Service Behavior of Reformer Outlet Manifolds

A detailed survey of reformer furnace radiant tube outlet manifolds in ammonia plants provided data that is useful for the improvement of operating performance

C. L. McMillan,
Heat Research Corp.,
Houston, Texas

A somewhat minor yet significant component of the reformer furnace in an ammonia plant is the radiant tube outlet manifold. In recent years, problems in reformer tube operation has increased the industry's already heavy attention on radiant tubes.

An AIChE paper in 1974 by W. S. Salot (*1*) mentioned the reformer manifold briefly, and that led this author's company to solicit and receive Mr. Salot's help in distributing a questionnaire on the operating history of outlet manifolds in M. W. Kellogg reformer furnaces. Most responses to the questionnaire were received by Sept., 1974, and then were updated in Aug., 1975. They make up a survey called a "reformer outlet manifold survey," the contents and analysis of which are presented in this article.

Figure 1 shows the general configuration of the process furnace. The process gas is fed from the convection section where it is preheated, through the inlet manifolds above the arch, to the radiant section of the furnace. The gas flows from the inlet manifolds through small diameter, flexible pigtails to the radiant tubes which are filled with catalyst. Flow is downward through the catalyst into the outlet manifold where it is collected and fed upward through a riser tube into the effluent chamber. The furnace is top-fired, and the flue gas is collected in tunnels at the bottom of the furnace where it is fed through the transition section to the convection section of the furnace. One row of catalyst tubes, its connecting outlet manifold and a single riser is referred to as a coil, or harp. The radiant section may be made up of any number of coils, but the furnaces covered by this paper contain from two to ten.

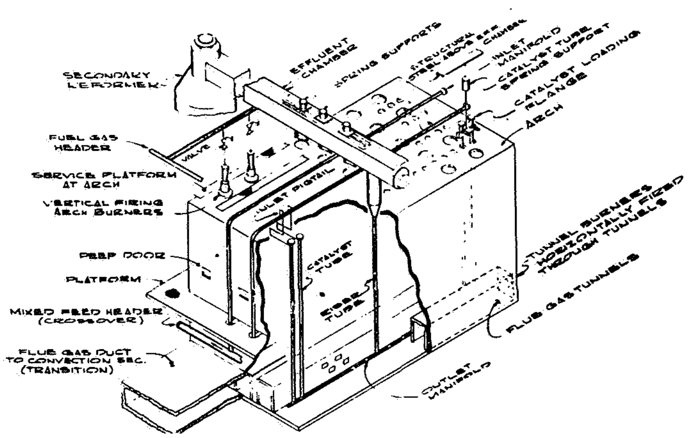


Figure 1. Ammonia reformer furnace.

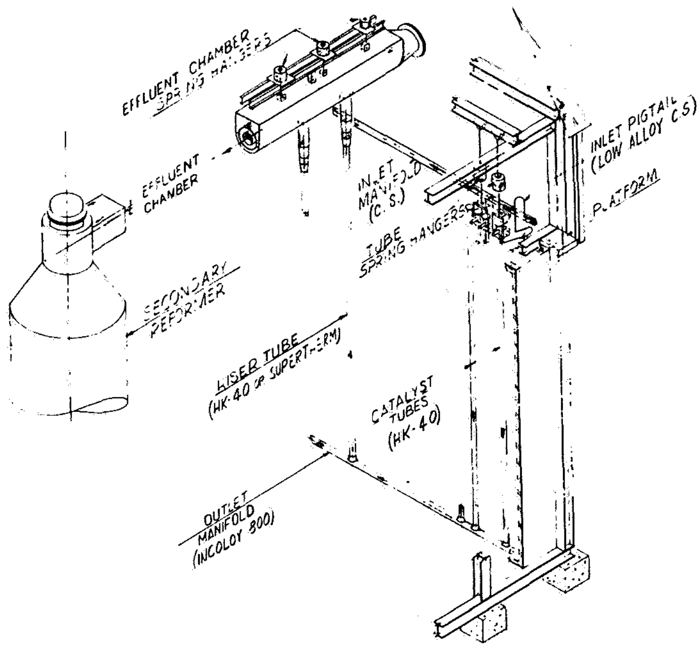


Figure 2. Reformer coil system.

