EXPERIENCES WITH PRIMARY REFORMER FURNACES AND TRANSFER LINES

Proper design and use of long-life materials for these services are more important than ever with today's big plants and their high downtime costs

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Increase in the size of ammonia, methanol, and other plants utilizing hydrogen has made it necessary to revise the design philosophy of primary steam methane reformers and transfer lines, in order to minimize the high cost of putting such plants on stream and to increase their on-stream reliability.

The introduction of high pressure reforming required the development of new materials capable of withstanding high stresses at elevated temperatures. It also led to new design approaches which can overcome problems both mechanical and operational. Because of the high cost of downtime in large units, it is essential that the industry standards be elevated to a reliability level higher than ever before. Cooperation between design engineers, field construction operating personnel, and equipment suppliers is of utmost importance.

Our experiences with the design and operation of primary steam reformers will be discussed first, then those dealing with transfer lines. In both cases it is hoped the industry will benefit from the presentation.

Design of reformer furnaces

To understand our experience with primary steam methane reformers, it is necessary to present a general description of our furnaces, with particular emphasis on the reforming section. The following basic considerations are involved in their design:

1. Uniformity of heat distribution.
2. Sound mechanical design, with emphasis on low stresses in high temperature alloy pressure parts.
3. Ease of operation and maintenance.

The terrace wall design insures uniformity of heat distribution along the length of the furnace, controlled degree of heat flux along the height of tubes, and uniform circumferential heat flux around the tubes. The special designed burner with no marked discontinuity assures uniform heat distribution along the length of the furnace at all terrace levels. The inclined terrace wall design, with continuous burners at each terrace, provides the means for controlling the degree of heat flux along the height of the catalyst tubes. Firing the tubes evenly from both sides assures maximum uniformity of circumferential heat flux.

The operating temperature and pressure levels in steam methane reforming requires use of high temperature alloy materials with rapidly decreasing allowable stress levels. The selection, therefore, of the material utilized in the reformers is of prime importance.

Materials are selected on the basis of their ability to withstand stresses developed by both internal pressure and external causes. These external causes are thermal expansion and weight stresses. Since the stresses caused by internal pressure are a function of process consideration, they are considered more or less fixed. The only variable stresses, therefore, are the ones due to thermal expansion and the weight of the various components. To insure low stress levels in the system, and especially in the high temperature alloy components, Foster Wheeler utilizes a patented design.

Design of header and tubes

The radiant section of the furnace, where the primary reforming reaction occurs, basically consists of the following: An inlet header which feeds the catalyst tubes by means of the inlet connectors, the catalyst tubes that contain the catalyst, and the outlet header connected to the catalyst tubes by means of the outlet connectors. The inlet and outlet connectors are known in the industry as inlet and outlet pigtails respectively.

It is essential that the stresses in each of the above components be kept to a minimum, and that the thermal expansion affect of each component on the others is minimized. It is also important that the pressure drop in the system be kept to a minimum since each pound of pressure drop savings ultimately represents more tons of daily ammonia production. Since the pressure drop in the catalyst tube is fixed by the catalyst volume, pressure drop can only be saved in the inlet and outlet headers and pigtails. This pressure drop savings must, however, be accomplished without sacrificing mechanical and stress reliability of the system.

The catalyst tubes are supported by a unique multiple counterweight arrangement. This arrangement, while it supports as many as four tubes with one counterweight, allows differential movement in the tubes that it supports. It provides positive means for free vertical upward expansion of the tubes and maintains tension throughout the length of the tubes at all times.

Since the tubes are supported by a counter-weight, the longitudinal stresses in the tubes do not vary as the tubes expand upward. Incidentally, a counterweight support, by nature, requires the least amount of field maintenance. By keeping the tubes in tension at all times, the tendency of the tubes to bow is materially minimized. It should be noted at this time that a special connection detail between the tube and its counterweighted support allows removal of the top flange for access to the catalyst without disconnecting the counterweight.

Provisions for tube expansion

The vertical expansion of the catalyst tubes varies between 7 and 10 in., depending on the metal temperature and the tube length. This expansion has to be accommodated by providing enough flexibility in the inlet manifold and pigtail system. If the inlet pigtails would have to absorb this expansion, they would be as much as 30 to 40 ft. long, and bent in intricate configurations. A pigtail of this shape and length would involve large pressure drop and would require extensive costs in both field installation and external insulation.

At the outlet manifold the horizontal expansion could be as much as 10 in. for large size reformers. Again, if this large expansion had to be absorbed by the outlet pigtails, a length of 30 ft. or more would be required. This would introduce the same type of complications as at the inlet pigtails, except costlier because we deal with temperatures around 1,400 °F to 1,700 °F. In this temperature range, even Incoloy 800 used for pigtails has low allowable stresses, making the support of such long pigtails very difficult. The average inlet pigtail is only about 10 ft. long while the outlet pigtail is *only* 4 ft. long.

This becomes possible by allowing the entire system to move freely in all directions, thereby eliminating the differential expansion between components. It is this differential expansion that introduces the large stresses in the pigtails and manifolds. A specially developed computerized stress analysis program gives the stresses and movements at every point in the system, keeping the actual stresses well within safe allowable limits for the various materials used. These limits are determined by extensive and continuous metallurgical testing in our laboratories and long field experience. It should be pointed out that the use of flexible hoses as inlet pigtails has long been discontinued because of repeated massive failures from chloride stress corrosion.

Materials for outlet manifolds

With the increase in the size of reformers, it has become necessary to use large diameter outlet manifolds. Manifold sizes between 12 and 18 in. inside diameter are not uncommon. For these large manifolds and for the high operating pressures and temperatures used in today's reformers, Foster Wheeler uses centrifugally cast pipe made out of HT modified material (35% Cr 20% Ni). In selecting this material, consideration was given to the high allowable creep and rupture stresses as well as to the loss of ductility of the material at low temperatures after the material has been in service.

