An Improved Header/Transfer Line

New design is developed for internally lining with refractory to solve problems of failures at outlet headers and transfer lines in reformer furnace service. Five case histories cited.

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Considerable experience over many years with failures in reformer furnace outlet headers and transfer lines has led to a refractory-lined header/transfer line design that can contribute materially to satisfactory operations.

This article discusses five specific examples, or cases, of problem situations and how they were solved. It describes the new design that Esso Research and Engineering Co. has developed and patented *(1)* as a part of its steam reformer system design, and which is being used to upgrade one of Exxon Chemical Co.'s ammonia units.

Exxon experience covers 12 years of operation and includes reformers with headers fabricated from HK, HT, and Incoloy 800 alloys; with direct tube-to-header connections, and with pigtails. Transfer lines have been provided in HT and Incoloy 800 alloys, and with internal refractory linings. The failures that have been experienced have prompted a search for improved materials, lower cost designs, and simplified designs. The latter is especially important since many reformers are located remote from major manufacturing centers and are therefore susceptible to repair delays unless costly spares are maintained.

The goal, therefore, has been to develop a design which could, if necessary, be fabricated and installed or maintained in the field without requiring special welding techniques and heat treating facilities.

Transfer line refractory failure (Case A)

In Case A, a 1500-ton/day ammonia unit in Holland, the reformer effluent transfer line is carbon steel, with a 6" dual layer refractory and insulating castable lining. The internal diameter of the lining is 33 in. The insulation has a density of 50-60 lb./cu. ft. with a 40% maximum silica content; and the refractory has a density of approximately 150 lb./cu. ft., with a low silica and low iron content. Two-piece, Type 304 alloy steel studs are used to anchor the lining. Approximately 3 studs are used for each 2 sq. ft. of lining.

In the conical alloy transition piece between the hot alloy reformer header and the internally lined transfer line (see Figure 1), a short alloy shroud is used to cover the start of the castable lining. Shrouds are not used in the line itself. The elbows in the transfer line are of mitered construction, and the line is painted with heat sensitive paint for "hot spot" monitoring purposes.

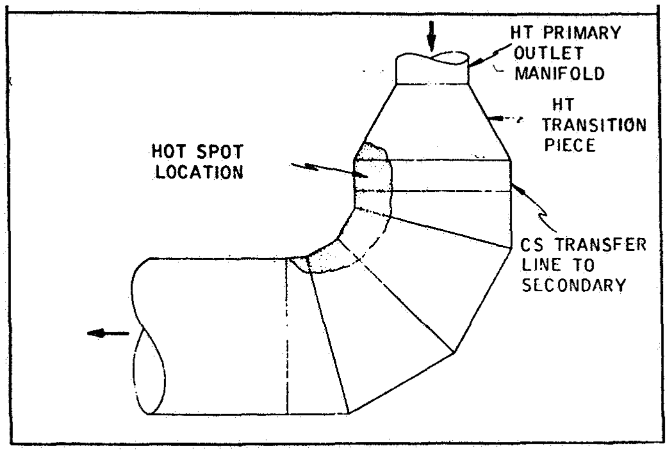

Figure 1. Transfer line hot spot—Case A.

After 3-1/2 years of operation, a "hot spot" developed in the area shown on Figure 1. It was detected by a change in color of the temperature sensitive paint. Steam cooling sprays were immediately applied to control the pipe metal temperature to below 600°F. Skin thermocouples were also installed to monitor the metal temperatures at the "hot spot" by recorder. After 14 days, the unit was shut down for other reasons, but at the same time repairs to this line were scheduled.

Inspection confirmed that the refractory layer and part of the light-weight insulating castable layer had fallen out in the overhead part of the elbow. Although no other gross lining loss was detected, the remaining lining in the transfer line appeared to be in poor condition, as evidenced by a non-uniform lining surface. Based on the appearance of the refractory, i.e. soft and hard areas, the failure was judged to be due to a poor quality initial installation, combined with the fact that the overhead of the elbow is the most sensitive to failure.

Figure 2 shows the condition of the refractory layer taken from this line vs. a normal sample of the same material. (It is apparent that the actual lining was not