Figure 2 (*2*) shows the coils in more detail. The inlet manifold is anchored near its midpoint and grows outward (thermally) from this point. The outlet manifold is stopped horizontally at its midpoint and similarly grows outward. The catalyst tubes and the riser tube of each harp grow downward due to thermal expansion. As shown in Figure 2, the riser tube is normally of HK-40 of "Supertherm" material, the catalyst tubes of HK-40, the inlet manifold of carbon steel, the inlet pigtails of low alloy steel, and the outlet manifold of Incoloy Alloy 800 or 800H. Note that this particular use of Incoloy manifolds began at about the same time the higher pressure, higher capacity plants were introduced in the mid-1960's.

The "first generation" design

Figure 3 shows the coil in still more detail; that is, the riser tube, the catalyst tubes and the outlet manifold. The configuration of the coil shown here represents what may be referred to as the "first generation" high-pressure reformer coil. "High-pressure" here means in the area of 500 lb./sq. in. The items shown are of previously described materials, but note especially the outlet manifold at the bottom of the figure. The riser tube is connected to the outlet manifold by a tee section, and the manifold it-

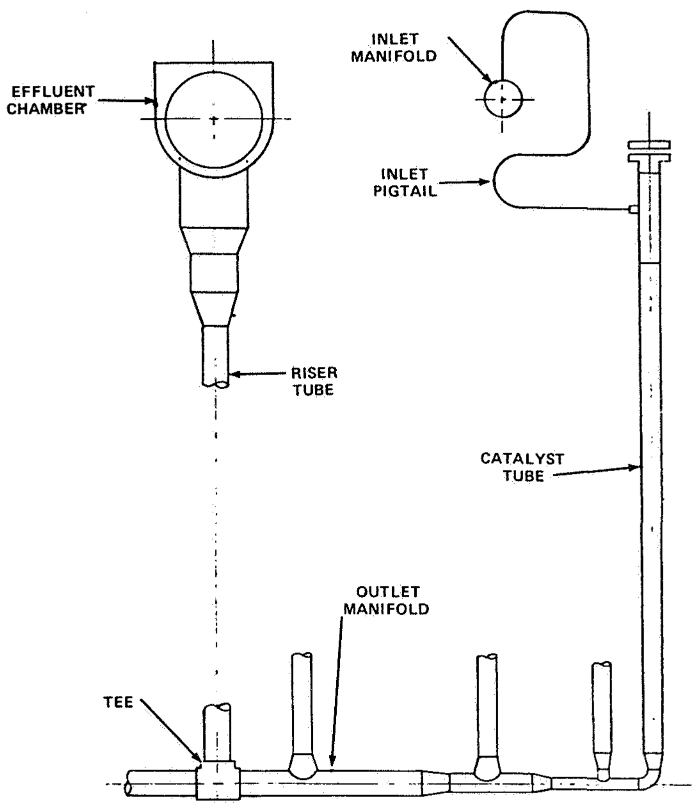


Figure 3. Radiant coil, first generation.

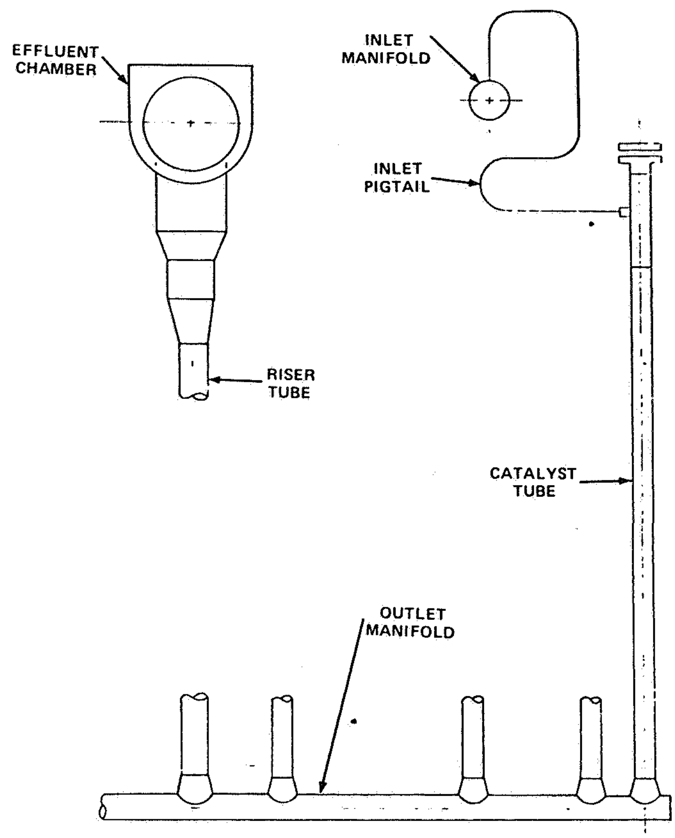


Figure 4. Radiant coil, second generation.

