RECENT IMPROVEMENTS IN PRIMARY REFORMER FURNACES

The primary reformer furnace is undergoing a continuing appraisal of refinements as influenced by service experience and based on advances in materials and design technology.

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As part of the recent increase in world ammonia production, the processing plants developed and installed by the M. W. Kellogg Co. have played a significant part. An essential contributing factor to this operation has been the successful development of an improved, high pressure reforming furnace. Considering the high pressure and high temperature conditions, various special materials and fresh approaches to mechanical design have been incorporated. The primary reformer furnace should be operated and monitored within close limits because it contains hydrogen rich gas under high pressure and temperature. Operating experience has included isolated incidents responsible for damage to the furnace and for lost production time but no injuries to personnel.

Careful design attention has been applied to safety considerations, including materials, fabrication and constructional procedures. This article outlines several of the more important concepts and details to which special attention has been directed and subsequent refinements made to the basic design.

There are no accepted safety Codes which are directly applicable to furnace coils, principally because the high metal temperatures involved are beyond the applicable Code range. Materials are, of course, specified and processed in accordance with the principles of recognized standards such as ASTM and ACI, and various components are designed and fabricated in accordance with the principles of API recommended practices, the ASA Piping Code, ASME Code for Pressure Vessels and the AISC Structural Code. To supplement these guides, we have prepared detailed design requirements consistent with these code principles. Materials and fabrication are supplied according to standards and methods developed with experienced and reputable vendors.

Arrangement and Operation

Figure 1 shows an overall view of a typical reformer furnace. Figure 2 shows a schematic reformer furnace layout.

The process stream from the furnace convection section is distributed to each row of radiant section tubes by a wrought carbon steel inlet manifold. The inlet manifold is supported from the arch steel and anchored at the center, with expansion guides at the ends. Each radiant tube is connected to the inlet manifold thru a carbon or low alloy steel pipe pigtail of small diameter bent to serpentine configuration which accommodates thermal deflection. The tubes are supported in pairs from the arch steel by springs.

The process stream flows downward thru the centrifugally cast 25 Cr—20 Ni (HK40) catalyst containing tubes and is collected in a wrought Incoloy 800 outlet manifold located at the bottom of and within the furnace. An HK40 outlet riser tube

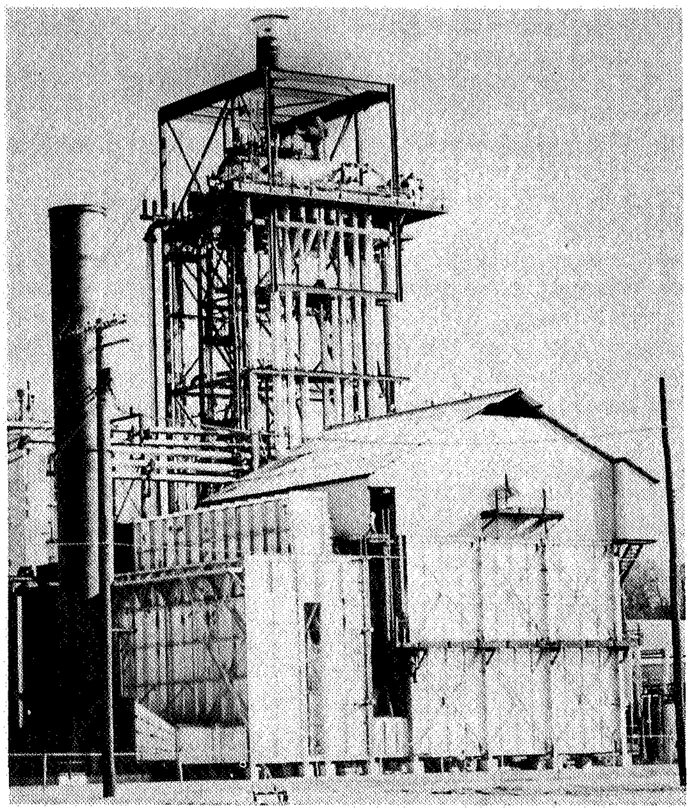

Figure 1. Primary reformer furnace

at the center of each outlet manifold then conducts the stream to the effluent chamber vessel (sometimes referred to as the transfer line) also supported above the furnace by springs. The process stream passes from the effluent chamber to the secondary reformer vessel. Note that the direction of firing is parallel to the vertical tubes, does not impinge on tubes or walls, and provides maximum heat input at the cooler end of the tubes, thereby minimizing metal temperatures.

Mechanical Design

As may be seen from reference to Figure 2, the furnace coil is an integrated design which accommodates various mechanical effects expected primarily from differential expansion and support considerations. During start-up operations, the secondary reformer expands upward, carrying with it the end of the effluent chamber. The harp system (which includes catalyst tubes, riser, outlet manifold, and effluent chamber)

