Lessons Learned from Radiant Tube Cracking

A case history review of problems in high pressure reforming furnaces in four different ammonia plants, and the steps taken to solve them

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This is a report on tube cracking problems encountered and solved in four high-pressure steam-methane reforming furnaces, all supplying feed gas to ammonia production units within Unie van Kunstmestfabrieken B.V. (UKF)

The experience covered by these four reformers began with the start-up of the first unit in June, 1967. A top-fired unit, it is part of the 1,000-short ton/day ammonia plant of Ammoniak Unie B.V., Rotterdam, a company owned jointly by Badische Anilin and Soda Fabrik (BASF) and UKF.

After start-up, we perhaps did not pay enough attention to the absolute metal temperature level of the tubes. Our reformer experience up to that time was acquired with low-pressure reformers, where tube problems were virtually unknown.

In March, 1971, after nearly four years of operation, we decided to make a spot X-ray examination of the hottest welds (upper welds) in the reformer tubes. The results were such that we did a complete X-ray check of all tube welds exposed to flame radiation. Of the 336 catalyst tubes, 85 had cracks in the upper welds and two had cracks in the lower welds.

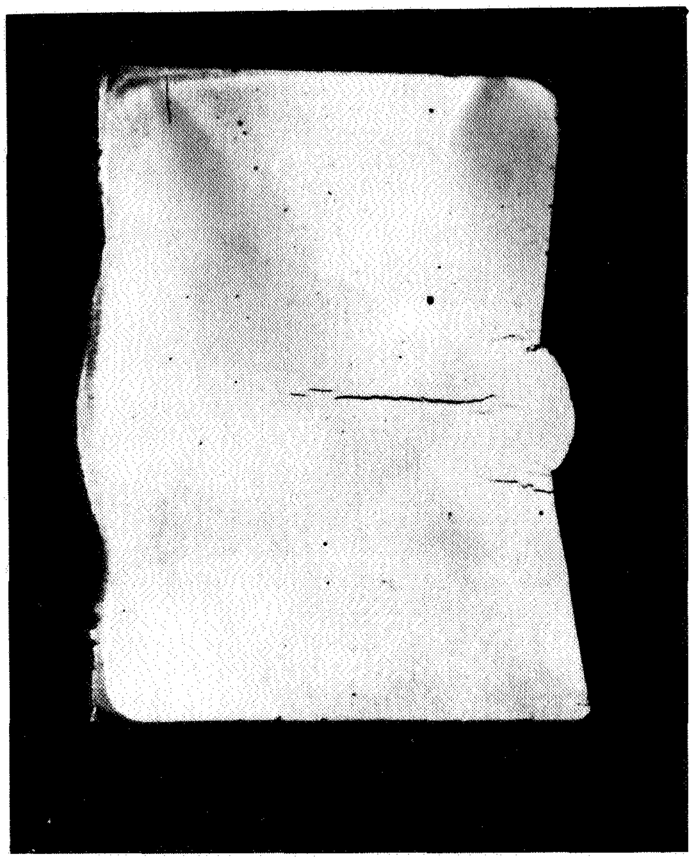

Figure 1. A typical weld crack.

Figure 1 shows a typical crack. It originates in the root pass and penetrates the filler passes. It was not possible to obtain an indication of the depth of the cracks from the X-ray pictures. Lengths varied from a few up to 340 mm., all around the weld circumference.

In Holland, the steam reformer is subject to the boiler code. Consequently, the X-rays had to be examined by government inspectors. It was mutually agreed that 62 of the 87 defective welds were not acceptable and had to be repaired. The remaining 25 showed only very short cracks, which were considered acceptable.

Four approaches to the repairs

Repairs were carried out as follows: 18 tubes were replaced by new tubes, which were available in stock; 12 were removed from the furnace and repaired in our own workshop; 17 were removed and repaired in a vendor's workshop; and 15 were repaired in the furnace itself.

A detailed description of the welding procedure as carried out in the workshop on aged HK-40, spun-cast, catalyst tubes, follows:

1. Preparation before welding: a. cut out the cracked weld; b. clear the affected weld zone over a distance of 5 mm.; c. machine both ends to the required bevel; d. dye-check the machined parts—all cracks must be eliminated to a clear dye penetrant indication; e. with both tube ends to be joined suitably prepared, set them up concentrically for welding on a rotator and roller jig; f. plug both open ends of the tube with tapered wooden plugs, one being suitably drilled to take argon purge gas connection; and g. purge the tube thoroughly with argon gas before start of welding.