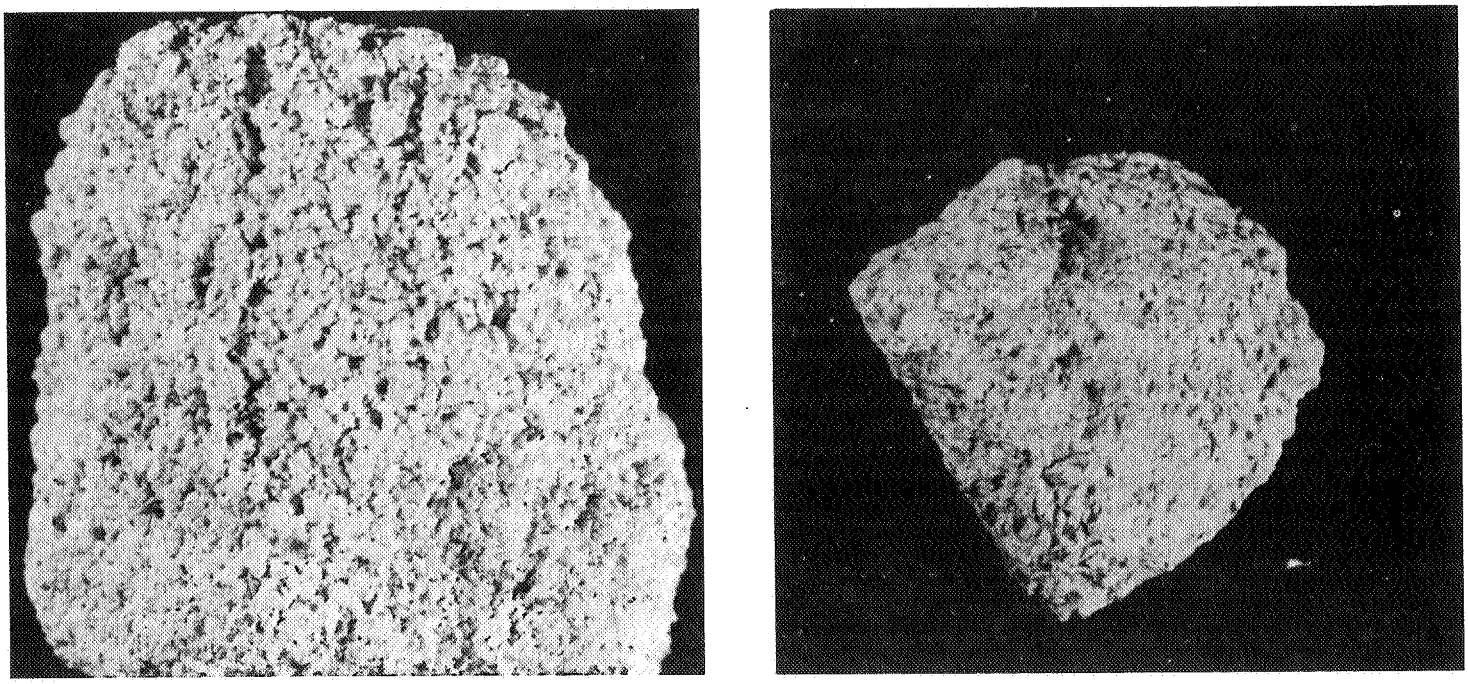

Figure 2. Refractory samples showing poor quality installation at A (note voids and lack of bonding) vs. normal conditions at B (expected condition of same material.).

homogeneous, and a compressive strength test showed it to be well below the 5,000-lb./sq. in. cold crushing strength value that would be expected for the material.)

The lining had been installed initially by gun-application. The inspection reports indicated, however, that several repairs had been made where soft spots were detected. These had been chipped out and repaired by hand-packing of the refractory castable.

Based on the appearance of the sample, it was suspected that insufficient water was used in the application. The overhead section at the elbow may be the most difficult area to line, and it may be that reduced water was used during application to make the refractory stay in place thereby affecting strength and susceptibility to failure.

A repair was then made with locally procured castables of the same make used originally. The castables were applied by hand-packing. During the dryout operation on startup, the pipe metal temperatures again indicated loss of internal lining, forcing a second unit shutdown.

Because of the failure of the hand pack repair, alternative repair schemes were investigated in contacts with European lining applicators. These schemes included, in addition to hand-packing, casting behind forms and gunning. Hand-packing was not favored, in view of the previous failure. Form casting was rejected because the geometry and the studs made form work difficult. After studying the access in the line, all the European companies contacted declined to offer to repair the lining by gunning. The reason given was lack of experience with gunning in such a tight space with the overhead lining surfaces.

A two-man gunning team from The United States was therefore engaged. As an indication of the capability in the U.S. of such manpower, the team was on the way to the unit in Holland within 24 hr. after notification. The lining repair was completed in 12 hr., and visual inspection and hammer testing showed it to be sound. No further lining problems have been experienced in this area. At a turnaround inspection, after 11 months of operation since the