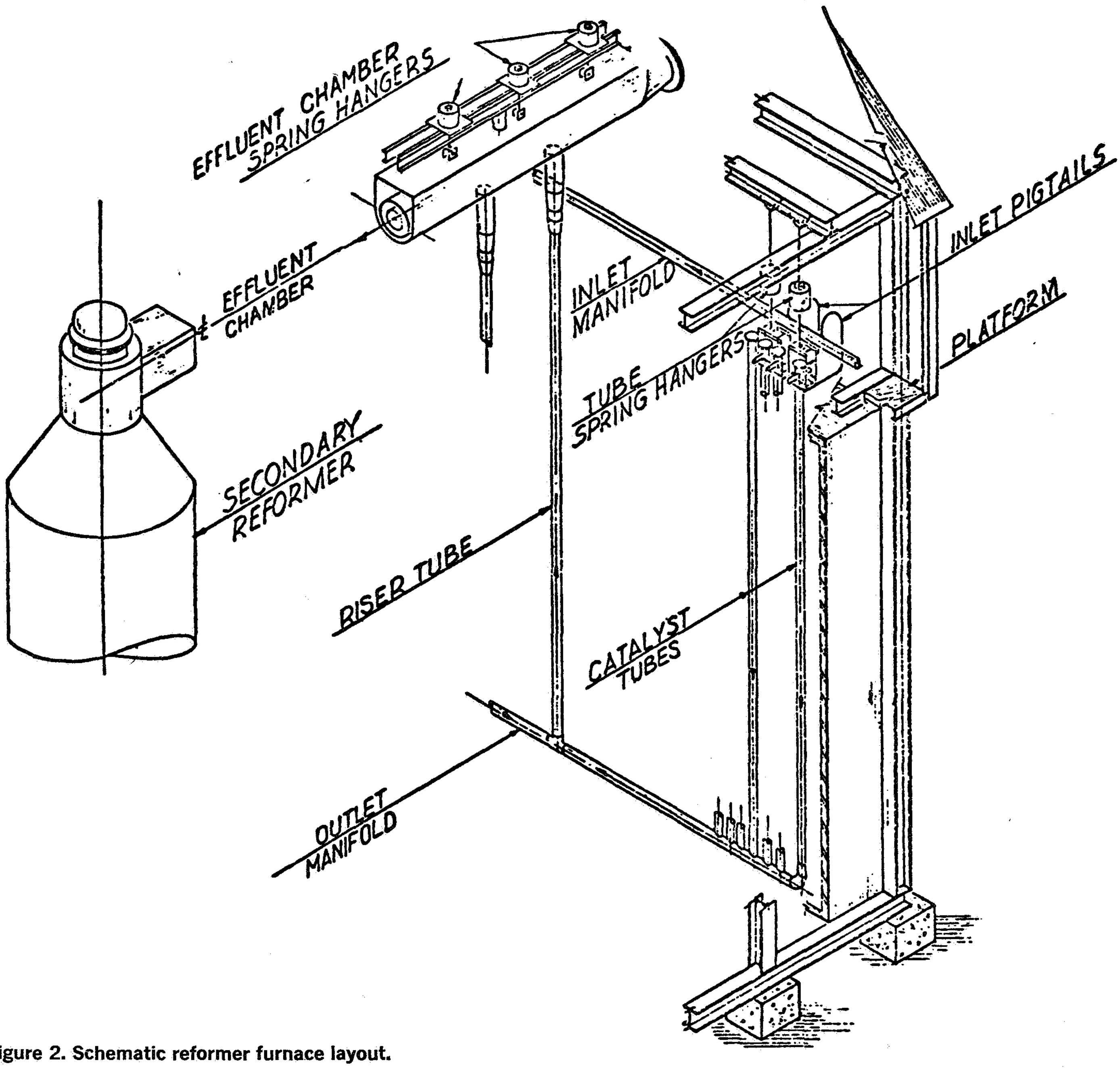

Figure 2. Schematic reformer furnace layout.

also expands but, because of higher temperature, and alloy materials, to a greater extent than the secondary reformer. The support system allows differential expansion between individual tubes in the event of local catalyst deterioration and consequent overheating. The spring support of the harp permits deflections in both vertical and horizontal planes. The permissible stress range for expansion stress given by ASA rules is based on the ability of ductile materials to withstand thermal cyclic operation. Our design uses criteria based on successful operating experience to establish the design of pressure components which are not ductile over part of the range. For design conditions, typical thermal bending stress in cast material is 4,000 lb./sq. in. The harp system is designed to be weight load balanced and free floating, with clearances to accommodate movement from thermal expansion.

The controlled movement of coil components under the foregoing conditions of high pressure and differential temperature expansion requires special attention to many areas. The principal ones are outlined below.

Tubes and Allowable Stress

Tubes and risers are centrifugally cast 25 Chrome—20 Nickel (HK40). This cast material is excellent for resistance to creep and rupture at elevated temperature, but, as is common to all high temperature strength cast furnace materials, elevated temperature strength is accompanied by low ambient temperature ductility after aging. More highly alloyed materials are sometimes used for high pressures and temperatures, but their ductility in all conditions is less than that of HK40. The low as-cast ductility of high carbon cast tubes becomes even lower after aging at service temperatures because of carbide precipitation. There are no known materials which will both have high temperature strength equivalent to HK40 and maintain ductility after exposure to reformer furnace temperatures. To accommodate this low ductility, the system is designed to minimize stresses at low and ambient temperatures. Tension, compression and bending are reduced to very low levels. Typical riser stresses are 1,570 lb./sq. in. hoop stress and 928 lb./sq. in. combined longitudinal including weight and pressure stress. As experience and laboratory test data have accumulated, the design basis for allowable stres sof HK40 at temperature for pressure and weight loading has changed as follows:

Temp. °F.	(Present) Allowable Stress, 75% of Stress to Produce Rupture in 100,000 hrs, lb./sq. in.
1,500	3,100
1,600	2,000
1,700	1,300
1,800	840

Temp. °F	(Original) Allowable Stress, 50% of Stress to Produce 1% Creep/100,000 hrs, lb./sq. in.
1,500	2,600
1,600	2,100
1,700	1,700
1,800	1,350

The change from a creep to a rupture stress more accurately correlates with the expected mode of failure of this material. Successful service results have corroborated this approach; of over 6,000 catalyst tubes in service above 450 lb./sq. in., only five tubes failures have been reported. Three were due to overheating and the two to unusual manufacturing defects.

Wrought Materials

The insulated bottom outlet manifold is constructed of Incoloy 800. This use of ductile material agrees with the recommendations to the U.K. Ministry of Power, (1, 2) which were made after a series of failures in cast materials. The higher ductility of Incoloy permits it to accept the bending stresses imposed by expansions in the system as compared to the expected brittle behavior of aged cast materials.

Outside the firebox, all pressure parts are restricted to the more ductile materials which maintain ductility during and after exposure to service temperatures. In these locations, where operating temperatures are one to two hundred degrees lower, the riser tubes are joined to the effluent chamber by wrought Incoloy designed to provide a safe transition between HK40 and insulated carbon steels.