self is made up of tubing of three different diameters, connected by reducers. Although shown only schematically, six circumferential manifold welds can be seen to the right of the riser, and there is actually one more, a field weld, not shown. Likewise, there are seven on the opposite side of the riser tube, making a total of 14 in each manifold.

Figure 4 shows a similar more detailed view of the reformer coil. The "second generation" began in early 1967 when a significant number of design improvements were incorporated into the Kellogg reformer furnace. Among these improvements, which had evolved through operating experience and had been developed by research and design, are the changes shown between Figures 3 and 4.

Again, the materials are as previously described, but note that the outlet manifold is of a constant diameter and that the riser-to-manifold connection is made by a saddle type fitting. This connection is similar to the ones previously used between the catalyst tubes and manifold. Note that in this manifold, *no* circumferential welds can be seen. Again, the one field weld to the right of the riser is not shown. The total number of circumferential manifold welds were reduced from 12 shop welds plus two field welds, to two field welds.

Survey results from 17 plants

Responses were received from 17 operating ammonia plants having a total of 116 outlet manifolds. The original manifolds have experienced a service life of 4 to 10 yr., averaging approximately 7 yr. each. Of utmost importance to everyone concerned is the number and frequency of plant shutdowns. Therefore, the reformer outlet manifold survey asked the question, "How many outlet manifold failures developed in service and caused a shutdown?"

With this as a basis, there is a large difference between the data received for first generation reformers as opposed to that received for those of the second generation. Although the constant diameter manifolds have been in service a somewhat shorter time than those with varied diameters, the data will be presented here with a major division between the two types.

Essentially all statistics presented have been affected by overproduction, i.e., beyond design capacity. Relative to this, the following facts are generally accepted: first, that plants typically "run" at capacities greater than that for which they were designed; second, that overproduction requires heat input beyond that required for design production; and third, that small increments of temperature in the operating range of these furnaces have a large effect on the life of metals.

With respect to the temperature effect on tube metal life, it is important to note that the design basis for the manifold is stress to rupture in 100,000 hr. at a given temperature. Normally the stress, mainly due to internal pressure, is fairly constant. Therefore, variations in temperature directly affect the life of the tube. The plant which reported the largest number of shutdowns caused by manifold failures is known to have averaged approximately 20% over design production since initial start-up.

With respect to the general data shown in Table 1, it should be noted that of the 17 plants included in the survey, six have not had a single shutdown caused by a manifold failure. (From this point forward, "manifold failure" refers to one which caused a plant shutdown.) The earliest reported failures were after two years' service; that is, all manifolds operated for a minimum of two years before experiencing a failure. Note also that the somewhat

Table 1. General data

Item description	Overall or total	First generation	Second generation
Operating plants responding to survey	17	12	5
Total manifold years	838	595	243
Average age (years) of original manifolds in August, 1975, or at time of replacement	7.2	7.7	6.2

shorter time in service is actually only 1.5 yr., which lends to the validity that there is a basis for comparing the two generations.

Far fewer failures in "second generation"

The large difference previously noted between first and second generation manifolds is that those of the second generation have experienced significantly fewer failures, as shown by the "manifold failures" data of Table 2. This also indicates that the second generation manifolds were truly an "improved" design. Table 2 also compares the failures occurring at welds, to those occurring in the manifold tube material itself.

The numbers indicate that a 2-to-1 majority of shutdown caused by manifold failures were failures occurring at welds. Of significance here is the fact that all but one of the 17 plants included in this survey had their original manifolds welded with Inco 182 (Inconel 182), which is now known to exhibit a loss of rupture strength and a loss of ductility at elevated temperatures. (*3*)

The plant that initially used Inco "A" (Inco-Weld A) instead of Inco 182 is now running successfully after being onstream for four years and has experienced no manifold failure of any kind. This run of four years is significantly lower than the average age of manifold surveyed, and its significance might therefore be discounted. It should be noted, however, that four years is two years beyond the minimum service life experienced before manifold failures were encountered in any of the other plants surveyed.