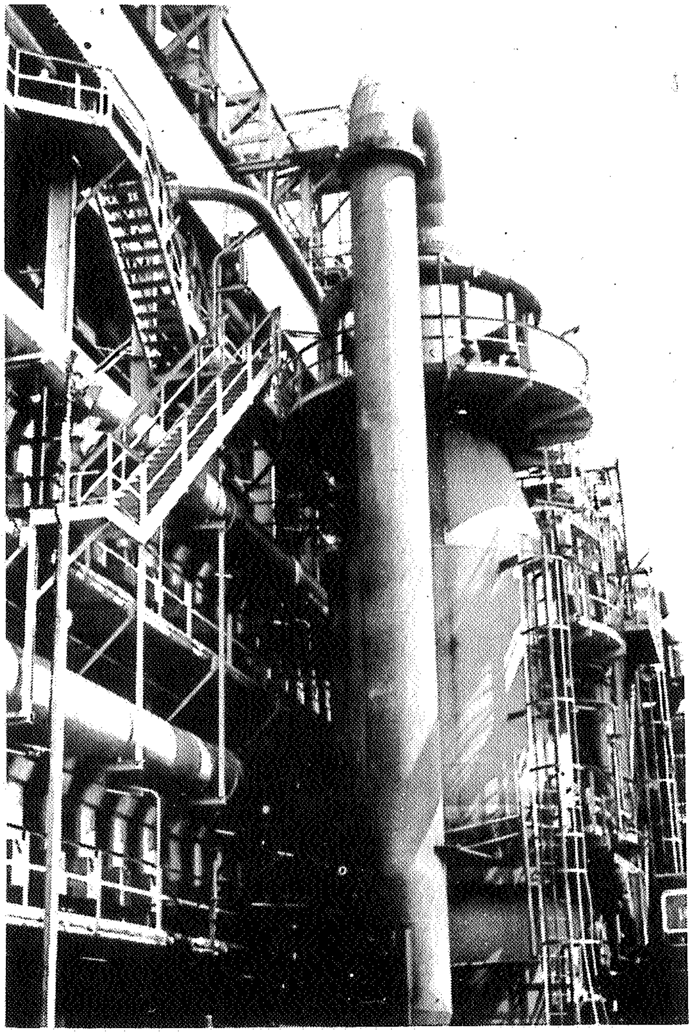

Figure 3. Primary/secondary reformer transfer line—Case A.

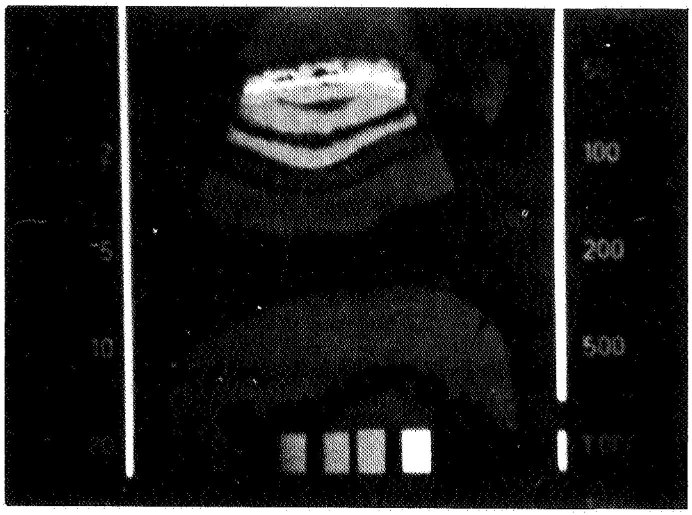

Figure 4. Infra-red thermograph of Case A transition cone. Lower portion shows beginning of No. 2 hot spot.

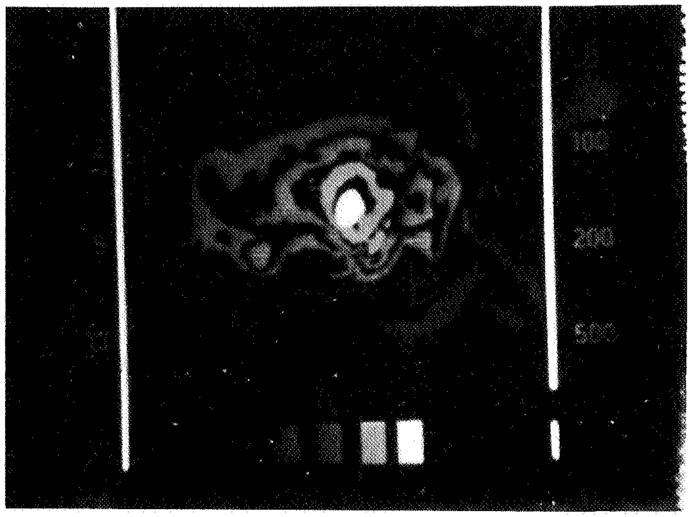

Figure 5. Infra-red thermograph of Case A No. 2 hot spot. Maximum temperature indicated is 760 to 780°F.

repair, there was no sign of lining deterioration. The repair area was visually superior to the remainder of the transfer line.

To avert unexpected future failures of the lined transfer line, shown in Figure 3, infra-red themography was selected by the plant as a practical method for monitoring the condition of the line. Two such photos, shown in Figures 4 and 5, cover the transition piece and elbow respectively. They were taken during the aborted startup attempt described previously.

Recent measurements on the entire line have indicated a few minor "hot spots" with maximum readings of 300°F. These are now monitored by skin thermocouples and recorder. An infra-red thermography scan is repeated on a regular basis to see if other problem areas are developing. The intent is to gain sufficient lead time to plan repairs if the existing lining deteriorates.

Transfer line refractory failure (Case B)

Another failure (Case B) due to internal lining deterioration took place in smaller diameter lined pipe that was part of the transfer line system of a hydrogen plant. A gunned lining repair technique as discussed previously is, of course, only feasible where the internal diameter permits access. We consider 24 inches the minimum for such repairs. In Case B, therefore, a different repair scheme was required.