2. *Welding*: a. keep argon backing gas flowing continually at a rate of 4 to 6 liters/min.; b. root-pass with TIG but without use of filler material, i.e. fuse parent metal; c. subsequent first and second pass filled with "HERA" NCT 3/40 electrodes; d. let weld cool down, grind it and examine by dye penetrant and radiography; e. fill out weld using 2.5-mm., 3.25-mm., and 4-mm. diameter welding rods "HERA" TCP 3/40 (25% Cr, 20% Ni, 0.4% C); f. after each electrode, the end crater must be ground out before starting with the next; g. after

each circumferential layer, the weld must be ground smooth and dye penetrant checked; h. on completion, the weld shall be 100% radiographed using the single wall technique.

The procedure for a repair in the furnace itself is as follows:

The catalyst tube is cut under the weld. The top segment is taken out of the furnace, the old weld machined off, and a new bevel is made. The lower segment is bevelled inside the furnace. All weld preparations should show a clear dye penetrant indication.

After proper alignment of the tube parts, the root pass is made, using Hera NCT 3/40 electrodes. The finished weld is again X-rayed.

Because of the anticipated short remaining life time of the original HK-40 tubes, it was decided to purchase a complete set of replacement tubes.

Other tube metals considered

The possibilities of other materials were studied, and Manaurite 36X was considered very promising. This is a high-temperature alloy developed and produced by Acieries de Manoir Pompey of France. There was good experience with thin-walled reformer tubes in a methanol plant in the north of France. We finally decided on Manaurite 36X tubes with the same outer diameter as the HK-40 tubes but with a minimum sound wall 66% of the old wall thickness (11.5 mm. instead of 17.3 mm.). This reduction in wall thickness is mainly due to the superior high-temperature creep properties of the new material.

The lowest part of the catalyst tube is welded to the bottom manifold. This is made of extruded tubes of Incoloy 800, and fitted with "Weldolets." Where the tube is welded to the Weldolet, the wall thickness is determined by the weaker material, in this case Incoloy 800. To overcome this problem, the bottom part of the tubes has an increased wall thickness (16.6 mm. instead of 11.5 mm.).

It was thought that the following advantages over the HK-40 tubes were to be gained:

Lower thermal gradient across tube wall, inducing less stress. With more catalyst per tube, plus a smaller catalyst pellet, a 50-55°C lower midwall metal temperature could be expected about 3 m. from the arch. Calculations to this effect were made by the contractor. At that time, the smaller wall thickness did offset the higher cost of the 36X material. And 30% more catalyst was considered to reduce the risk of hot banding.

The calculated metal temperatures for both the 36X and the HK-40 tube are shown in Figure 2. At the top is the old situation; thick walled HK-40 tubes and larger catalyst rings. The lower sketch shows the thinner walled 36X tubes together with the smaller catalyst rings. The midwall metal temperatures shown are those at a distance of 3 m. from the arch: 887°C for HK-40 tubes and 830°C for 36X.

The new coils were installed in March, 1973, and the reformer has been in continuous operation since then. The expected drop in temperature was achieved; the tubes look cool and the furnace appears to remain in excellent condition. As a further precaution against the formation of crack in the welds, the welds were insulated. Figure 3 shows the furnace with 36X tubes in operation. The tubes are filled with BASF type G25/1 catalyst.