At the time the Incoloy manifold design was developed, available test data showed that three weld deposit materials were suitable—Inco 82 (Inconel 82), Inco "A" and Inco 182. The data showed that all were equally acceptable for the service intended, based on approximately equal amounts of testing and research. On this basis, Inco 82, a bare wire, was chosen for the root pass; and Inco 182 was chosen for the weld-out rather than Inco "A", as it was believed to produce better quality joints.

Table 2. Manifold weld and material Failures per manifold year

Item description	Overall or total	First generation	Second generation
Total manifold years	838	595	243
Manifold failures	0.029	0.035	0.012
Failures in welds	0.019	0.024	0.007
Failures in material	0.010	0.012	0.004

In 1967, approximately four years after its original use and installation, the manufacturer of this weld rod discovered through further testing that after long term exposure to elevated temperatures, Inco 182 became brittle and exhibited a loss of rupture strength. (*4*) Of course, some period of time elapsed while the manufacturer verified its data and notified its users, (*3*) but within a short period of time owners were notified of the situation and advised that any weld repair should be made with Inco "A", instead of Inco 182. Also, the same change was made in the building of new furnaces, which is reflected in the statement above concerning the one plant's successful use of Inco "A" instead of Inco 182.

Specific numbers of weld cracks were apparently not readily available. Responses varied from specific numbers (normally reported by younger plants) to generalities such as "numerous," "several" and "a few per year."

From a review of all responses, however, the following conclusions have been reached on the subject of manifold weld cracks:

1. Use of the Inco 182 weldment resulted in a significant number of weld cracks beginning after approximately two years of service.
2. If such cracks are not detected early in their development, i.e., during normal shutdown inspections, they may result in manifold failures similar to those tabulated in Table 2 above.
3. The majority of weld cracks are found during shutdown or turnaround inspections and can therefore be handled on a preventive maintenance basis rather than on a crashdown repair basis.

Table 2 also focuses on material failures and compares those occurring in first generation with those occurring in second. Design calculations show reduced stresses at all critical coil locations, which seems to be verified by this data. Ballooning (i.e., localized creep) was present in all cases of manifold material failure. At least one, and possibly two, instances of these failures appear to be related to eccentricity and to less than minimum wall being present after extrusion of the manifold material. The remaining failures were all at locations where the specified minimum wall thickness was present, but the presence of ballooning indicates that overheating probably took place in the area of the failure. Indeed, these failures occurred at four plants, two of which answered "overheating" to the survey question "What do you believe is the largest single cause for manifold failures?" Table 4 shows owner/plant response to this question.

In summary and analysis of the data and comments in/on Tables 1 through 3:

Table 3. Primary cause for manifold failures

Percent of total plants responding	Responses
35	Overheating.
12	Temperature cycles.
6	Loss of insulation.
17	Weak weld metal/weld strength.
6	Bending at welds.
6	Lack of tube material strength.
6	Support of catalyst tubes.
12	No comment.

1. Manifold failures were substantially reduced in second generation reformers.

2. Better weld filler material has been the most significant element involved in improving outlet manifold performance.

3. In instances of tube material failure, the most frequent cause was overheating, either from general operation at over-design through-put, from lack of adequate insulation or from lack of adequate process flow.

Six general comments

With respect to all data submitted and tabulated, the following general observations can be made:

1. Insulation at time of failure (no particular type insulation, other than having none at all) was common for any significant number of failures or cracks either in material or welds.

2. Although not definite, there is a slight trend to the effect that the plants which detect the most cracks during shutdown inspections experience the fewest on-stream failures. It does seem reasonable to expect that with high quality shutdown inspection, cracks can be found near the time of their inception and will be less likely to cause on-stream failures or plant shutdowns.

3. As might be expected, cracks or failures occurring in the tube material were of a longitudinal nature, while the cracks found in the welds, of course, followed the weld. Also, there was no trend toward a specific length of weld or material crack. The weld cracks ranged from a length of ½ in. to complete circumference, while splits in material ranged from 2 to 60 in.