The effluent chamber is internally lined with castable refractory material which permits use of carbon steel for the pressure shell. The castable is faced with an austenitic stainless steel shroud which incorporates in its design expansion provisions by way of slip joints and vapor stops. For additional safety, the entire chamber is surrounded by a level controlled atmospheric pressure water jacket.

Weld materials are selected for matching strength and ductility. Inspection methods as detailed below are intended to verify the specified composition of the electrodes, and of the deposited metal.

Inspection and Testing

Inspection and non-destructive testing has been increased as service experience has been gained.

Failures have occurred when critical portions of the riser assembly have been found to be out of specification with re-

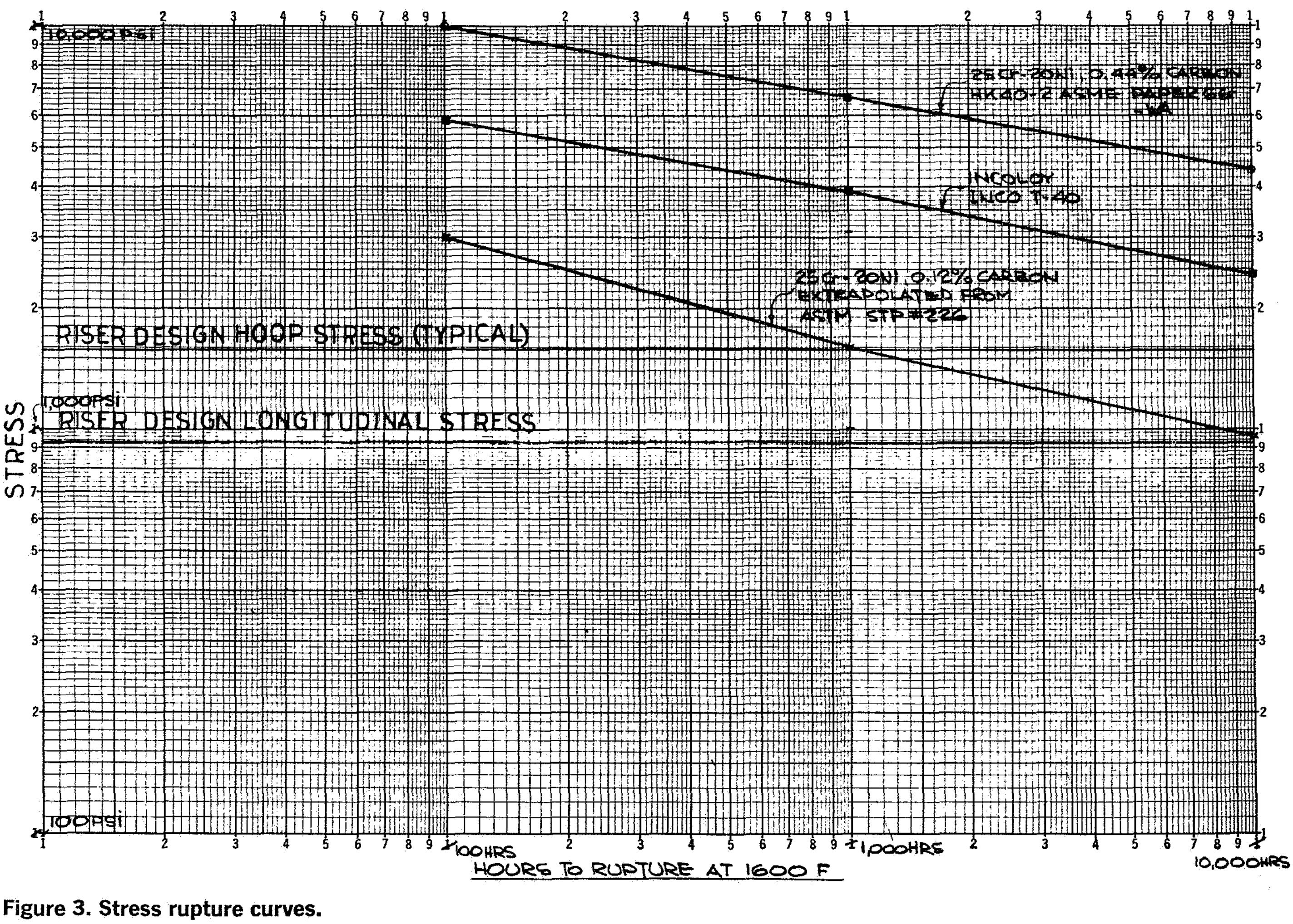

Figure 3. Stress rupture curves.

gard to chemical composition. Where this condition occurs, it results in the lowering of expected mechanical properties and possible failure of components. Low carbon 25-20 weld metal and high chromium content castings have contributed to shorter than expected life. As Figure 3 shows, the expected strength of low carbon weld metal is well below that of the specified carbon range material and so low that failure can take place in a short time under design conditions. The high chromium content can lead to sigma formation. These off specification incidents have occurred in spite of what is normally considered searching inspection by reputable vendors. Presently, it is required that additional independent check analysis of all components in the riser system be made to assure that the proper analysis is present. Drillings are taken from each heat of HK40 in the riser and from the welds joining the riser components. These drillings are analyzed by an independent laboratory for % Cr, % Ni and % Carbon.

Referring to the 1967 AIChE meeting, Messrs. Avery and Valentine (3) presented results of their work on expected elevated temperature properties of Incoloy. They showed that the elevated temperature strength is dependent on proper heat treatment. We have developed stringent standards for temperature measurement during heat treatment to assure a true solution annealed condition in all Incoloy parts not heat treated by the producing mill. A metallographic examination is made as a further check on proper heat treatment, although Avery and Valentine indicated that there is not a direct correlation between grain size and properties.