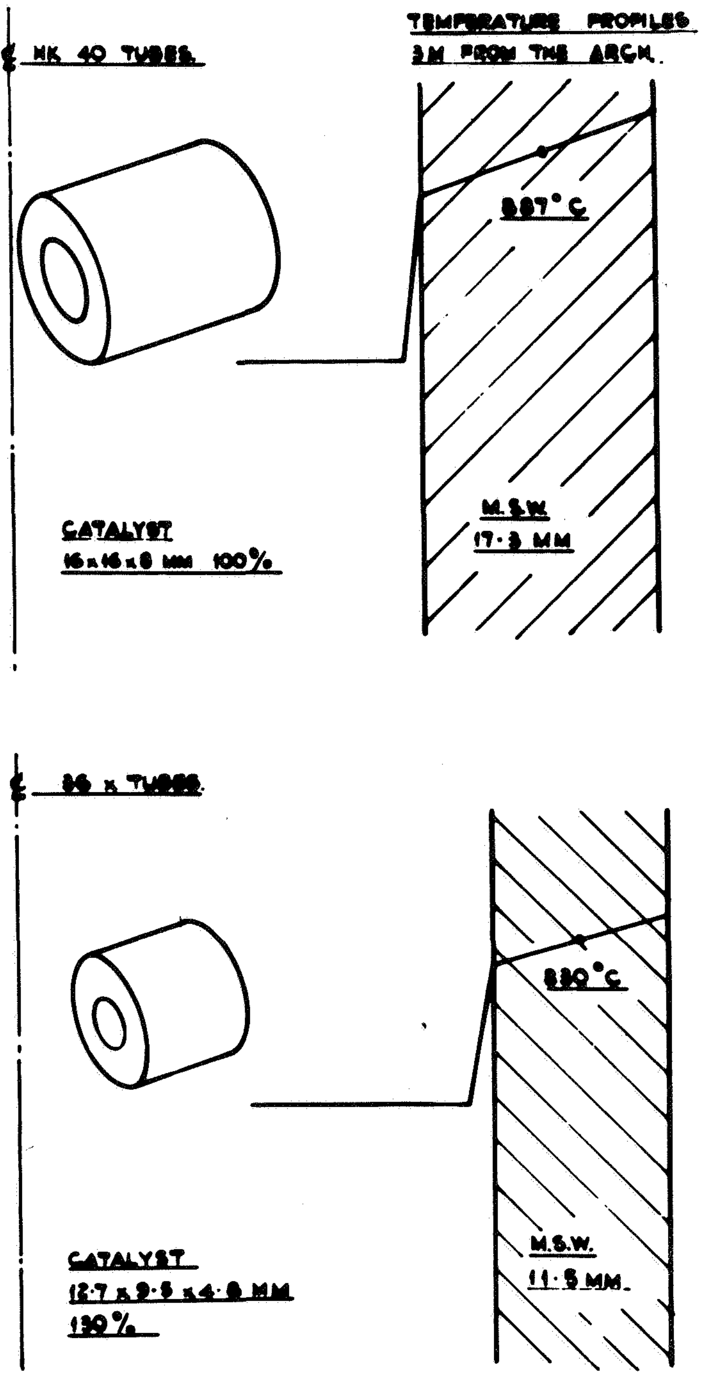

Figure 2. Calculated metal temperatures for HK40 and 36X tubes.

The unit at Ijmuiden

In the beginning of 1971 we started up an 851-short ton/day ammonia plant in Ijmuiden. Its primary reformer is exactly the same design as the No. 1 reformer, except that seven instead of eight rows of tubes are used.

To avoid the same cracking of the welds after four years of operation we did two things:

1. The tube wall temperature was kept at the design level by increasing the methane outlet content of the secondary reformer according to the formula developed by Lombard and Culberson and presented before this Symposium in 1972. This implied that when going up from