To overcome the loss of ductility of the centrifugally cast manifolds, we have designed a system with very small bending stresses. It is for this reason that a rigid anchor at the connection between the outlet manifold and the transfer line is of the utmost importance. In the cases where outlet manifolds have failed, we have traced the failure to the absence of a rigid anchor. A rigid anchor must be defined as one that prevents any movements, forces and moments from being transmitted from the transfer line to the outlet manifold. The installation of such a rigid anchor has eliminated any further difficulties in the above cases.

Allowable stresses for the modified HT cast material have been developed by creep-rupture tests in our metallurgical laboratories. These tests are being continued and any additional information gained is incorporated in the design procedures for the use of this material. It should be noted that the introduction and use of centrifugally cast fittings such as tees, caps, and reducer cones has improved the reliability and performance of the cast outlet manifold assemblies.

Need for inspection procedures

To assure good quality and performance reliability of the high alloy material, a rigid inspection procedure is required. Such rigid procedure is used during all stages of manufacturing the reformer tubes and outlet manifolds, with particular emphasis applied to welding. Outlet manifold assemblies are turned and bored in accordance with ASTM A-451 specification. They are then dye penetrant inspected throughout and all welds radiographed. The entire assembly is hydrostatically tested to a predetermined pressure that depends on the design pressure and temperature conditions of the reformer.

The importance of rigid inspection, and particularly the inspection of welding of high alloy material, cannot be overemphasized. Selection and use of the proper welding rod must be carefully controlled and secured. High alloy parts and assemblies must be protected from being contaminated by any low melting point materials such as zinc, copper, or aluminum in the form of paint, marking, or attachments.

Types of failures experienced

Foster Wheeler's experience in steam reforming consists of a total capacity upward of 15,000 in equivalent tons per day of ammonia in upward of 30 furnaces. We have experienced failures in some reformers. These failures occurred in the outlet manifolds and were of two types: Those due to thermal shock, and failures due to thermal stresses.

In the first type of failure, the manifolds were chilled by water in the inside of the pipe while operating at temperatures above 1,000° F. The water got to the manifolds either by being trapped in the loops of the long pigtails or by being carried over in the process steam because of misoperation. We calculated that the thermal shock stresses developed are in the magnitude of 30,000 lb./sq. in. for every 100 °F. change in metal temperature. Under these conditions, no material can survive.

The solution to this problem is, of course, the elimination of water presence in the system. This can be accomplished by better steam quality control and also by the elimination of loops in the outlet pigtails. Our new design with the straight short outlet pigtail eliminates the possibility of water accumulation in the pigtails during a shutdown.

In the second type, the failures occurred while the units were coming down either slowly or abruptly. The failures were due to excessive bending stresses caused by forces and moments imposed on the manifold by the lined transfer line. In a system where the transfer line is connected to the outlet manifold without a good anchor, the manifold has to absorb the reaction forces and moments developed by the thermal expansion of the transfer line. Since the lined transfer line is very stiff, the reaction forces and moments are of such high magnitude that cause bending and axial stresses in the manifold well above the allowable levels for high temperature alloy materials.

The differential expansion between the transfer line and the secondary reformer is maximum while the unit is coming down, because of difference in skin temperature. This maximum differential expansion imposes extremely high stresses on the manifold causing the failure. It should be noted that ductility of the outlet manifold is very low during this period when the metal temperature goes below 1,000 °F.

The design and installation of rigid anchor on the lined transfer line was the ultimate solution. The solution is credited to a large extent in the close cooperation between the plant owners, the general contractors, and the furnace supplier. Excellent performance by the foundry in furnishing replacement fittings and pipes for the outlet manifold kept the downtime to a minimum. To avoid repetition of such failures we now request that anchoring of the transfer line at or near the connection to the manifold be reviewed and approved by us.

Part 2: Transfer line design

This portion reports one contractor's experience in transfer line design with the hope that the ammonia industry may benefit and, in turn, build on the present level of knowledge as opposed to repeating past problems.

A transfer line is defined for our purposes as a pipe transferring synthesis gas from the primary reformer furnace to the secondary reformer. To present a brief but general description of transfer line design the following topics are covered:

1. The state of transfer line design immediately prior to the birth of high pressure reforming.
2. A description of the several basic types of transfer lines.
3. Advantages, disadvantages and economics associated with each basic type of transfer line design.
4. Operating problems occurring in each type of transfer line design.
5. General details and fabrication procedures for shrouded transfer lines.

The first and simplest type of transfer line is wrought austenitic or high nickel alloy pipe. A direct alternate to wrought pipe is centrifugally cast pipe of equivalent chemical composition. The third, and presently most popular, type for high pressure reforming is internally insulated or refractory lined pipe.

There are essentially two different types of internally lined transfer pipes. The first consists of a two-component refractory lining, insulating and hard facing, poured or gunned on a carbon steel shell. The second type, referred to in this discussion as internally insulated pipe, consists of a pumped or poured insulation contained between an internal alloy shroud liner and outer pressure containing, carbon-moly pipe. A variation of internally insulated pipe, which is far less popular than the other two types is the substitution of a fiberous insulating blanket material for the pumped insulation between internal shroud and external shell.

Wrought transfer lines

Between 1950 and 1960, wrought 18/8 stainless steel pipe was the accepted material for transfer piping carrying effluent from cracking furnaces in ethylene plants. Temperatures of 1,400 °F and pressures of about 25 lb./sq.in. seemed ideal for this material, but operation quickly produced transfer line problems. Coke deposition not only resulted in local thermal gradients but necessitated frequent shut down of the process so that decoking by thermal shocking or mechanical vibration could be performed; fatigue failures resulted.

It also became apparent that inadequate design knowledge existed in connection with hot anchor constraints, reinforcing pads, material embrittlement with time, carburization, etc. In plants that did not have in-line exchange, the most marked offender was water or oil quenching of the process gas, which caused severe thermal transients.

Shrouded and insulated lined pipe was a reasonable solution to these early problems. The internal, nonpressure bearing shroud absorbed the temperature gradients that occurred at the quench point, while the external pressure containing pipe operated at a relatively cool and uniform temperature. Proper design of the internal shroud meant long life for the contained insulation that was subject to oil and water soaking and rapid thermal cycling during startup and shutdown.