Continuing studies of relative coefficient of thermal expansion in materials, both in furnaces and by materials suppliers' laboratories, show generally good agreement. As more experience is gained, further refinements in design will be make. These values, used throughout the industry, are directly related to thermal stresses in the tubes.

Similar studies of the strength of welds in HK40 materials are in progress. This is being supplemented by analyses of relative stresses and creep deformations at the base metal to weld metal interfaces.

Mechanical Details

The importance of free but controlled movements in the system and the minimizing of stresses due to temperature differential was mentioned above. Of prime importance are these factors:

Supports and Springs Deflections of the entire harp system are carefully analyzed for all possible movements of each component during start up, operation, emergency (local overheating) and shutdown. Springs, Figure 4, are selected to permit appropriate movement with strict attention given to travel, spring constant and reliable operation. Tubes are supported in pairs by a yoke, which, by virtue of its universal joint, maintains positive support during extraneous movements and compensates for erection deviations and fabrication tolerances.

The springs are calibrated and tested in the shop in accordance with a procedure which sets tolerances more rigid than the industry standards. This control of spring characteristics and performance further includes an actual shop weighing of the harp and a check field weighing on service springs to assure weight balance.

Pigtails The pigtails contribute to the spring constant of the support system. Stresses are analyzed by flexibility methods. Deflections have been checked by test loadings. Result are then combined with the constant of the support springs themselves for an overall coil characteristic. Alloy pigtails with thin walls may be used for increased flexibility.

Penetrations Through Furnace Enclosure The points where

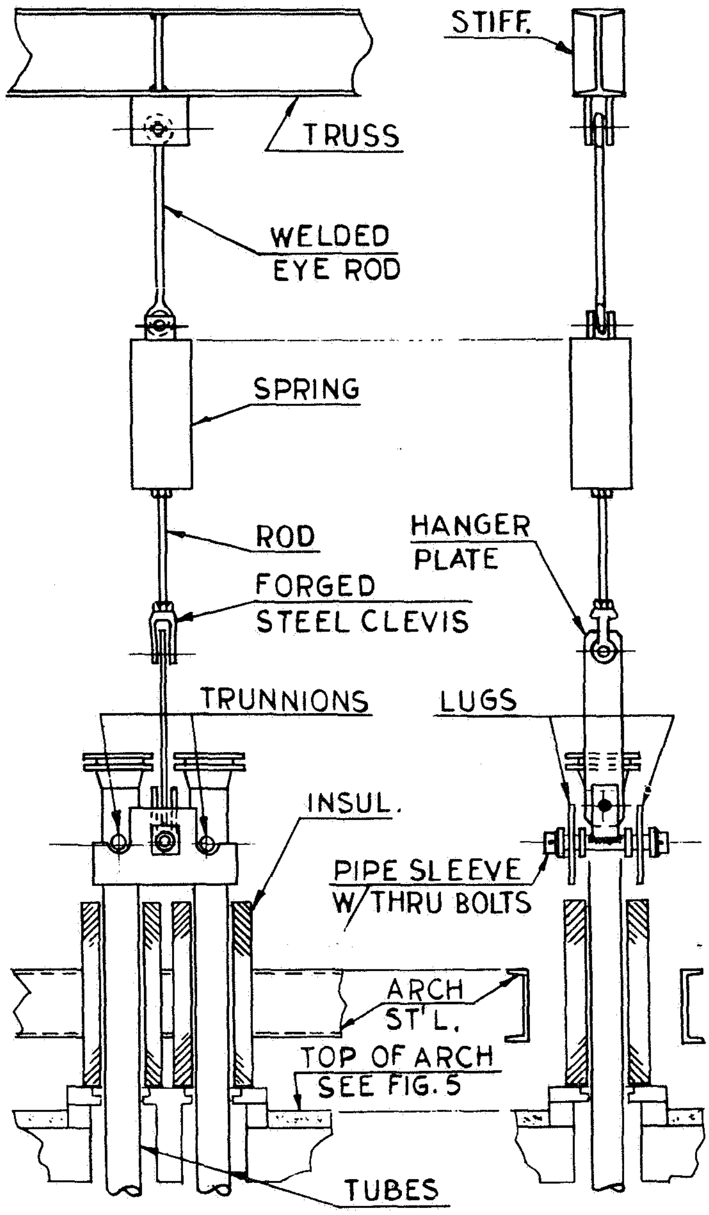

Figure 4. Spring support assembly for reformer tubes.

tubes and riser penetrate the arch (passing the process stream in and out of the furnace) Figure 5, are sealed so that excessive air will not be pulled into the furnace. However, these seals are so designed that they do not provide any restraint to expansion which could add appreciable bending stresses anywhere in the coil system. Special seal details, utilizing high temperature insulation, have decreased the magnitude of localized or extraneous stresses due to tube friction at these locations. These penetrations are principally in areas of low draft and thus have little effect on performance.

Through close cooperation between subcontractors, engineering, and construction, the brick arch has been redesigned so that better fitup is attained with adequate clearance for tubes, risers and burners. Design improvements to bottom manifold guides and thermowells, which must also penetrate the furnace casing, allow free movement during start up and shut down.

Bottom Manifold Tees and fittings were originally used for tube connections. Experience and calculations have shown that a manifold with weldolets for tube attachments provides simpler and stronger construction and fewer welds as compared to tee connections. This change has not affected the essential flow pattern of the gases.