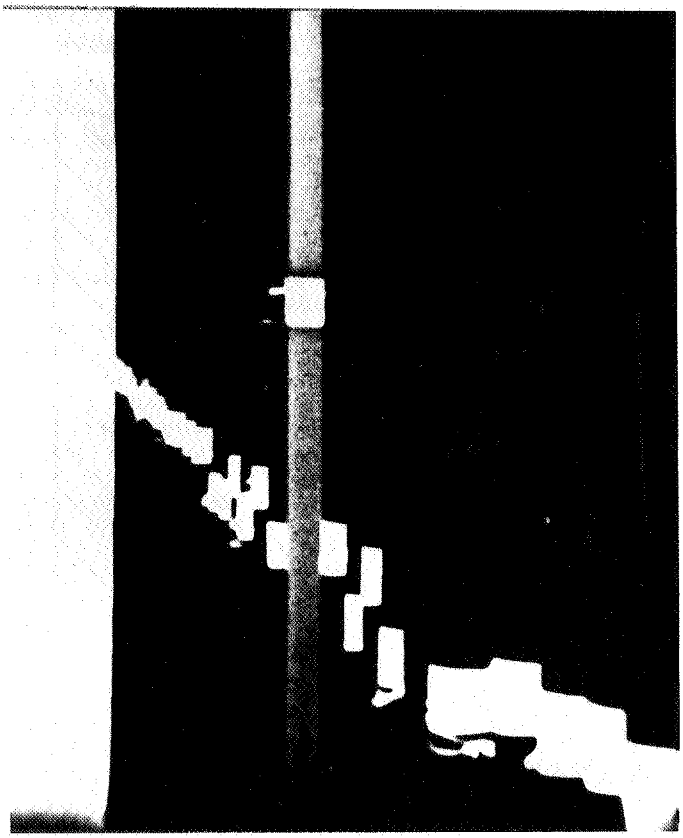

Figure 3. Furnace No. 1, with 36X tubes in operation.

100 to 115% of design throughput the methane content was increased from 0.35 to 0.5%.

2. All welds were insulated. After experimenting with different materials, all welds were insulated with 1-mm. thick, 100-mm. wide "FiberFrax" wrapped around the welds after dipping in "Rigidizer W," and secured during drying by means of "Kanthal" wire. Details are given in Table 1.

This method of insulation was developed by the UKF research department corrosion and materials group. It has been very successful; less than 1% of the 1,000-plus insulating bands installed so far have come off.

Based on the measured temperatures of tube and insulation, the decrease in temperature caused by the insulation is calculated to be about 100°C, shown in Figure 4.

Although the temperature measurement is not very accurate, the calculation is not very sensitive to errors in measurement. Figure 5 shows black bands close to the insulation, which confirms that the insulation has significantly decreased the tube wall temperature.

Tube inspections after startup Jan. 1, 1971, showed a number of cracks in the top welds. At shutdown in April, 1972, eight cracks appeared, then insulation was applied. At shutdown in Sept., 1973, there were 12 cracks, and in April, 1975, eight cracks. After the initial cracks formed in the first 1½ years without insulation, hardly any further cracks were formed nor did they propagate after the welds were insulated. It is assumed that the cracks found were not original weld defects. The extent to which the more careful operation of the reformer has reduced the cracking is not known.

The No. 3 reformer is in the Shellstar plant at Ince, England, now part of our company. It started producing ammonia at the beginning of 1971, and it has a capacity of 960 short ton/day. The plant was designed for naphtha and soon after start-up was converted to natural gas for both feedstock and fuel.

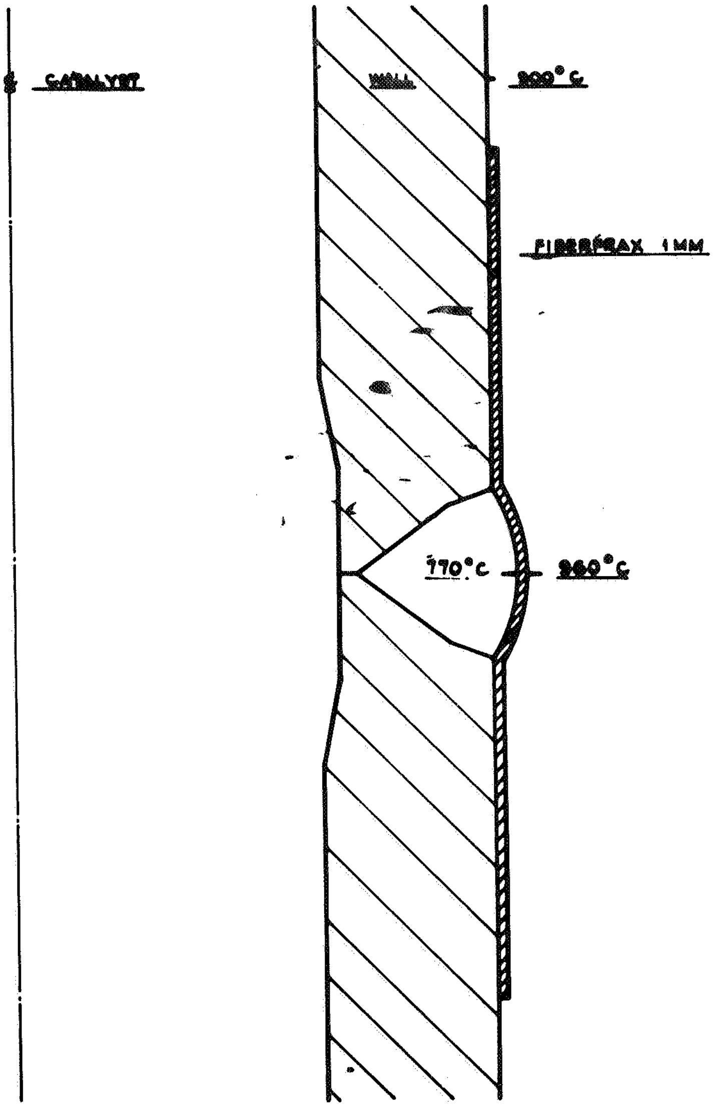

Figure 4. Effect of insulation on tube wall temperature.

