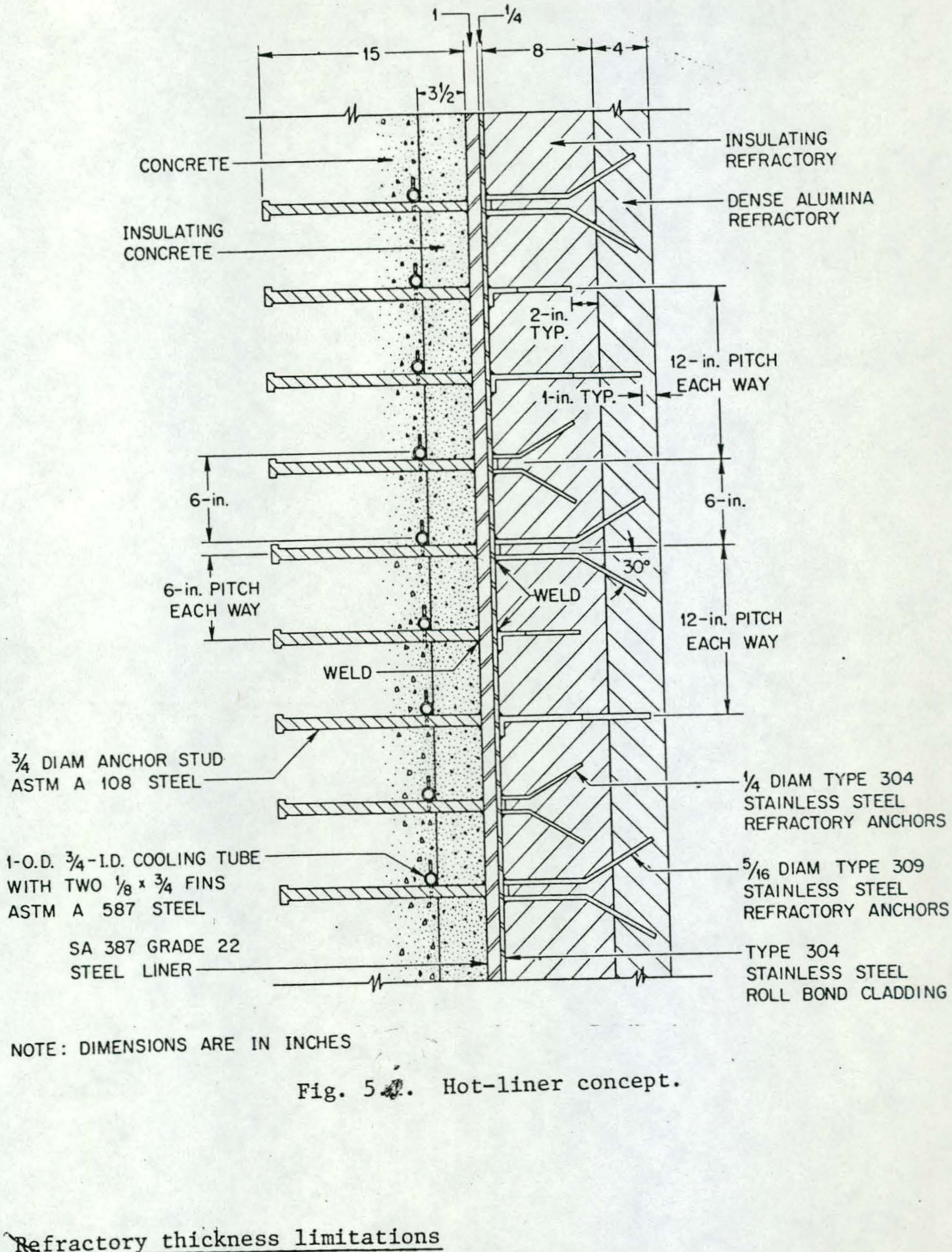

NOTE: DIMENSIONS ARE IN INCHES

Fig. 5[illegible]. Hot-liner concept.

Refractory thickness limitations

The vessel design configurations and requirements established by C. F. Braun and Co. specified inside diameters of the inner surface of the refractory lining. In establishing the inside diameters of the steel liner surfaces, the following refractory thicknesses were assumed at an early