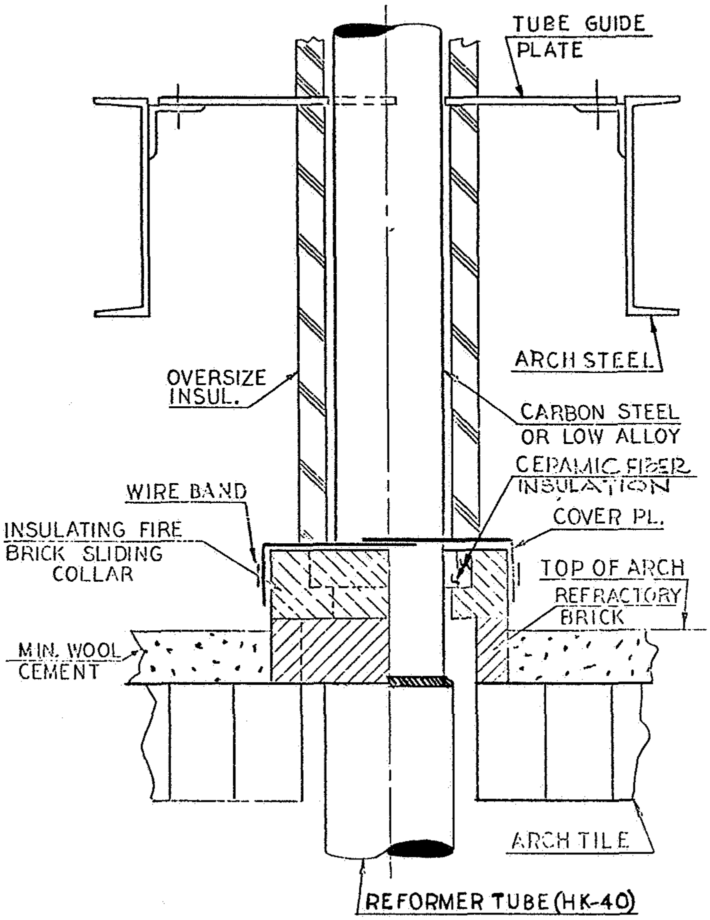

Figure 5. Reformer tube penetration details.

To protect the Incoloy manifold from overheating, long life insulation on the outside of the pipe has been installed, Figure 6. This has been recently redesigned as preformed halves for ease of installation and positive positioning to the manifold contour.

Effluent Chamber Several modifications have been made in the effluent chamber as experience has shown the way toward continued improvements, Figure 7.

At thermowell openings at the top, the water jacket has occasionally overflowed with water spilling down risers and causing thermal stresses. Thermowells have now been relocated and dams installed around any required openings.

The insulating castable lining material has been changed. The present material can be handled and installed more easily and minimizes voids. The fabricator radiographs the installed castable as a quality control on the extent of voids.

Riser Insulation Furnace performance has indicated that the top of the riser within the furnace can be insulated without seriously affecting overall efficiency. The benefits from this insulation and retainer are threefold, Figure 8. First, the lower metal temperature provides a higher allowable stress in what had been the highest metal temperature area, and, for existing furnaces, results in lower metal temperature for the welds in that area. Second, there is provided a measure of protection against arch damage due to escaping process gases in the event of a riser failure just below the arch. Third, in the event of water spillage at the top of the furnace, the insulation protects the riser weld at the arch against possible corrosion and quench cracking.

Location of Riser Field Weld Current designs call for the riser field weld to be in carbon steel material above the arch rather than in HK40 material below the arch. Position field

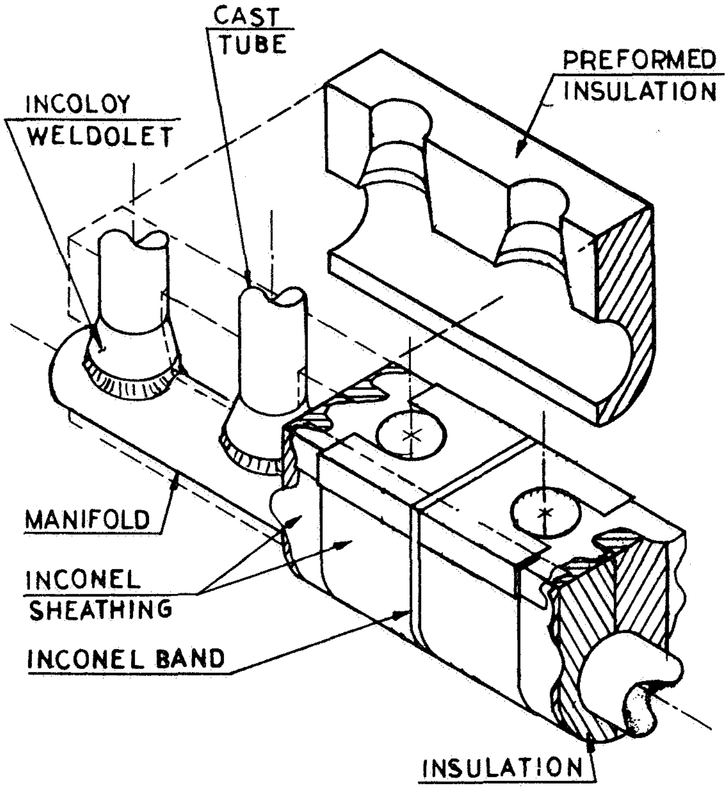

Figure 6. Bottom manifold construction.