Interest in high pressure ammonia and hydrogen plants in the early 1960's added stimulus to the design of internally insulated transfer lines since 300lb./sq.in. and higher operating pressures were excessive for wrought pipe. As an example, austenitic wrought pipe for a 250 ton/day ammonia plant requiring, say a 10-in. inside diameter would have 1½ -in. wall thickness; a thickness of both pipe and fittings not readily available.

Centrifugally cast transfer pipe

Centrifugally cast pipe, a development wherein the molten chemical constituents of stainless steel are fed into a rapidly rotating mold, became an early replacement for wrought stainless steel pipe. Extrapolation of information available in 1960, to either a minimum of 10-yr. rupture life or the stress for 1% creep in 100,000 hours, resulted in a ¾-in. pipe wall thickness for the same 10-in. inside diameter transfer line. Specifically, HK, which contains 25% chrome and 20% nickel, has twice the rupture or creep strength of its wrought type 310 stainless steel equivalent.

The two-fold advantage of high creep strength and economy of centrifugally cast pipe are offset by a rapidly reduced room temperature ductility caused by precipitation of carbides in cast pipe operating at reforming temperatures. Comparatively difficult weld repairs, even after only short service periods, and the necessity of overdesigning the pipe wall thickness to compensate for the lower strength of welding electrodes are also debits for cast pipe.

It should be pointed out that centrifugally cast pipe has no equal as an economical reformer furnace tube material. In the furnace it must only support itself, and if designed correctly it is subject to minimum weight stresses. It is also called upon to grow and shrink freely during startup and shutdown and thus is not affected by reduced ductility.

HF centrifugally cast pipe, 304 stainless steel equivalent, was the earliest material used for transfer lines. Its 19-23% nickel and 9-12% chrome content placed it in the sigma forming range, i.e. embrittlement by formation of iron-chrome carbides in the grains. The reforming industry soon substituted centrifugally cast HK due to increased rupture life. The nominal elongation of HK (25 cr. or 20 ni:) is 20% at ambient temperature, but after a short time at operating temperature elongation have reduced to values as low as 2%.

Cast pipe, constrained between the anchors of the primary and secondary reformer, suffers a change in length due to creep during operation and when cooled retains this deformation. Repeated cycling increases the magnitude of creep and plastic deformation. And as described by the ASA B31.3 Piping Code's "Stress Range" concept, after several cycles the line is stressed almost equally in the cold or shutdown condition as in the operating condition.

Proof of this concept is that centrifugally cast lines have only failed during shutdown or startup. Then they are subject to high bending stresses, and simultaneously their ductility is a minimum. The authors do not know of a cast transfer line failure that has occurred during normal operation.

Another disadvantage of centrifugally cast pipe is the shrinkage pattern existing on the inside and outside surfaces. When dye checked an uninterpretable fissure pattern results. To insure that cracking does not extend below the shrinkage layer, the refinery piping code requires I.D. and O.D. machining thus increasing the price substantially. Statically cast fittings and conical reducers early gave problems due to poor quality but constant improvement by foundries resulted in class I and II quality fittings to ASTM E71.

A major improvement is the successful centrifugal casting of fittings. To date we have not had a single centrifugally cast reducer rejection in over 30 manufactured. The 310 welding electrodes initially used for cast transfer line fabrication suffered cracks, with some failures occurring before the pipe went into service. Substitution of 310 high carbon electrodes for HK pipe and Inconel 82 or 182 electrode for HT transfer lines has been completely successful.

Cast pipe experiences

Foster Wheeler has installed two cast HK transfer lines in ammonia plants and has replaced a third centrifugally cast line installed by another contractor. The first cast line was built for the original high pressure reforming plant. On the basis of $90/ft. quoted price vs. about $300/ft. estimated cost of internally insulated pipe, the centrifugally cast line was selected. Loss of room temperature ductility during operation dictated that the design stress be kept to a minimum to limit deformation. An allowable flexural bending stress of 7,000 lb./sq.in. produced a line (Figure 1) with over 180 ft. of straight, six elbows, nine spring hangers and four wind guides.

This elaborate design has worked satisfactorily for 6 years. Although it appears overly conservative, noticeable rotation is occurring at points where the design stress is as low as 1,000 to 2,000 lb/sq.in. During October, 1967, this cast line was to be removed from service and replaced by an internally insulated transfer line built by Foster Wheeler.

Our second cast HK line design was an attempt to economize on overall length. The primary reformer heater tubes were top supported so that their thermal growth down equalized the vertical growth of the transfer line from the primary to secondary reformer. Again design stresses were low, but because of an offset in this line slight creep rotation of the header occurred. This original line after 5 years of successful operation is being replaced with a duplicate HT cast line.

Terminal connections

Of considerable importance in the design of cast transfer lines are the details of the terminal connections. At the secondary reformer inlet nozzle careful consideration must be given to the transition from 1,400 °F and higher cast pipe metal temperature to a cold vessel wall temperature.

A design, shown in Figure 2, which relies on forced cooling in this transition region can result in failure. Steam cooling of the pocket causes a high thermal gradient over a very