Lining specifications were similar to those described in Case A, but the lining had been installed by casting with forms. A number of "hot spots" developed soon after initial startup, with one of these culminating in a line rupture. Although steam cooling was in use at a number of the "hot spots" on the transfer line system and the metal temperature of the pipe was satisfactorily controlled, a rupture finally occurred at one part of the line where steam cooling was not being applied. A local repair was made and operation was continued with employment of more and more steam cooling sprays.

The decision to plan a shutdown for repair of the transfer line system was made when a total of 34 local "hot spots" was reached. At that time, visibility under the furnace was impaired by the amount of cooling steam, and the noise of the steam made voice communication impossible.

The transfer line system comprises an H configuration and consists of 20-in., 30-in., and 40-in. carbon steel piping with 9-in., 17-in., and 24-in. inside lining diameters, respectively. The "hot spots" were in the 20-in. and 30-in. piping. A time study showed that the optimum approach was to prefabricate and preline replacement pipe sections.

Field installation could then be made in 10 days. As a comparison, dismantling of the existing piping, relining and reinstallation would have required approximately 25 days shutdown.

The repair lining technique specified utilized precast refractory cores. The cores were cast in a temporary shack facility at the site. The cores were then placed within the replacement pipe sections and castable insulation was poured into the annulus between the cores and the pipe This permitted rapid assembly of the transfer line system since lining of the pipe and assembly of the pipe sections could be made in a "building-block" fashion. Figure 6 illustrates the lined pipe connection, and Figures 7 and 8 show a typical casting operation of cores and insulation, respectively.

The repaired system has now been in operation for three years without a single "hot spot". On the basis of the excellent service, a second identical reformer at the refinery

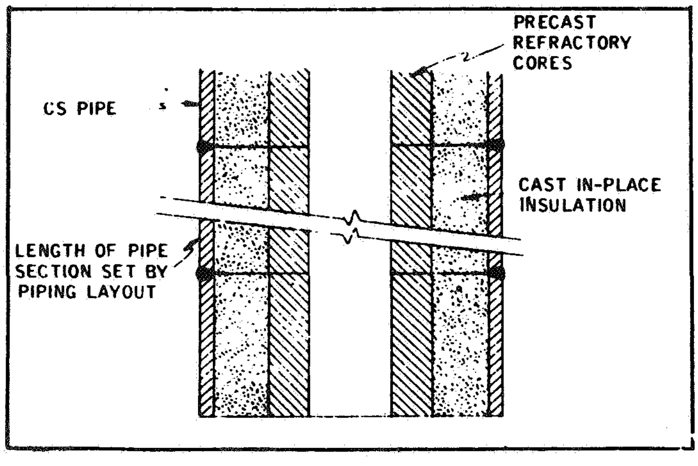

Figure 6. Prelined pipe assembly.

Figure 7. Refractory core casting method.

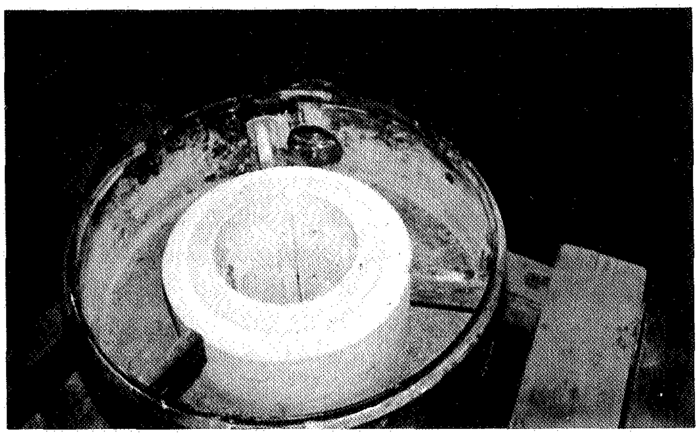

Figure 8. Header with core positioned for casting insulation layer.

has been converted and has been in operation for more than one year without problems.

Transition piece weld cracking (Case C)

A number of Exxon's plants have experienced cracking problems with the alloy transition piece between hot alloy headers or transfer lines, and refractory lined piping or equipment. The cracks are located at the weld in the hot end section of the transition piece.

A typical transition section design is shown on Figure 9. One of our units (Case C) has four reformer header-to-outlet transfer-line transitions featuring HK-40 headers and wrought Type 316 stainless steel transition sections. The cracking history has been as follows:

- The first failure occurred seven months after startup, on the hot weld of one transition section (NE), precipitating a shutdown. A 3-1/2-in. crack was found on the same weld on one of the other transition sections (SW). Both were repaired by grinding and rewelding.
- During a scheduled turnaround, 10 months after startup, cracks were noted in the hot ends welds at the NW and SE transitions. These cracks were not considered serious enough to warrant repair.
- At a scheduled turnaround, 21 months after startup, the weld crack found previously on the SE transition had grown, and it was then repaired. The crack on the NW transition was still not considered serious enough to warrant repair.
- Thirty-five months after initial startup, the hot weld on the NE transition failed again, causing an emergency shutdown. A new weld crack on the SW transition was also found and repaired.