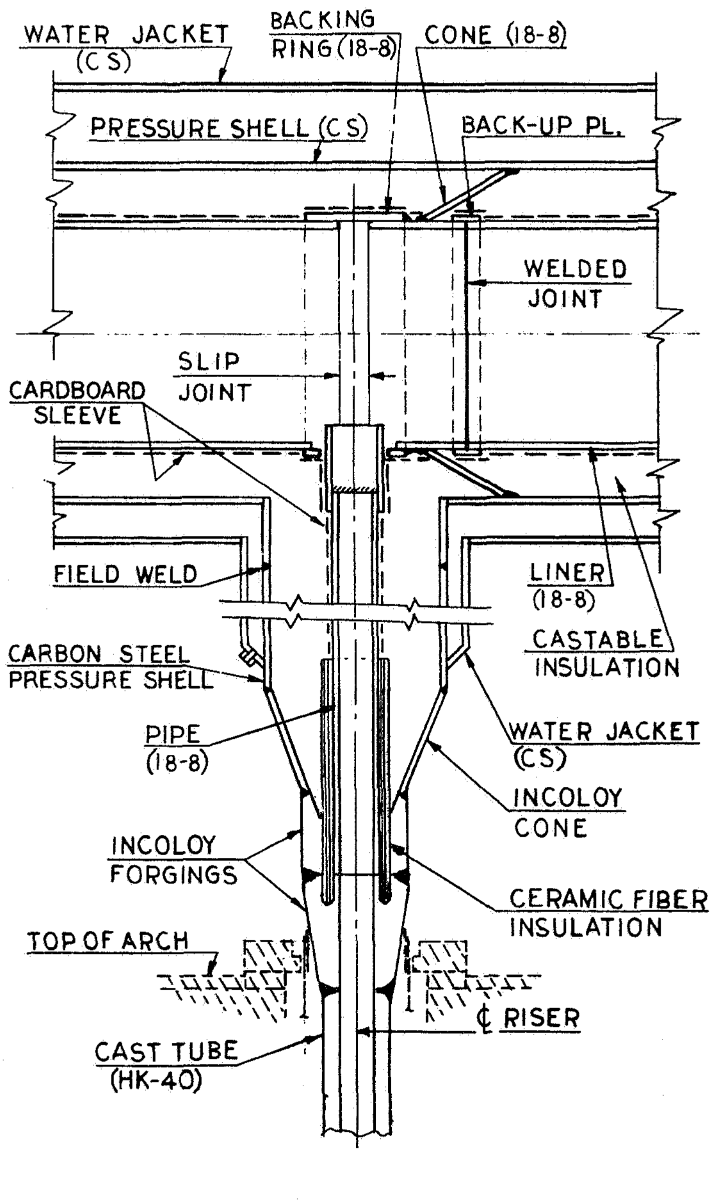

Figure 7. Effluent chamber section.

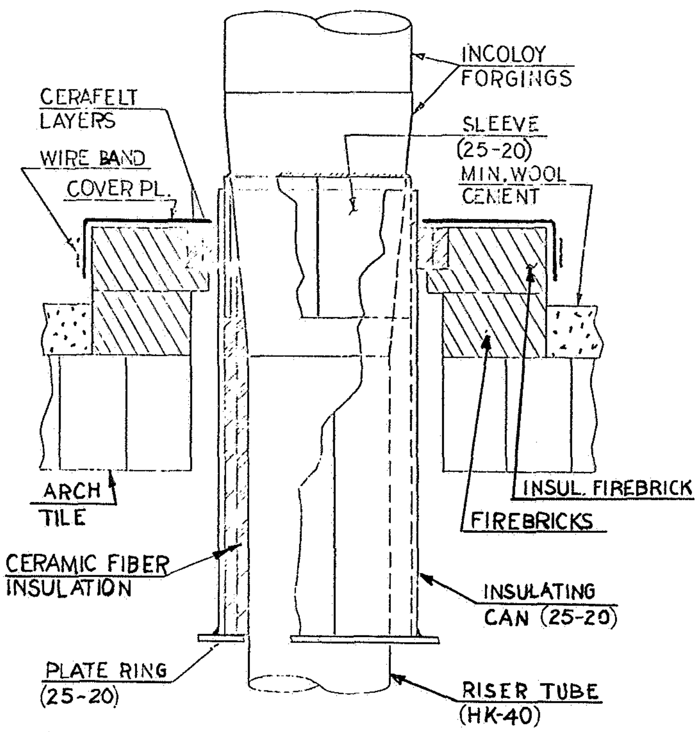

Figure 8. Riser insulation.

welds are difficult to make and the more ductile carbon steel will be easier to weld.

Fabrication and Erection

Dimensional tolerances and weld quality are important in positioning the harp and in minimizing stress intensification. Steps are presently being taken by the vendor to make improvements in these areas by closer control of weld procedures. The welding sequence and technique will affect distortion due to shrinkage.

The entire furnace structural steel network is erected with careful attention to bench marks. Column straightness, beam elevations and clearance dimensions are maintained closely. The effluent chamber, harps, manifolds, and secondary reformer are also carefully checked for alignment. This gives assurance that the harps will be in the correct position during all operations and that no unaccounted stresses are imposed on the coils due to the field installation.

Field erection of the reformer furnace is controlled to achieve a balanced system. For this reason, a complete procedure devoted exclusively to field erection of the primary reformer furnace has been developed and is in use on current jobs. Its detailed step by step sequence, checklists and feedback information are particularly useful in continuing improvement in construction methods.

As can be seen from the above, significant steps have been taken to extend high quality reliable performance of the furnaces. To carry these improvements beyond the initial start-up operations, maintenance manuals for reformer furnaces have been individually prepared for each furnace placed in operation within the last four years. Each manual contains a complete checklist for maintenance and inspection, and includes criteria for clearances, tube temperature, alignment, weld inspection and deflections. Detailed inspection methods are described. A short explanation of the stress analysis of the coil is given so that a prudent operator can assess the effects of changes in observed conditions and take appropriate action if required

As we have shown, the primary reformer furnace is undergoing a continuing appraisal of refinements as influenced by service experience and based on advances in materials and design technology. The basic design has remained unchanged, but improvements have been and will be make. Modifications to long time successful operation will be gained from knowledge and application of the principles and practices illustrated herein.

Literature Cited

1. Report on Shortages of Gas, Supplies in West Midlands During the Winter of 1965/66.—Sir Robert Wynne—Edwards, 1966, p. 21.
2. Metallurgical Aspects of High Temperature Reformer Furnace Alloys, The Gas Council Research Communication GC 129, R. G. Baker and W. L. Mercer, 1966, p. 14.
3. High Temperature Piping Systems for Petrochemical Processing, Vol. 10, Safety in Air and Ammonia Plants, AIChE, 1968, R. E. Avery and H. L. Valentine, p. 21.

Discussion

Q. You mentioned radiographing insulation. I take it you're talking about castable insulation; is radiography done in the shop when it's cast?