The reformer contains a total of 240 tubes in two cells. Tube material is HK-40. Each cell contains two rows of tubes in a staggered pattern. It is sidewall-fired, with a total of 420 burners in seven rows. Tubes are bottom-supported only. It has gone through a large number of start-ups, particularly in the early years of operation.

We have a severe tube bowing problem with this furnace. After about three years of operation, bowing was such that some tubes started to touch the furnace wall. Just before or just after touching the wall, the tubes cracked at the lower weld and the pigtails had to be removed. The failed and badly bowed tubes were replaced at the next plant turnaround. At that time there were no tube failures in straight tubes; only badly bowed tubes touching the furnace wall failed.

Bowing rates were studied

Trying to analyze this problem, we measured the amount of bowing in each tube on three occasions over a period of about 18 months and from this developed a pic-

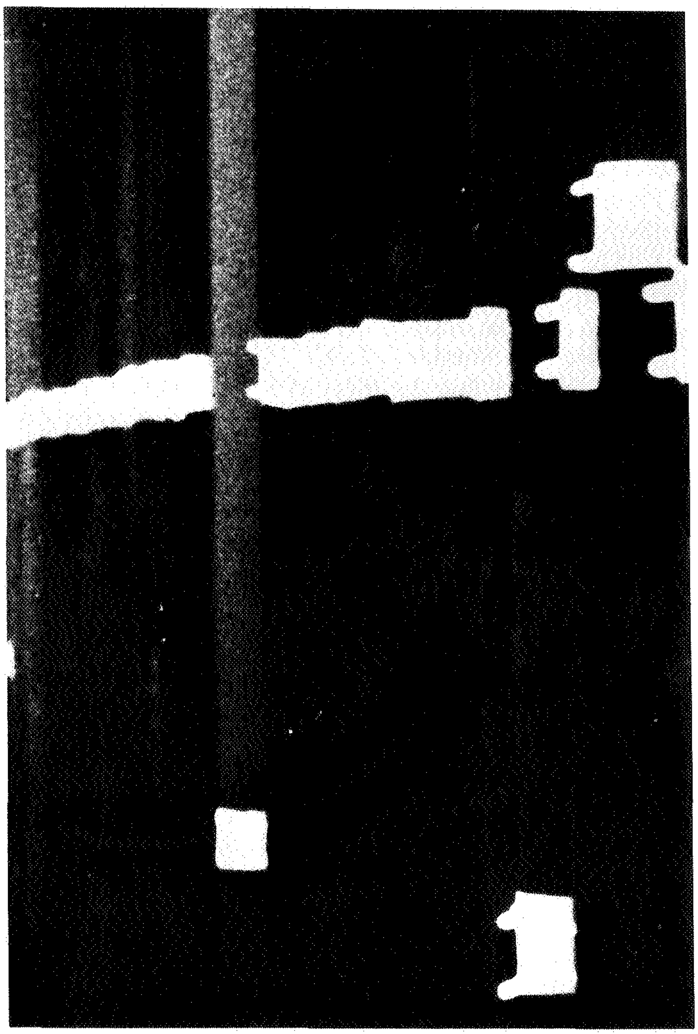

Figure 5. Black band close to insulation.

ture of the typical bowing rate of a tube, which is shown in the graph in Figure 6. We found that the tubes remained straight during an incubation period varying in length but that once a tube started bowing it followed approximately this typical curve.

This graph shows that the amount of bowing is quite acceptable during the early years of operation. For example, two years after a tube has started bowing it has, typically, a deflection of about 4 in., or less than one diameter. However, during the next three years it can be expected to reach the furnace wall, a deflection of 30 in.

A complete retube of this furnace was planned for the January, 1976, turnaround.