These weld failures are considered to be the result of the following three factors:

1. Thermal stresses at the welds due to differential expansion between dissimilar metals.
2. Lack of ductility of the cast HK-40 component.
3. Piping movements caused by thermal expansion imposing additional bending stresses on the weakest component of the system.

Similar cracking has been experienced at the hot end joint of the outlet header/transfer line transition cone in the plant in Holland (see Figure 10), although these have not been serious enough to cause a shutdown. The header and cone at this location are HT (Modified) alloy.

We favor a design of transition sections that would employ wrought alloy throughout the critical zone for more ductility, and the use of generous knuckle radii for the transition ends in order to avoid or minimize stress and temperature gradients at the points most susceptible to failure. This preferred design, also considered by others *(2)*, is shown on Figure 11. It utilizes an Incoloy 800 concentric reducer. The Incoloy 800 alloy provides improved ductility to withstand cyclic stresses. The use of knuckles locates the welds away from the conical transition into the straight pipe section to avoid the stress intensification due to change in geometry at the weld. Careful thermal flexibility

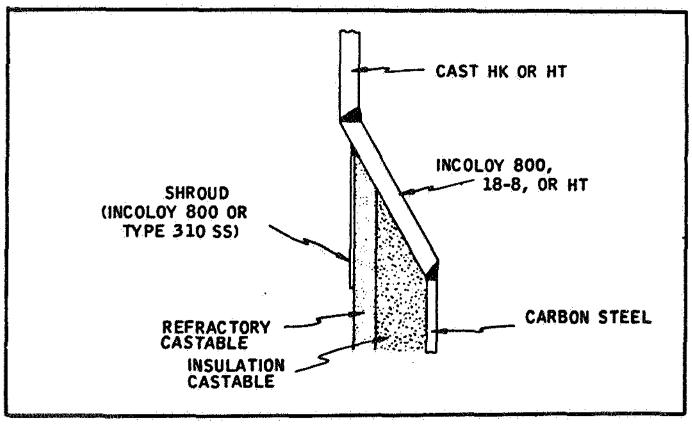

Figure 9. Transition piece design.

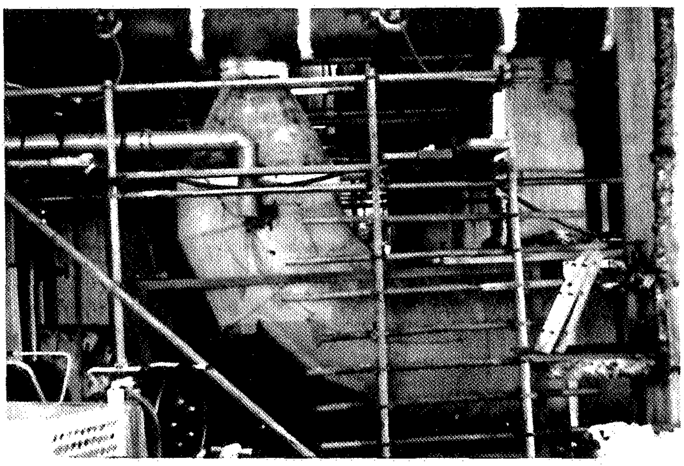

Figure 10. Transition cone—Case A.

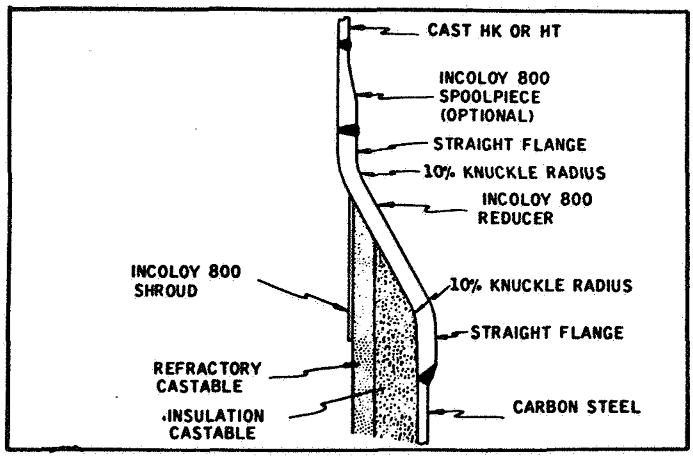

Figure 11. Improved transition piece design.