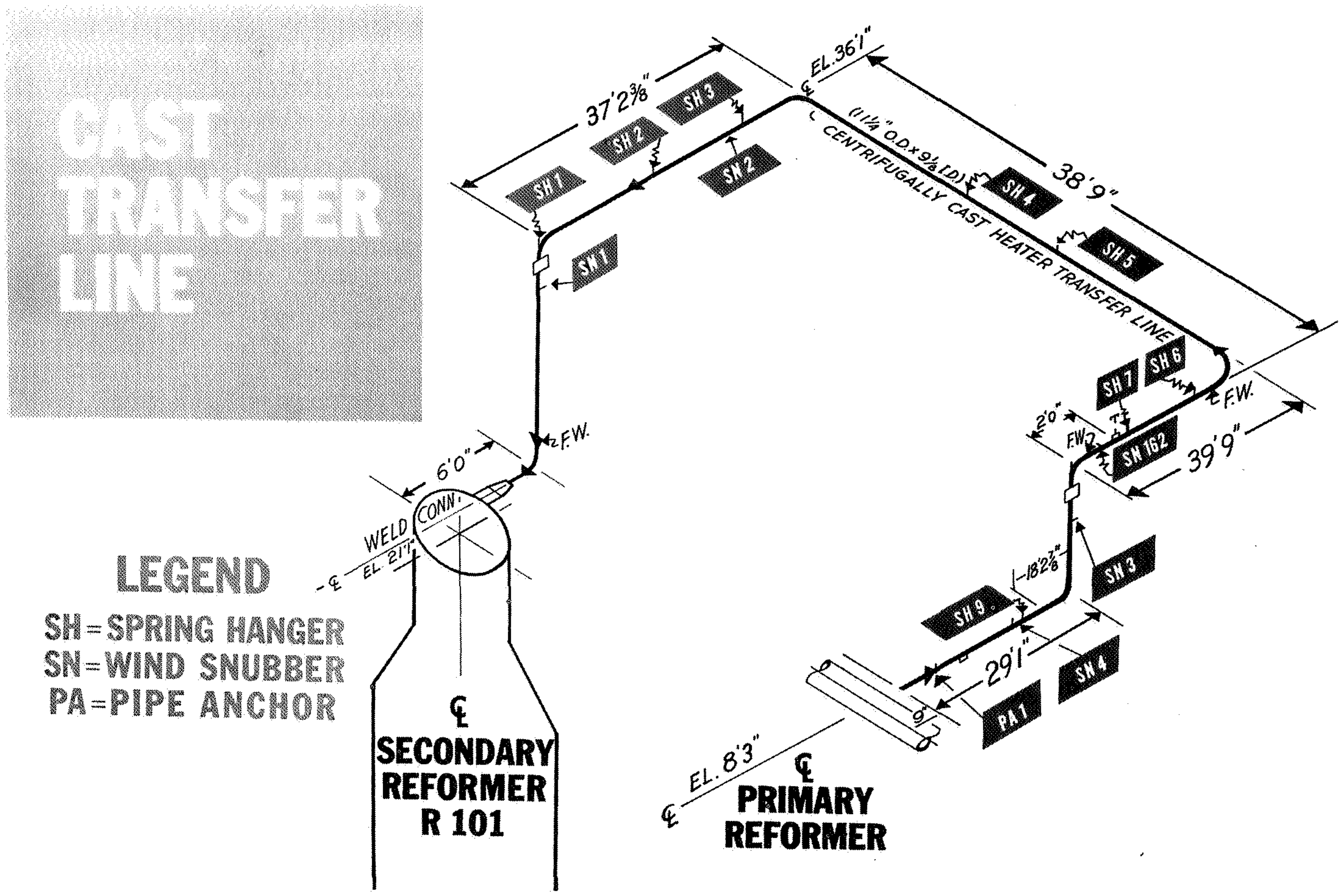

Figure 1. Details of a cast transfer line built for a high pressure reforming plant.

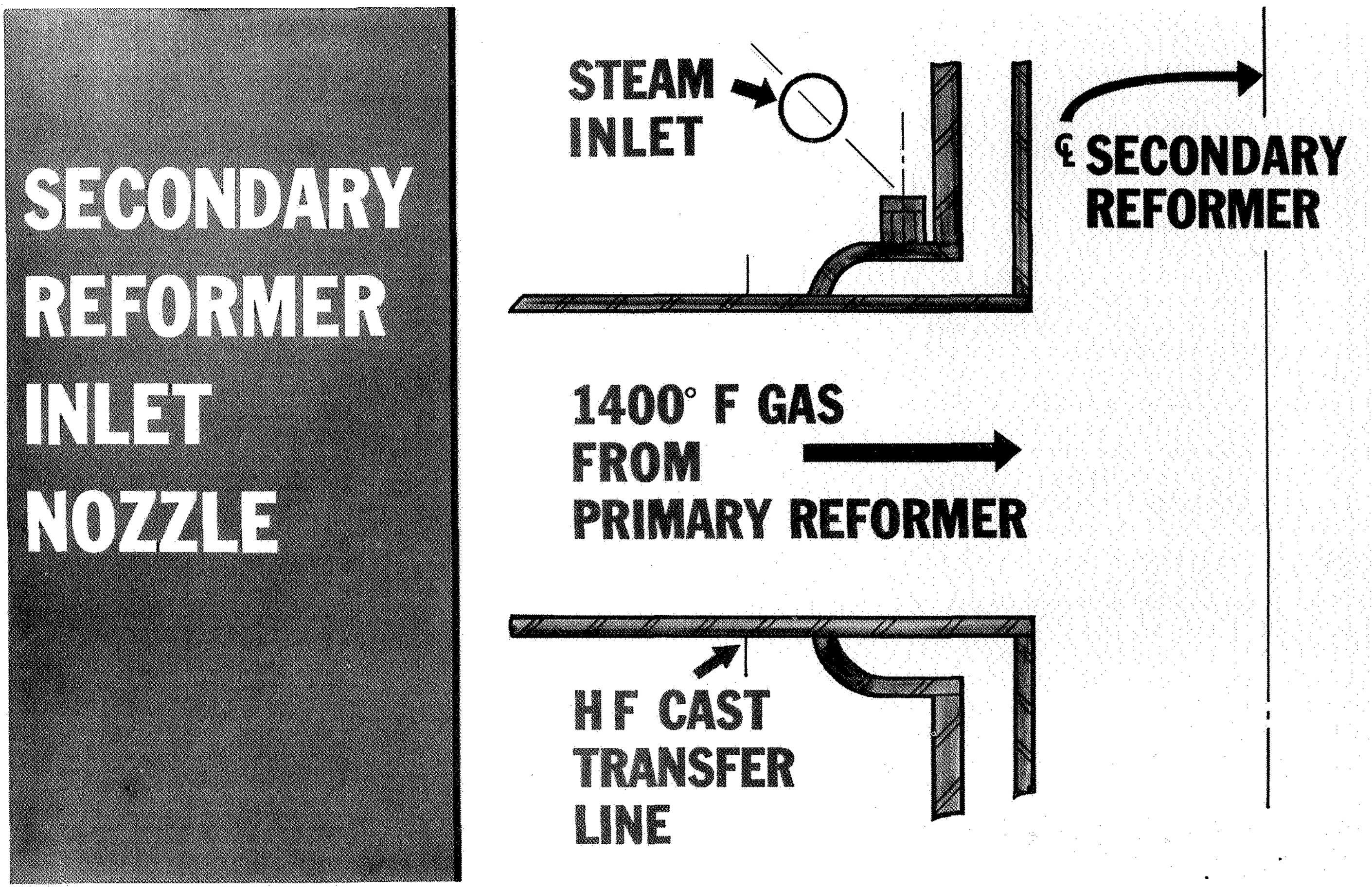

Figure 2. Secondary reformer inlet nozzle which relies on forced cooling.