JACOBOWITZ: It's done in the installer's shop in individual sections.

Q. You mentioned that the field weld is above the arch. Current construction calls for field welding below the arch.

JACOBOWITZ: That's correct. Current designs, not yet in construction, will have the field weld in the carbon steel pressure shell above the arch.

Q. I'd like to take that question just a little bit further, please. You showed now that the field weld is not in the cast riser tube or the Incoloy transition piece attached to it. It's ten feet higher up. In other words, it's a part inside which you have the castable insulation. This means that if you radiograph in the shop, you're not radiographing the last bit of insulation you put in, because presumably you don't have insulation there when you're doing the field weld.

JACOBOWITZ: This is correct, but the final castable is hand installed with continuous visual inspection. The provision for radiographing in itself has been a considerable improvement. Radiography is an additional quality control measure.

Q. Do you have experience of hot spots in the line transferring from primary to secondary? How do you detect a hot spot in a water jacket and how do you locate the hot spot?

ZEIS: In the transfer line, as it's sometimes called, hot spots will be detected by a rise in temperature and boiling in the jacket water.

As far as locating it, radiography would be one way and there are other ways such as drilling from the inside to locate the void.

Q. I think it's evident that there is good reason for concern about the integrity of the insulation between the liner and the pressure shell on this type of vessel. I'm interested in any comments on means for insuring that that insulation is intact after a year, two years, three years of operation.

My first question, would be, does Kellogg believe that the radiograph technique is suitable for maintenance inspections, and if so, has it been done? Does Kellogg know of successful inspections of the external part of the pressure vessel to determine if the internal insulation has been lost through erosion or some other process by observation of the formation of scale due to high temperature on the inside of the shell?

ZEIS: On the second question, the observation of the external surface of the pressure shell would have to be through the water jacket. I don't think it has been done as a control. It's related to your first question it becomes a matter of concern primarily when the water begins to boil violently in the effluent chamber jacket. I don't believe radiography has been applied to an operating unit. One chemical company has developed techniques for inspecting the condition of the refractory during shutdown. It involves a series of tests with cast panels of refractory to set up standards and exposures for radiography.

In the vendor's shop it's a control mechanism. They have a reproducible technique of film, exposure and distance which does show voids when they are present. It becomes a matter of judgment as to whether they're serious or not. It's pretty hard to give directions as to what film and exposure to use, but it can be done, and it's readable.

A. Relative to hot spots on the transfer piping, how do you consider a recommendation that a water meter be installed on the makeup water line to the bathtub?

Secondly, in existing plants where the insulated can has been installed on the riser connections, what do you do about examination of that critical field weld?

R. FREY, M. W. Kellogg: We have a meter on the makeup water as well as level control.

ZEIS: For the second part of the question—how to examine the riser weld which is under the insulation can—it's a simple matter to take that can off and replace it after radiography.

Q. What is the desirable condition in the riser? Is it a condition of zero tension, slight compression or tension within prescribed bounds, design assigned?

ZEIS: I think we'd all prefer to have no stress at all on the riser, but it's designed to go through a variety of conditions during start up, operation and shutdown. Normally there is a slight compressive stress in the riser.

Q. Would you expect this to be manifest as a slight bow in the riser, or would bowing be due to an excessive compressive stress?

ZEIS: I think you'd refer to an excessive compressive stress as one that would cause a permanent shortening of the length of the riser. This we have not seen. From what we have been finding out, slight bowing does not necessarily indicate an excessive compressive stress.

Q. Have you attempted weighing spring loads, that is transferring the spring load in an individual catalyst tube to any sort of dynamometer or proving ring with the furnace active to check out your spring calibration?

ZEIS: The recommendation would be periodic recalibration of springs during turnarounds, rather than during operation.

Q. The Incoloy used in the bottom header system—do you require a grain size for the criteria of establishing whether it's been heat treated or not? This would be other than the mill product, I imagine. Or do you use creep rupture tests for that? What is the grain size that you require?

ZEIS: The reference to the heat treatment of Incoloy, concerned forgings which are not mill products. We do not perform stress rupture tests. On forgings, for example, we believe more in the monitoring of calibrated thermocouple readings to be sure that the proper heat treatment was done.

We referred to last year's meeting and the work that International Nickel Co. has done. They did not say that grain size by itself indicates that the proper heat treatment has been applied.

In order to be sure that the part which is supplied meets the requirements of the Code Case and will give the expected high temperature properties, there are two effective means of control. One could be the creep rupture test that Avery and Valentine indicated and the other would be an accurate monitoring of the temperature. We believe this latter is the way that is most economical and which has proven reliable. We don't use grain size as a criterion for acceptability as proving that proper heat treatment has been applied.

The reason that we metallographically check grain size is that it's of concern to us that a part has not been overheated in heat treating. Where solution treatment is out of control, you can get a monstrous growth in grain size. This can also occur in heating the forging and there will be difficulty in the forging operation. It will come apart at the grain boundaries. There's been at least one failure of an Incoloy forging to which we think the large grain size has contributed.

Q. I understand **Inco** has some recent data that says their Incoweld A has somewhat better stress rupture properties than the Inco 182. Have you any experience with it?

ZEIS: I think that Incoweld A was used in the early days, and there were troubles with getting sound welds. We haven't reviewed this recent Inco data.

Q. I understand some people are doing some work with Inconel 625 as a filler metal for high temperature service. Do you have any experience with it?

ZEIS: No, we have not.

Q. I notice that one manufacturer's product has been used for the insulation around the tubes at the top of the arch. I wonder whether another type rope insulation might not be a better gasketing material than the felt layers.

JACOBOWITZ: It is true that up till now we have used only one manufacturer's high temperature ceramic fiber insulation for this service. We have had successful experience with the product. Other products of a similar consistency, conductivity may be used if they undergo a successful field trial.