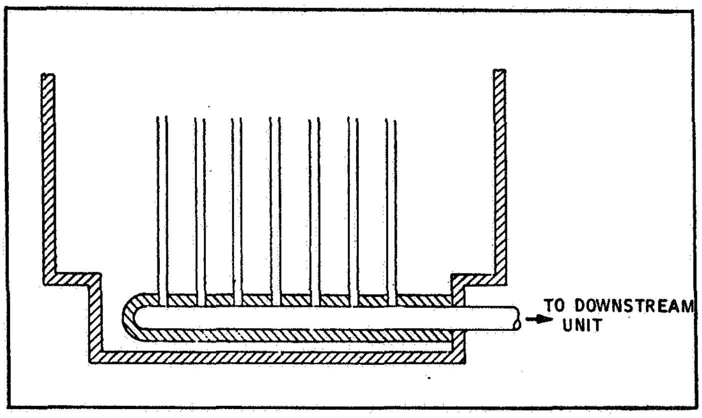

Figure 12. Internal hot-alloy header configuration—Case D and E.

analysis of the piping system and proper piping support design is also required in order to avoid imposing high price bending stress on the weaker transition section joints *(3)*.

Reformer outlet header failure (Case D)

The next two cases describe similar failures with HK-40 reformer furnace outlet headers, and two different approaches taken for solution of the problem. In these plants, the headers were located in a trough below the main floor in the furnace (Figure 12). Both failures were precipitated by thermal shock from water impingement from the onsite steam generators; also inherent design weaknesses were thought to be a contributing factor. Other authors have described similar problems with weld cracking in this type of design.

In Case D—a small, two-train hydrogen unit having 24 tubes in each furnace—the HK-40 header was supported by sliding support shoes welded to the bottom of the header. The tubes were connected to the header through an HK-40 Y-piece shown in Figure 13. The No. 1 train of the unit experienced header failures on two occasions. In one, a tube failure in the downstream process gas boiler led to water backup and failure of the header from thermal shock. The second failure, threee months later, was caused by water carryover from the onsite steam drum. Water may possibly have penetrated to the header which, in any case, exhibited severe cracking. Many of the Y-pieces were found cracked, and a crack was found in the header originating from the support shoe weld.

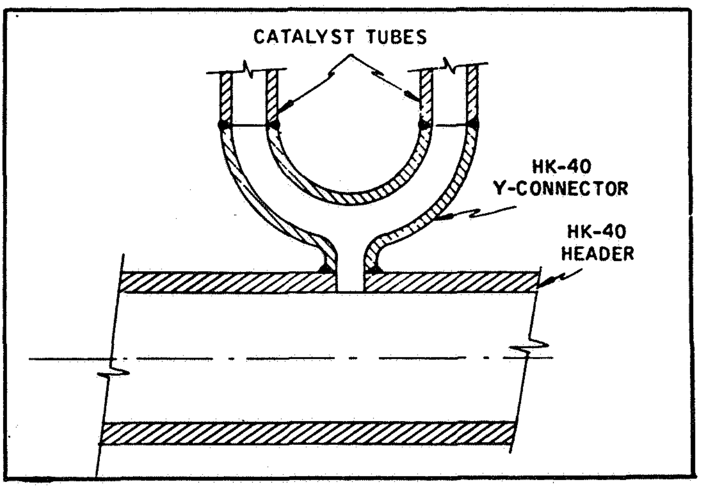

Figure 13. Y-connection, catalyst tube-to-header—Case D.

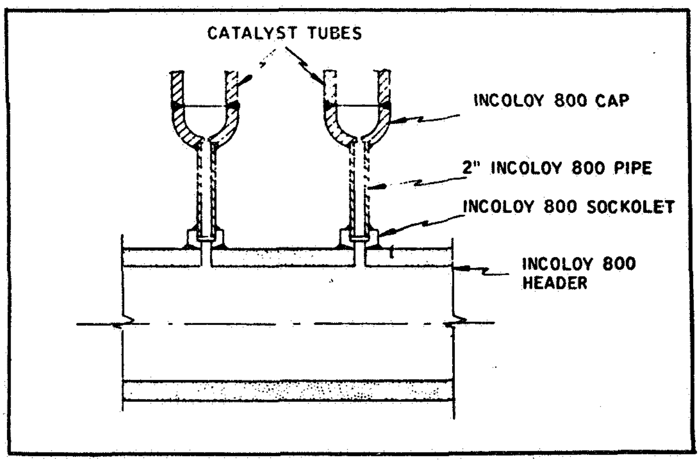

Figure 14. Revised Incoloy 800 connection, catalyst tube-to-header—Case D.

Repairs were made to the header, and a number of replacement Y's were installed. The repairs were time-consuming because it was necessary to solution anneal the exposed HK-40 components prior to welding. To improve the reliability of the design, and to facilitate future repairs should these be required, it was decided to revise the system by utilizing a more ductile material for the header, specifically Incoloy 800. In addition, the troublesome HK-40 Y-connectors were eliminated, and an improved header support system was provided.

The revised tube-to-header design is shown in Figure 14. Full size tube-to-header connections were not feasible due to close tube spacing in the furnace. Therefore, short, 2-in. Incoloy 800 straight-run connectors were used. That also provided flexibility for the small differential thermal movement between header and tubes. The header remained in the furnace trough to protect it from direct heat input. An external header and external tube outlet pigtails were considered to permit onstream tube isolation by clamping. However, the increased complexity of the design and the fact that two furnace trains were available reduced the incentive for "on the run" tube isolation. The new header support, shown in Figure 15, avoids welding on the header.