4. The circumferential locations of cracks varied and no trend was apparent.

5. Crack origins were generally indeterminable for material failures. Weld cracks were generally found to be from the outside, although some were found to be from the inside and a few to originate internally, that is, neither inside nor outside, but within the metal thickness.

6. Crack depths showed no definite trend and ranged from ⅛ in. to full thickness. Again, these were reported in welds, rather than in tube material.

What has been done?

Contractor (designer/fabricator) organizations (ie., author's company and its associated companies) have done the following. The previous mentions second generation reformers, which was a significant action taken by these organizations. In addition, the furnace outlet manifolds have been continually improved to currently include the following:

1. Specification of Inco "A" (or Inco 82) weld filler material for shop and field welds, instead of Inco 182.

2. Provision that the minimum specified tube wall thickness is present by requiring suppliers to make ultrasonic thickness measurements—at one-foot intervals, either scanning a continuous circumferential band or spot checking at 60° intervals around the circumference.

3. Initial provision of rigidized blanket insulation which is easily replaced and which allows efficient inspection methods and techniques.

Operating companies (including only those replying to the questionnaire) have done these things.

Insulation. Three plants continue to use fiber layers with original sheathing, which is similar to the original insulation installed in their furnaces. Nine now use fiber layers with rigidized outer surface. Two of these nine have increased the original thickness. Five plants have gone from original sheathed fiber to rigidized fiber, and finally to preformed or premolded fiber.

Weld filler material. All plants report they have gone to Inco "A" or Inconel 112 to repair or replace welds; and no plant reported a failure in such a new weld, although no data was submitted on age of these welds.

Inspection. Seven of the 17 plants report that they now use an ultrasonic system to inspect for cracks and/or leaks, and five of the seven also dye-check. Eight plants use dye-checking without ultrasonic. All those 15 report that when cracks are found by dye-checking or ultrasonic means, they are confirmed by radiography.

Of the two remaining plants, one reports that it randomly X-rays, and the last reports only visual inspection. One might note, however, that this last plant has had only one failure in nine years of operation.

What is the outlook?

Plant owners and operators might consider investigating the wall thicknesses of their manifolds. Although encountered infrequently in plant histories included in this data, tube walls of less than specified thicknesses have been reported.

Analysis of the data in this survey indicates that once the Inco 182 welds have been replaced, the subject outlet manifolds should be an insignificant source of operating problems, especially those which cause shutdowns. If plant owners and operators will carefully maintain the manifold insulation and follow a well planned system of inspection for cracks during shutdowns, the manifold problems which do occur can be handled on a preventive maintenance basis.

An often quoted maxim is that "one pays for what he gets." As applied here; production beyond design capacity, which is obtained by over-firing the reformer furnace, will be ultimately paid for in reduced service life of both outlet manifolds and catalyst tubes.

Although there is no reason to doubt current welding procedures or materials, it is certain that both will improve. Also, tube materials are likely to be improved, and operating experience will continue to be accumulated. The author's company will incorporate the resultant knowledge into new furnace design, as it has done in the past, thereby providing furnaces of continually increasing reliability.

Acknowledgments

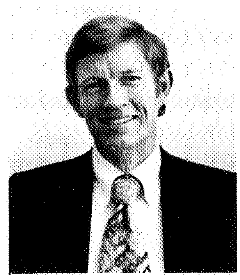
Firstly, to Mr. E. Blumenaus, the man who originated the outlet manifold questionnaire and arranged for it to be distributed through Mr. Salot. He tabulated a great deal of the data presented in this article, and he reported some of it last year to M. W. Kellogg ammonia plant owners. His efforts are gratefully appreciated and acknowledged.

Secondly, the data presented depended totally on the responses from plant operators/owners. The author's company appreciates each and every response. Also, it hopefully anticipates similar sharing of experience and in-

formation in the future, which can be mutually beneficial. #

Literature cited

1. Salot, W. S., "The Trouble with HK-40 High Pressure Reformer Tube Operation," AIChE Ammonia Plant Safety Symposium Vol. 17, pp. 34-37 (Salt Lake City, Utah, Sept., 1974).
2. Zeis, L. A., and Jacobowitz, J. C., "Recent Improvements in Primary Reformer Furnaces," 1968 Tripartite Chemical Engineering Conference, Montreal, Quebec. Air and Ammonia Plant Safety Symposium, Vol. 11.
3. Letter TS-102968-MP1, of Oct. 29, 1968, from International Nickel Co. Inc., to M. W. Kellogg Co.
4. Statement by International Nickel Co. representative at 1967 AIChE Conference in Mexico City.