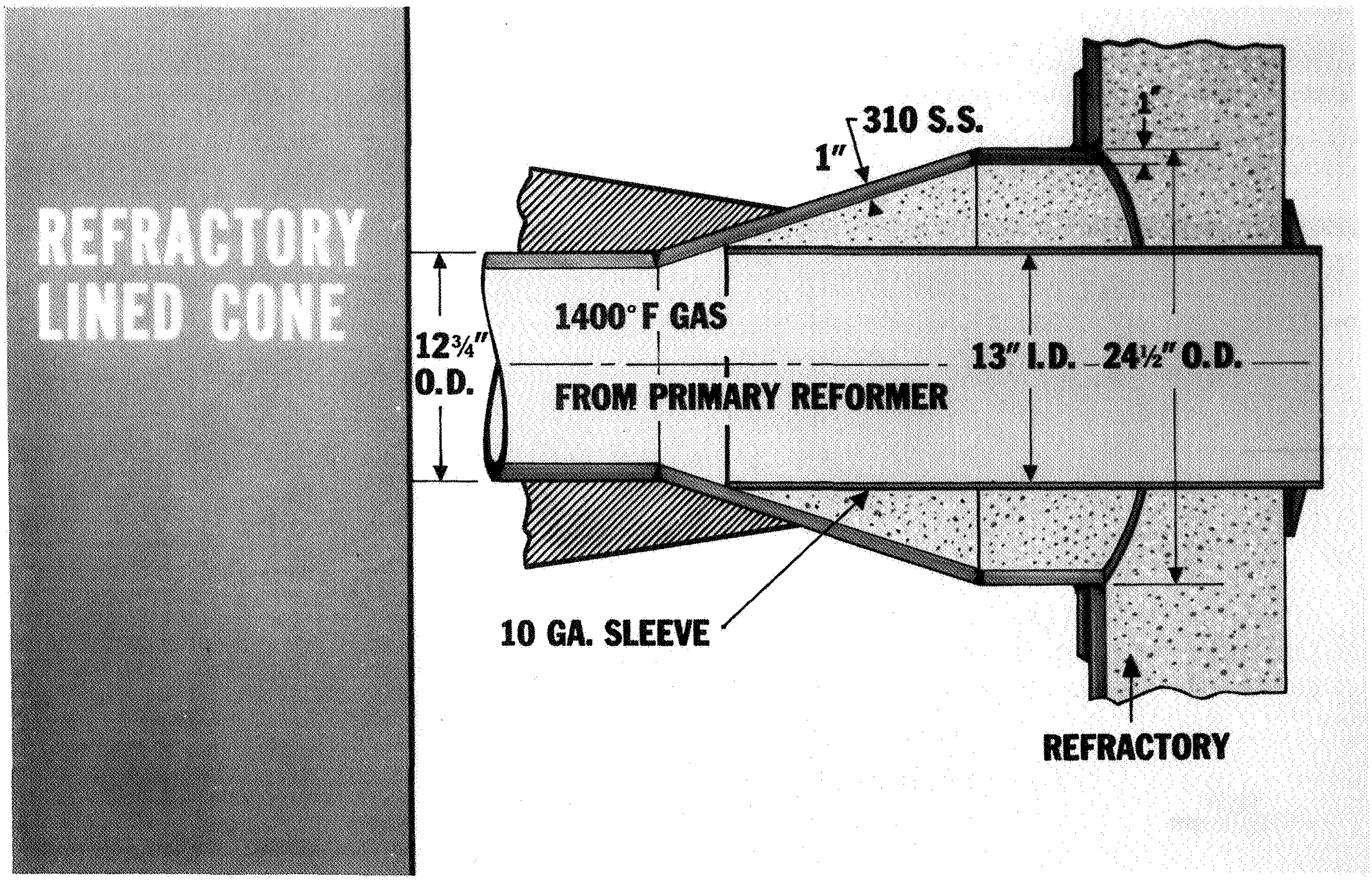

Figure 3. Refractory lined reducer used as a terminal connection.

short distance. Although cracking may not occur during initial operation, the difference in strain between the hot gas and steam cooled sections will eventually result in failure.

Refractory lined reducers have proved to be excellent at this location, Figure 3. The design of a reducer requires careful consideration of the slope and length of the cone and the shape of both the inside and outside insulation to insure a gradual temperature drop. It should be noted that integrity of insulation in a transition section is almost as important as design. Installation of refractory is usually performed in the cone manufacturer's shop and not in the field. Refractory is poured while the longitudinal axis of the reducer is vertical. Weep holes in the internal shroud at the small end of the cone allow drainage of water.

At the primary reformer end of the transfer line positive anchorage should be provided. A design which relies on counterweights, guides or spring reactions at the primary reformer outlet may not react properly to long term creep and strain, and is susceptible to human errors during installation. Machined trunions at the reforming heater guiding the vertical downward growth of the heater outlet manifold can give trouble.

Needless to say, these systems do not respond as expected. Firstly, a temperature difference of over 100° F in tube metal can occur across a primary reformer tube bank, causing rotation of a symmetrical collection manifold. Secondly, when uneven heater radiant fluxes occur radiant tube bowing results, causing nonuniform tube growth. Distortion of the radiant tube will increase resistance to its movement through the packing and cover plates at the top of the furnace. Thirdly, cast collection headers subject to bending stresses, caused by the transfer of thermal movement either exerted by the transfer line on the heater manifold or the heater radiant tubes on the manifold, are very susceptible to brittle failures as the unit cools or heats up.