Some theoretical calculations into the bowing problem led us to believe there are two causes:

1. There is a temperature difference between the two sides of the tubes in a furnace of this configuration. Once bowing has set in, this temperature difference increases and so does the bowing rate.

2. The tubes are bottom-supported only and the thermal effects are added to by creep caused by the weight of the tube itself plus catalyst.

To solve this situation we are going to:

1. Improve the burners. The present burners are a flat-flame radiant-wall design, but adjustment is difficult and there is often flame impingement on some of the tubes. These burner problems clearly aggravate the inherent circumferential temperature difference.

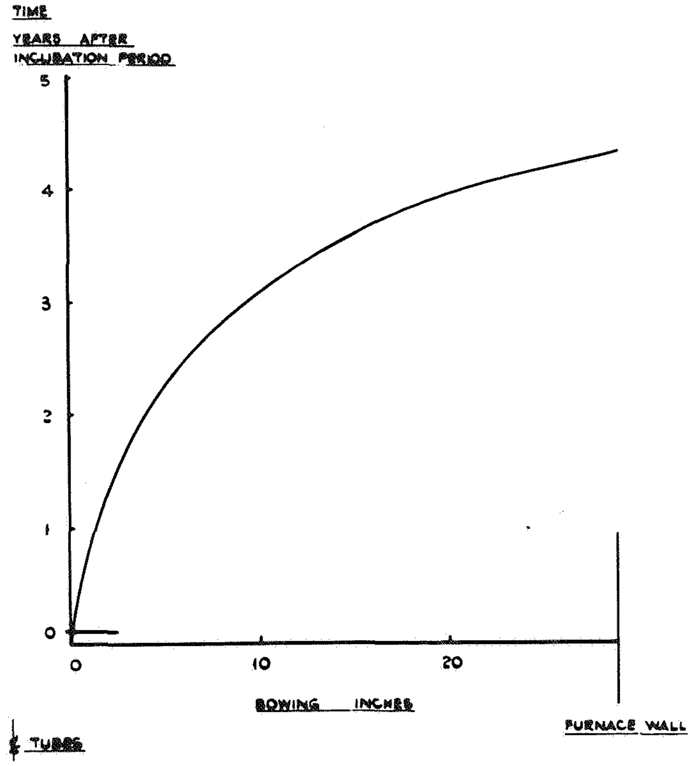

Figure 6. Increase in bowing over four years of operation.

2. Top-support the tubes by counterweights or spring hangers. We are now carrying out trials with counterweights to top-support a number of tubes and check the theory. If these trials are successful, we will consider top-supporting all the reformer tubes.

It is known that some other reformers of this design do not have serious bowing problems with the tubes. It is possible that the particularly severe bowing in the Shellstar furnace can be related to the burner problems and to the frequent cycling of the reformer in the early years.

The No. 4 Reformer, a terrace wall type, is in the 1,500 short ton/day plant at Geleen which was started up November, 1971.

Problems were encountered with cracking of the pigtail-socket weld at the bottom outlet of the tubes. In May, 1973, a cracked weld caused a fire at the bottom of the reformer, damaging four tubes. An examination by dye-checking resulted in rewelding 8 of the 196 tube pigtail connections. Three months later, another shutdown of the plant was necessary as a result of a cracked weld. This time, 89 weld failures were found. After repair of the cracks, the decision was made to change the construction. The modifications were made in a shutdown of three weeks in April, 1974. Details of the old and new construction are given in Figure 7. Design pigtail temperature is 830°C.

Improper welding also a cause

A study of the possible causes of the cracks led to a conclusion that bowing of the catalyst tubes and bad welding caused the failures. In a furnace with staggered tubes bowing cannot be avoided. The staggered pattern gives a shadow-effect on the tube surfaces, resulting in a temperature difference and an unequal elongation. An