C.L. McMillan

DISCUSSION

KEN WRIGHT, Camex: We are one of the companies that experienced a failure in a lower manifold last fall, and this was a center section failure which was a glorious rupture. In going through our furnace, we found that approximately seven of the field welds cracked, which were not apparent when we examined them about 3 or 4 months earlier.

We repaired these welds and found some other manifold sections in the furnace which had shown creep which predicted that failure would be in the next year or so. We replaced those sections.

We've adopted the practice of going through the furnace during turnarounds and calipering the outside diameter of the manifolds. This is the only way you can really tell when you are about to lose it all.

MCMILLAN: Well, I'm not sure if you asked a question, but I'd like to respond in token to your comment about the weld cracks. This is very possible if your original failure was in the manifold material itself. And, when you went in after this failure, I assume you found these cracks in the same manifold?

WRIGHT: The weld cracks were not in the same manifold.

MCMILLAN: If not, I will refrain from commenting now, but would like to talk to you after the meeting.

MCMILLAN Subsequent Comment): Camex welds were orignally made with the 182 weld rod; therefore, such cracks could/can be expected.

JOHN LIVINGSTON, ICI, Billingham: Just in case any people in the room are getting the impression that cracks only propagate at shutdowns as a result of ultrasonic and dye penetrant checks, I could just add to the story that we have, in fact, detected outlet header cracks on line. And, indeed have monitored them until a suitable shutdown, by the use of this Delcon sound detector. This is something we recommend for people to check on line for development of any of these cracks.

And indeed because we agree with you that it is an overheating problem, we have in fact instigated on the Kellogg furnaces at Billingham, direct thermocouple temperature measurement of each and every pigtail, and there is strict control on the temperature of these headers.

BILL SALOT; Allied Chemical Co.: I think it might be worth mentioning a couple of other factors that may have contributed to the improved performance of 2nd generation manifolds. One of them was that the 2nd generation manifold had an increased diameter. The diameter was increased from four inches to five inches, and that increased section modulus certainly reduced the bending stresses under any given load. A second factor may be the design stresses in the Incoloy. Were they not reduced between the two generations? The reason I suspect that they were is that when the 1st generation design appeared there was no ASME code case on Incoloy, and the only data available was what International Nickel could provide. But at the time of the second generation design, ASME Code Case 1325 was available and may well have given different figures for the 100,000 hour rupture life which you were shooting for. Can you comment on this?

MCMILLAN: Well that's correct. The allowable stresses were reduced, but only slightly. The major improvement here was, as you specified, the larger diameter. Again, as I noted—the decrease in the number of welds, that is, the decrease in the amount of fabrication required in the whole of this manifold was the main improvement. It is now basically an extruded material, which has no large openings in it. We just eliminated a lot of the problem areas.

As you mentioned, code case 1325 did come into play. It perhaps aided in another way, and that is we had something to specify to, at that point, rather than using just qualifications, inspection methods and material requirements that we had initiated on our own and through the manufacturer of the material.

DAVID MILLER, CF Industries: Curt, since your remarks and the response to your survey indicated that over heating was the culprit in a majority of the manifold failure cases, both in the 1st and 2nd generation plants, what are your recommendations on the insulation? Do you recommend staying with the original 2 inches, or increasing to three, or something greater. Could you give us your thoughts on this?

MCMILLAN: David, we'll stay with our original recommendation. Right now we are using about 2½ inches of insulation. Two inches we really feel is adequate; with the proper material and K factor, but we have gone to what we call a fool proof method for the surface of this insulation and that is a pre-wet blanket, which we originally install on this manifold insulation. We realize that some of you plant owners use 2 inches or 3 inches and spray the outside surface to get a rigidized surface, but we feel obligated, as an initial responsibility, to provide a more fool proof method, or one as fool proof as possible.

With this pre-wet method we don't miss any spots by mis-spraying or something.

MILLER: You are indicating that if application is correct, 2 inches is adequate?