In any arrangement where the collection manifold is required to do its work - that is be subject to high bending stress - when it is in its most brittle state, failures will result. Two design considerations or rules based on experience are:

1. Always place a positive anchor at the centerline of the heater manifold so that neither movement nor reaction from the transfer line can be imposed on the heater header. Normally, anchor steel is designed for double the transfer line reactions. A rigid anchor at the heater manifold is also good politics in that it permanently divides the prime contractor and heater manufacturers' responsibility. Counter weights, springs, hinges or guides are only poor substitutes for a rigid anchor. Presently we know of no Foster Wheeler reforming furnace manifold failures occurring in plants built by other contractors or Foster Wheeler where anchors were provided.
2. The second rule is to design the heater manifold to be subject to direct axial movement only, i.e., allow it to push or pull but not to be bent in cantilever action.

Refractory lined pipe

A two-component refractory lined pipe is usually the most economical of the internally insulated pipe alternates, normally costing about $100/ft. for installation of insulation only. Pipe fabrication is normally quoted as an extra. Insulation is cast in the line in the shop. As the inside diameter of the lining averages about 20 in., as shown in Figure 4, this allows inspection from the inside. The large inner diameter also allows internal field repair. The lining consists of approximately 6 in. of low iron, 50 lb./cu.ft. insulating material, cast against the carbon steel outer pipe and 3 in. of a low silica-low iron, 130 lb/cu.ft. hard facing cover. The low iron prevents formation of iron carbide in a CO atmosphere which tends to spall the refractory. Although investigators have found no volitization of silica at transfer line temperature, a low silica content, less than 1.0% is normally specified for the hard facing cover. The refractory is supported on 304 stainless steel clips.

Some disadvantages of the cast, two-component refractory lined transfer pipe are:

1. Erosion and refractory spalling that could lead to hot spots

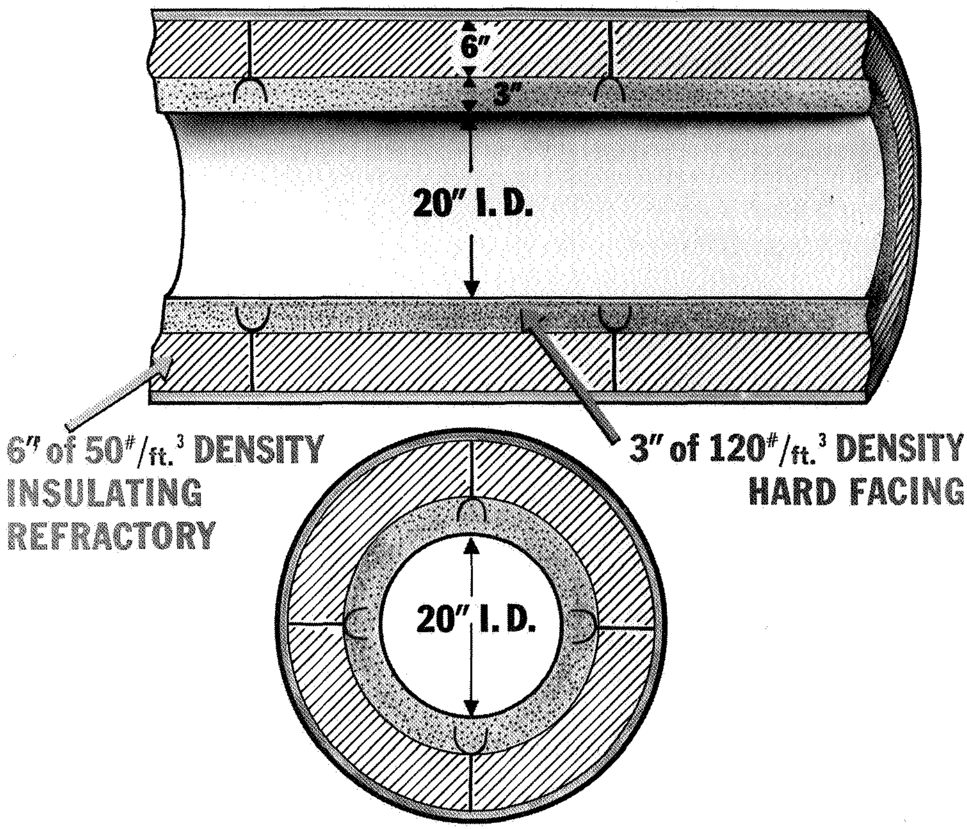

Figure 4. Two component, refractory lined pipe.

and catalyst bed plugging in the secondary reformer. Original designs had refractory washouts at mitred elbows that, in at least one case, resulted in hot spots and actual rupture of the carbon steel outer pipe. A hot spot on the outer pipe in this type of lined pipe is an ever growing problem in that increased radial growth of the outer pipe puts more of the refractory in tension thereby promoting cracking and further failure.

A water jacket would be a possible solution in keeping a uniform outer pipe temperature at the hot spot but it effectively prevents detection of any increase in the size of a hotspot. Undetected hot spots can lead to major refractory failure, sometimes rather quickly, and their extent and magnitude should be known before continued operation is decided upon.

2. Cast refractory does not possess the uniform physical properties of a gunned refractory. Alternately, gunning of refractory in a pipe can result in trapping of rebound which will eventually cause failure.
3. Long runs of transfer line force thermal growth on the most flexible section, resulting in tensile refractory cracks that become points of possible washout.
4. Water saturation in the refractory due to the water loading of catalyst, condensation of saturated steam during normal shutdown and startup operations, or condensation of moisture during shutdown and then subsequent rapid starting can lead to refractory spalling.