W. D. CLARK, Imperial Chemical Industries, Ltd., Billingham, England: You referred to the paper given by Avery and Valentine of **Inco** at the symposium last year in which they stressed the importance of differentiating between Incoloy in the mill-annealed and solution-annealed conditions, the latter having higher creep-rupture values, and appeared to blame certain failures on the use of the weaker mill-annealed material.

Close study of the paper showed, however, that there were only a small number of tests and the difference between the two grades was only about a factor of two on life. Now we know from our own and other published experience that even with the greatest care the scatter in results of identical creep tests can easily be ten to one. The evicence for the difference between the two grades of Incoloy as presented in the Inco paper is therefore not convincing. Do you know whether any further work has been done?

One or two points concerning our reformers. We periodically cut off the protective covers over the field welds in our risers and radiograph and dye-penetrant test them. This is quite easy to arrange.

We did find one part of a riser top where the insulag was missing over a height of about a foot, all the indications being that it was an original void. It was clear, however, that radiation across the void had not caused the carbon steel pressure shell to become unpleasantly hot. In this area, of course, it would be deeply submerged in the jacket water.

The inner liner of the riser tops and transfer line in our plants is 304 and after about one years service about 30% of the 0.120″ thickness has oxidised away. It would seem that within another 12-18 months we shall have to renew the whole of this rather complex system. Has anyone else had the same trouble, or are more resistant materials preferred?

ZEIS: I could perhaps comment on the first part of Mr. Clark's comments on International Nickel Co. and the data that were available. I believe before this material was accepted by the ASME Boiler and Pressure Vessel Code, Inco did produce data which backed up the stresses which were allowed by the ASME Code up to a temperature of 1500F. I believe they also have and have published similar data in the higher temperature ranges, and I don't believe that there was a scatter of ten to one. We performed no testing on these materials, and we have relied to a large extent on the data from International Nickel and that which they presented to the ASME Boiler and Pressure Vessel Code.

F. W. S. JONES, C. I. L, Montreal, Canada: We have Incoloy 800 throughout the system as a shroud material and the reports that I've had from the plant indicate that we have not encountered any appreciable oxidation but have experienced some buckling.

G. SORELL, M. W. Kellogg: I think it should be pointed out for clarification that the choice of Incoloy in the CIL plant was based primarily on improved resistance to stress corrosion cracking relative to 18 Cr-8 Ni or 25 Cr-20Ni stainless steel. Actually we have never encountered any instances of stress corrosion cracking of stainless steel shrouds, but the Incoloy would provide greater protection in the event that some chlorides get into the system. The oxidation reported by Mr. Clark has, as far as we know, not been previously encountered

Q. What has been your experience with tube materials other than HK-40?

ZEIS: Recently we have furnished proprietary alloys for higher temperature rupture strength than HK-40. These alloys contain tungsten and other high temperature additives and have performed satisfactorily to date.

Q. You mentioned that pressures are above 450 lb./sq. in. How high can the pressure go?

ZEIS: Many are considering higher and higher reformer pressures, but at present all we can say is that pressures being considered are above 450 lb./sq. in.

Q. I'd like to ask what Code criterion is used to design both the outlet header and transfer line. We have recently bought three reformers and there seems to be no general conclusion that can be drawn. One was designed to B31.3, the other two were not. I'm referring to the outlet header below the tubes and the transfer line to the boiler.

ZEIS: As we mentioned in the beginning, most of the metal temperatures are above those for which the recognized safety codes give allowable stresses. So the designer would analyze the data that's available, and using similar formulae to those in the codes, select the thickness which would satisfy that design condition.

We mentioned also the thermal cycling stress which the ASA Code considers—you have to consider the unique features of the materials that are being used to see what allowable thermal stress should be applied. Although there are no codes that cover these elevated temperatures, the same basic principles would apply.

Q. Well, what I'm concerned with chiefly is which would you use, B31.3 or RP530?

JACOBOWITZ: There are certain aspects of the design of this manifold that can't properly be handled by piping codes or recommended practices like RP530—and that's why we go to the pressure vessel codes. The ASME Codes include methods for calculation of nozzles and reinforcements. These methods are more thoroughly covered in the ASME Codes than in the ASA Code.

Since there is no specific code which applies to all the details we have in the furnace, we make an assessment of which Code has the best design criteria and what seems to fit our conditions best.

Q. I notice in your reformer design bottom header arrangement, that you mount your catalyst tubes directly onto the header. We tried this design many years ago on a gas reforming plant, a methane reforming plant with tubes the same length as yours and we suffered seriously from deformation of the catalyst tubes because of the expansion of the bottom headers. As a result of this, our design has now moved to the pigtail arrangement at the bottom. Could you please explain to me how you now accommodate this natural expansion of the bottom header so that you do not get deformation of the catalyst tubes.

JACOBOWITZ: A good part of this is meant to illustrate our principles of design which are quite different in concept from previous designs utilizing outlet pigtails. In connecting the catalyst tubes directly to the internal bottom manifold we are able to accommodate all of the coil and header expansions within the furnace enclosure. This allows us to eliminate the outlet pigtail which can be a troublesome item as reported in this meeting last year in two papers which noted that outlet pigtails were the location of a number of reformer coil failures. Our expansion arrangement also has the advantage of utilizing a short straight transfer line to the secondary reformer without requiring troublesome bends and expansion loops.

Q. Most of the experience cited has been with natural gas reformers. Are there differences in your experience with stresses and metallurgy with naphtha reformer?

ZEIS: The mechanical design would be the same but there could be differences in the behavior of materials.

Q. What considerations led to the use of Inconel 600 for sheathing the bottom manifold insulation and Incoloy 800 for the cone at the effluent chamber.

ZEIS: The sheathing of the bottom manifold is chosen primarily for oxidation resistance in furnace atmospheres. The Incoloy 800 cone has adequate strength at temperature and is consistent with our practice to restrict materials outside the furnace to those which are ductile and which will retain ductility after exposure to service temperatures.