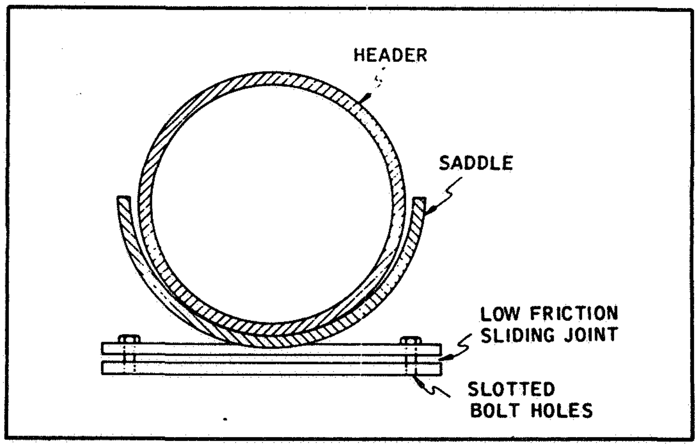

Figure 15. Revised header support guide—Case D.

The time from initiation of the redesign to installation was nine months. The new headers have now been in operations on both trains for nine months without problems.

Reformer outlet header failure (Case E)

In Case E, another HK-40 header with direct tube-to-header connections, cracking was first experienced in the tube-to-header welds after 3-1/2 years of operation. The cracking in this case also appeared to be an immediate result of an upset in the steam system which permitted liquid water to enter the catalyst tubes. The thermal shock split one of the catalyst tubes. It is possible that water also entered the headers, but this was not confirmed.

Dyechecking showed external cracking at 60% of the header/tube joints. Of these, 40% were ground out and repair welded with Inconel 182 rod, while the rest were ground out only. Most of the joints required solution annealing to obtain a satisfactory weld repair. Although thermal shock from water carryover did cause the actual shutdown, low ductility of the cast HK-40 and stress concentrations due to joint geometry could have contributed to the susceptibility of the system to failure. The total outage for repairs was 28 days.

Only three months after this repair, a leak was detected at one of the previously repaired tube-to header joints. Operation was continued, but after one additional month the crack had opened up sufficiently to require shutdown. The crack was found to extend almost fully around the tube-to-header weld joint, and it ran through the HK-40 header ligament into the adjoining tube-to-header weld joint. The rest of the welds were dyechecked and 40% showed cracks and 40% of those were repaired. This time, repairs were made using Incoweld A electrodes which were judged superior to Inconel 182 electrodes for this service. This repair accounted for another 15-day production loss.

Based on the severe production outages caused by these furnace header failures, the plant staff requested a design revision. Service factor is of major concern at this unit, and a design was needed which would assure a minimum probability for future outages. Only one onstream tube failure had been experienced (the first shutdown described above). However, it was decided that an external outlet header and external pigtails to permit onstream tube isolation, if ever needed, would be a desirable feature.

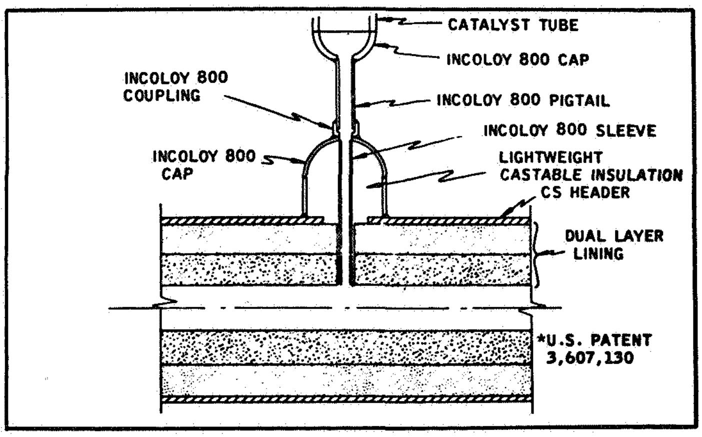

Figure 16. Replacement internally-lined header connection —Case E (U.S. Patent 3,607,130).

A design providing maximum reliability, in our opinion, could be achieved using the Esso Research and Engineering Co. patented *(1)* internally-lined header system. The internally-lined header design, shown in Figure 16, is our preferred header design, developed originally for use in hydrogen plants. It consists of a dual-layer, internally-lined header (without shroud). A refractory core method is employed, similar to that described in the Case B repair. An Incoloy 800 cap is used at the base of the catalyst tubes, while an insulation-filled Incoloy 800 cap is used against the header. The vertical pigtails are of Incoloy 800, and are of sufficient length to permit onstream pigtail clamping. The vertical orientation keeps all thermal movement in one plane and simplifies the mechanical design. The HK-40 tubes in the Case E revised design are extended below the main floor of the furnace and require removal of the original header box and installation of a new floor/tube seal.