Internally insulated pipe

Internally shrouded pipe that uses an insulating blanket between an inner shroud liner and outer pressure bearing pipe has been used rather infrequently by other contractors. The main advantage of this design is the positive placement of the refractory blanket, resulting in a fixed amount of insulation, free of the voids that sometimes appear in improperly cast or pumped insulated lines. Two problems that have occurred in the blanket design are:

1. The loss of the blanket material due to aspiration or erosion by process gas stream when the inner shroud seals are not properly designed.
2. Accumulation of solids during normal operation and steaming operations which foul the insulation and result in increased conductivity of the blanket material and corrosion of the outer pipe.

Foster Wheeler transfer lines

Internally insulated and shrouded transfer lines have been used by FWC in 10 ammonia and hydrogen plants for an overall total footage of 700 ft. These lines have logged a total of 30 operating years without a single hour lost to *shutdown.* FWC presently has 5 lines operating in plants built by other contractors and offers the primary reformer and transfer line as a package to other contractors or owners. We have not included a drawing of the internal details, since they are considered proprietary, but a general picture of the design is shown in Figure 5.

The internal shroud straight pipe is sectioned by an upstream anchor and down-stream vapor stop, which prevents bypassing of gas back to the hot shell. At elbows and tees shorter sections are added since higher pressure drops result in greater bypassing tendency. The internal shroud anchors are designed to:

(1) Absorb the radial growth of the shroud, (2) keep the shroud aligned during operation, and (3) direct and simultaneously receive the axial thermal growth of the shroud. Proper design at the slip joints will insure that refractory washout does not occur.

The shroud serves as both a form for the pumped insulation and as an erosion protector for the soft insulation, which becomes

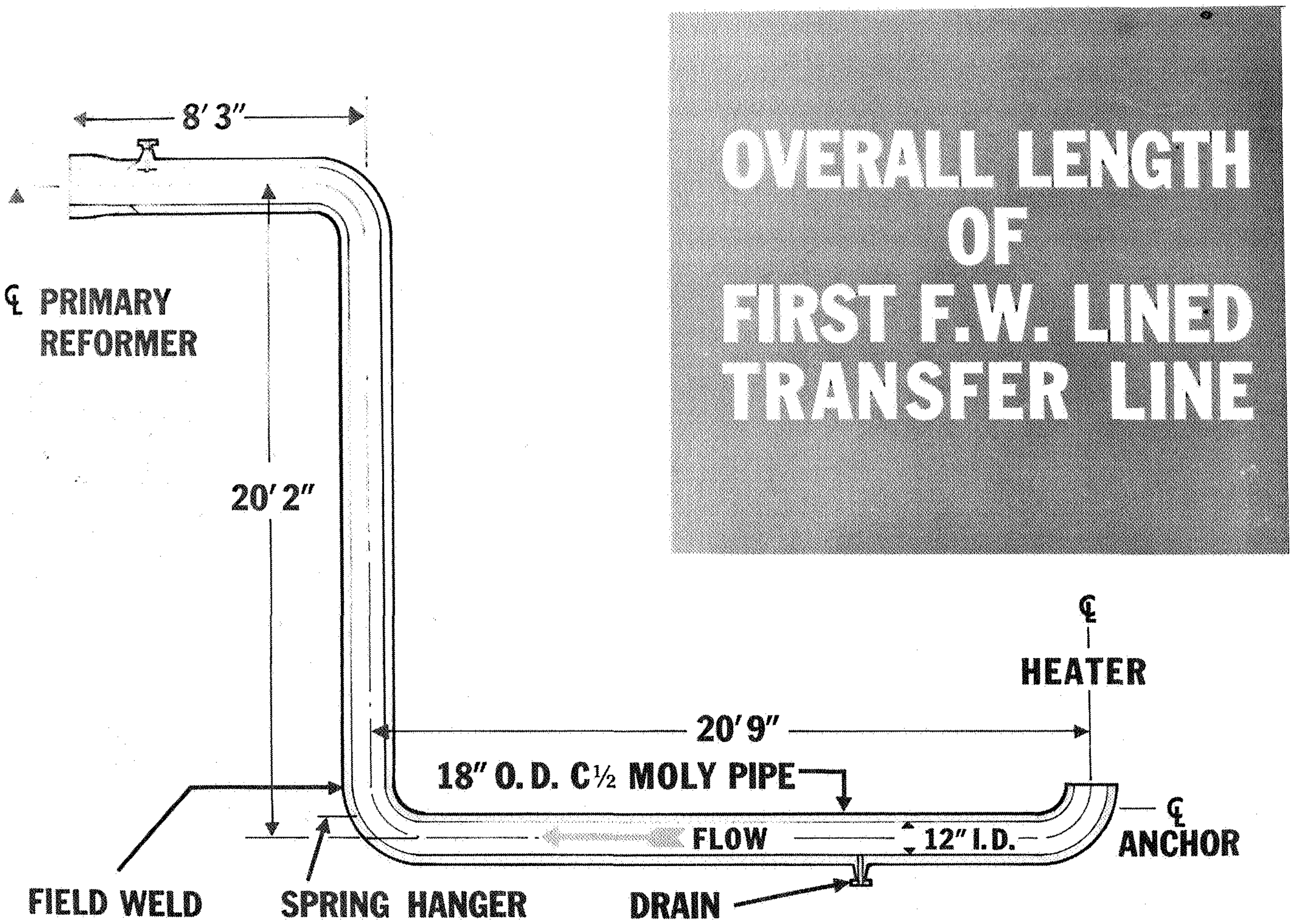

Figure 5. General dimensions of the first Foster Wheeler lined transfer pipe.