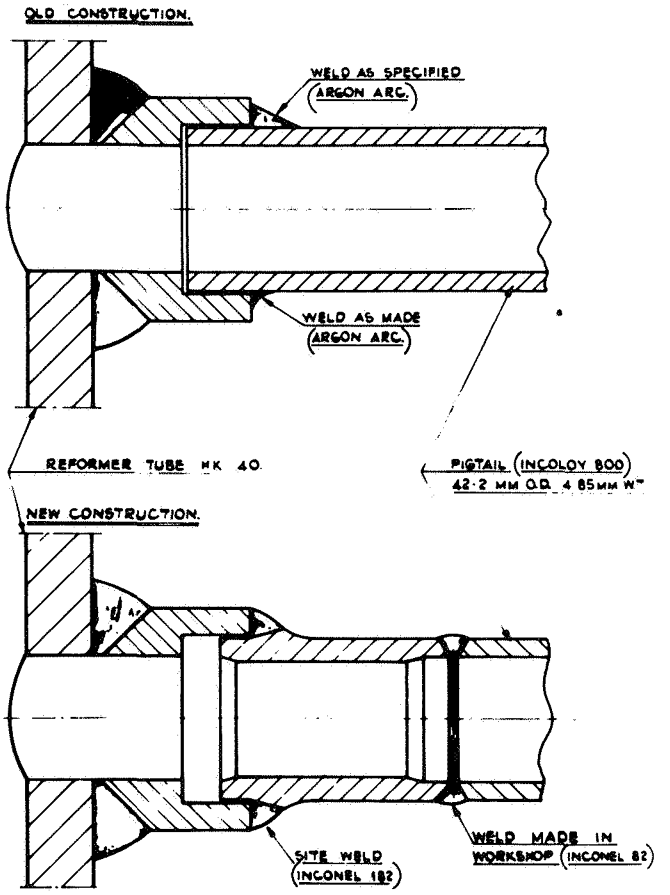

Figure 7. Old and new construction in furnace at Geleen.

angle of rotation of approximately 1.7° and a maximum stress of about 1.2 kg./sq. mm. in the pigtail were calculated; this stress is very close to the allowable value.

The bad welding and the incorrect weld profile caused a high stress concentration of the already heavy loaded pigtail. Because of this it was possible to get fractures by low-cycle fatigue after a very small number of cycles. During the period before May, 1973, the reformer had been cycled 27 times.

These conclusions about the causes of the failures were confirmed by:

1. The position of the cracks in the toe of the weld on the 6 and/or 12 o'clock position.
2. The similar results of investigations at Shell Oil Co's refinery at Martinez, Calif.

It was evident that the main goal of changing the construction should be to lower the stress concentration factor. The most simple solution, making better welds, was impossible to achieve. The specified weld profile can only be made by argon-arc welding; however there is not enough room in the existing layout of the reformer outlet system to use the argon-arc torch for high quality welding.

To solve the problem a transition piece was used between the pigtail and the socket. The connection was made by electric-welding using Inconel 182 electrodes. #

J. Jansen

DISCUSSION

BILL SALOT: Allied Chemical: Referring to your reformer #4, the last one you showed, the pigtail weld repairs were made with Inconel 182 in 1973. In view of the deficiencies of Inconel 182 that were pointed out by the previous speaker, and have been publicized for at least 5 years, I wonder why you used it in that repair, and would you do the same today?

JANSEN: I wouldn't be able to answer that question why this particular electrode was chosen. Maybe Mr. De Koning could comment on that, if he's present.

DE KONING, UKF: As far as I know the only electrode we had in store was Inconel 182.

FEIND, BASF, Germany: Creep rupture tests of BASF materials testing department, with 940 degrees Celsius, had shown that the weld material (coated electrodes in HK-40 material) of the first HK-40 reformer tubes in the Pernis plant had a rupture strength 40% below that of the HK-40 tube material. That was a cause more to choice a material with a higher rupture strength so as 36 X.

After retubing reformer Nr. 1 in Pernis, in March 1973 it was possible for the BASF material testing department to test the upper welds from 36 X and HK 40 tubes which were built in, into the reformer during the repair in spring 1971. These tubes together had an operation time of 15,500 hrs. with exactly the same conditions of temperature and pressure, startup, shutdown, and so on. The test pieces of the upper welds of these tubes gave the following values of creep rupture tests with 940 degrees Celsius and 2 kilograms per sq. mm. rupture strength: The weld of the HK 40 tube ruptured after a testing time of 280 hours and the weld of the 36 X tube was not ruptured after a testing time of 2152 hours.

JANSEN: Yes, the weld in the HK-40 tube has a creep value of about 40 to 50% lower than the original tube material, and we think the same goes for 36X. But the 36X material has about 1½ times the creep rupture value of HK 40 so the weld is correspondingly stronger.