To reduce downtime for the revision, a full set of catalyst tube replacements has been planned. This eliminates the need for time-consuming solution annealing and welding during turnaround. Materials and components are on order, with installation scheduled for early 1974.

Why an internally-lined header?

Selection of the internally lined header concept for Case E was based on what we consider to be several definite advantages over a hot alloy system (whether HK-40 or Incoloy 800):

- The low metal temperature of the lined header eliminates expansion problems and simplifies tube and header supports.
- The internally lined header is insensitive to temperature excursions and much more resistant to thermal shock than alloy systems.
- The lined header and short pigtails can carry the tubes should the spring supports fail.
- Furnace design is simpler because tubes and header can be oriented in one plane.

The internally-lined header design lends itself to conversion of existing reformers regardless of original design. This can best be illustrated by the conversion in Case E where

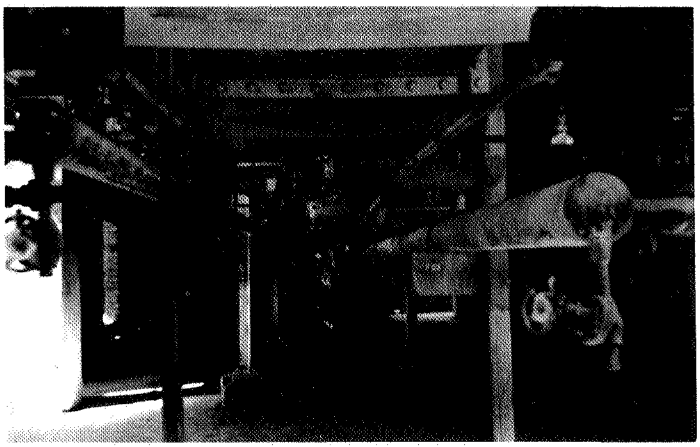

Figure 17. Header location—Case E.

space was limited, as shown in Figure 17. The concept of minimum thermal expansion and single plane tube/pigtail/header arrangement is particularly attractive for such cases.

The internally-lined system does require careful attention to details of lining installation. A satisfactory lining installation is the key to the reliability of the design. All castables must be tested to verify that they meet specification. The use of refractory cores and subsequent cast-in-place insulation techniques does permit more careful quality control, compared with other refractory installation methods. We have experienced no lining failures with this system to date.

Conclusions

Just as with any other design, internally-lined transfer lines or headers require correct fabrication and installation techniques in order to insure a reliable design. The fact that the lining is internal does make it more difficult to evaluate once it is installed other than by means of onstream temperature observations. Consequently, cast-in-place refractory application methods require expert application personnel. Our experience with precast refractory cores, however, indicates that adequate installation procedures can be assured with this technique, requiring no more definitive engineering effort in review of materials used, procedures, personnel qualifications, etc., than is normally allotted to high temperature alloy piping installations.

All reformers presently in operation utilize field installed linings applied essentially by locally available labor forces supervised by one or two knowledgeable refractory installers. Where stubborn problems exist with "all-alloy" type reformers, conversion to the lined header concept is feasible and practical. #

Literature cited

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WORLEY, A. C.

RUZISKA, P. A.

DISCUSSION

RICK FLOOD, Wisconsin Centrifugal, Inc.: I would just like to comment on your remarks regarding ultrasonic inspection. I think that your paper pretty well demonstrates that conventional ultrasonic techniques don't work too well on cast materials because of the attentuation of the signal, due to their coarse grain size. But I'd like to note that the Steel Founders' Society has undertaken a program to develop some refining techniques for ultrasonic signal enhancement, especially with cast materials, based on some rather promising results obtained with some work done at Battelle (Memorial Institute). So hopefully something better will be forthcoming.

Q. Do you have any experience with electrical as opposed to centrifugal castings?

RUZISKA: We have no experience.

W.D. CLARK, ICI, England: Two questions. There is an old argument as to whether the cost of internally boring furnace tubes is justified by service performance. From the point of view of internally calipering tubes, would you say that such measurements can be far more revealing if the tubes were bored rather than having the more erratic 'as-cast' surfaces.

Secondly, inspection of the furnace tubes by radiography, calipering etc. tends to be time-consuming and difficult to interpret. Usually, however, you can look into the furnace during operation and recognise the location where tubes are running hot and therefore likely to be suffering. Could you say whether in your experience it is common to find that they are cracked in locations which have never been rated as running hot?

RUZISKA: Taking the second question first, it is true that tube failure is likely to occur in a hot zone, and one can limit the areas of the tube which must be covered in the inspection, in most cases. But, in some cases it is not easy to identify the hot zones. For instance, we have some furnaces using side wall burners, and hot spots can occur at any elevation due to deterioration of the burners. In such cases, the tube will run hot at that position for a while, until the burner is cleaned or adjusted. It can be hard to judge where to look for damage with a furnace of this design.

Regarding the question on inspection techniques with internally machined tubes, it seems to me that it might be possible to employ an eddy-current flaw detection technique to search for cracking at the inside surface. This would be the only method I can think of which would be favored by a machined bore.