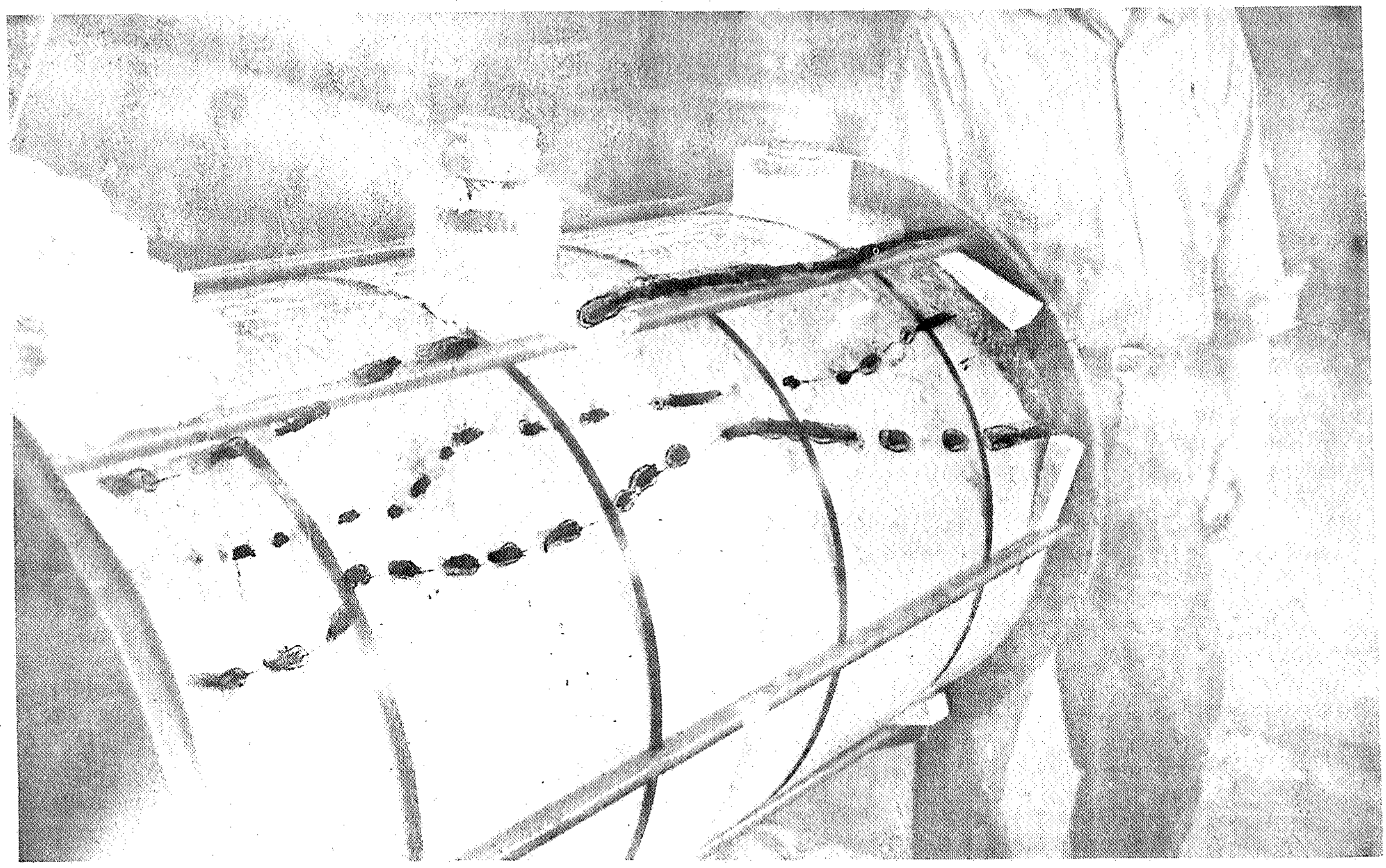

Figure 6. Plastic model of a 22-in. line fabricated to determine why hot spots had developed in the operating transfer line.

plastic at higher temperatures and thus readily receives the diametrical growth of the shroud.

A water jacket is not used in this design although they have been successfully used by other contractors. The possibility of corrosion behind the insulation and the hindrance in detecting the location of a hot spot have prevented widespread acceptance. When a hot spot occurs at an intersection or other location where refractory can be progressively lost, its exact location should be known.

Choice of insulating material

The insulating material has been chosen because of its volume expansion during initial cure, which allows it to fill all areas between the shroud and outer pipe. Placement of couplings on the outer shell allows inspection of the filling operation, proper venting, and positive escape of moisture during dryout from each internal section.

The insulating material is also selected for its low thermal conductivity; 3 in. is equivalent to the insulating value of the 9 in. hardfacing and insulation normally utilized in refractory lined pipe. Complementary to good design is the fabrication and quality control of this line.

All of our lines have been fabricated at our Dansville plant. Engineering drawings complete with all details are made for each line; shop drawings detail the location and type of every weld to be performed. A written assembly procedure is established prior to fabrication. Before shipment, the line is hot tested by placing a torch inside the shroud and slowly increasing the temperature to 50°F above expected operating temperature while the outer shell is inspected for hot spots. In this way the line, as installed in the field, is ready for service and the customer is assured that delay in startup will not occur due to refractory failure or hot spots.

The first internally insulated line in a FW ammonia plant was installed a year after our first cast transfer line went into operation. Figure 5 shows the overall length. The simplicity of this run resulted in a saving of over $75,000.

Problems have occured in these lines in that:

1. The original insulation binder was Portland cement which disintegrated during operation but there was no loss of insulating value. Substitution of a completely resistant binder has been made.

2. When the insulation material, which worked successfully in small diameter lines was installed in a 22-in. diameter line a few small hot spots occurred. An extensive testing program was undertaken by our research department. A 6-ft. long plastic model was fabricated, equal in detail and dimension to a section of the operating transfer line. Several different insulating materials were pumped into the plastic model and the effects of moisture content, pumping pressure, slope and composition of insulation were observed.

This testing clearly showed that the insulation which was installed in the operating line subsided due to weight during initial cure, Figure 6, at exactly the same location that field hot spots occurred. Substitution of more appropriate insulation eliminated this problem. Incidentally, the hotspots that occurred in this case did not cause plant downtime, did not progress, did not exceed 700°F metal temperature, and were easily repaired from the outside at a normal shutdown.

3. Failure of a convection tube in the primary heater in one plant created reforming temperatures in the transfer line. Although partial failure of the shroud occurred, the transfer line withstood this excessive punishment and allowed an orderly shutdown. This is the only case of back burning to our knowledge. Our instrumentation has now been modified to insure that backburning will almost instantaneously be eliminated.