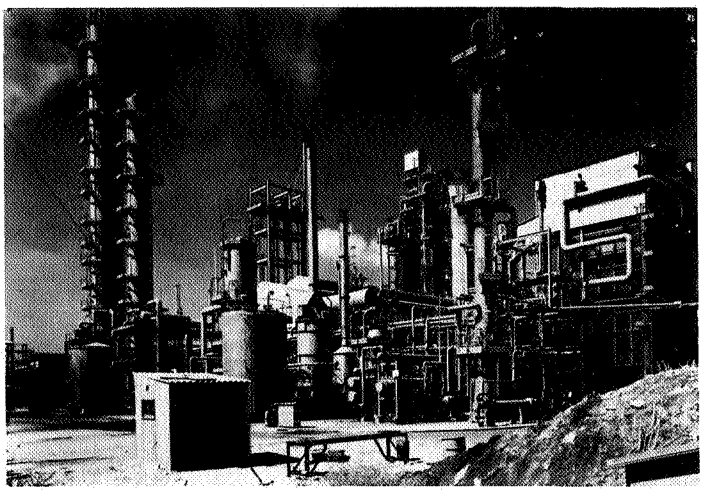
Solving a Steam Reformer Tube Failure

Here's a case history of stress corrosion cracking in tubes in an Israeli ammonia plant reforming furnace and how the failures were detected and prevented.

J. Fuchs
Chemicals and Phosphates Ltd.
Haifa, Israel



A serious failure problem in reformer tubes of an Israeli ammonia plant has been solved by redesigning the steam drum and careful monitoring of the sodium content of the steam. Boiler salts carryover had evidently been initiating stress corrosion cracking in the tubes.

The reformer is in a 240-ton/day ammonia unit operated by Chemicals and Phosphates Ltd. in Haifa, all a part of the largest chemical complex in Israel. The processing scheme is based on naphtha steam reforming and a conventional ammonia loop. Although this is a new unit, C&P has been producing ammonia at this location for almost 20 years by steam reforming as well as partial oxidation processes.

The primary reformer consists of 72 tubes, divided into four rows of 18. The tubes in each row are fed from one of the four top headers through inlet pigtails, and the gas leaves through two bottom headers. These headers are connected to the secondary reformer by a transfer line. The reformer is top fired by 25 Air Oil naphtha burners, arranged in 5 rows of 5 each, as shown in the cross section view in Figure 1.

The reformer tubes are centrifugally cast heat resistant 25/20 Cr Ni - 0.4% C, ASTM A351-HK40 4-in. ID x 0.5-in. wall thickness x 41 ft. long. The tubes are bottom-supported, top-hung and top-loaded. Top flange is of Type 321 Stainless Steel. There is no flange on the bottom.

Heat is recovered from the flue gases in the convection bank heat exchangers, arranged in the usual order. Superheated steam at 760°F and 540 lb./sq. in. gauge generated in the plant is used to satisfy process requirements to the primary reformer and to drive combustion air and flue gas turbines. Steam at 450 lb./sq. in gauge is supplied for start ups from the main boiler.

Demineralized water containing less than 2 ppm sodium, 1 ppm silica and much less than the design 50 ppm total dissolved solids (TDS) is used as boiler feed.

The reformer was commissioned in May, 1971, and had operated for approximately 10,000 hr., until the failure being discussed here. During this period the reformer had been cooled to ambient temperature at least ten times, due to mechanical or electrical failures or planned maintenance. This is a large number of cooldowns.

At the beginning of July, 1972, several hot tubes were detected in the furnace, with a skin temperature approaching 1,650°F. (vs. 1,508°F.), as determined by optical pyrometer. The solution to this problem was as follows: replacement of the hard, agglomerated catalyst at the top (ranging from 1 to 3 ft. downward) with new catalyst. Some of the removed catalyst was found broken and covered with a white solid. A further deposit was noted on the

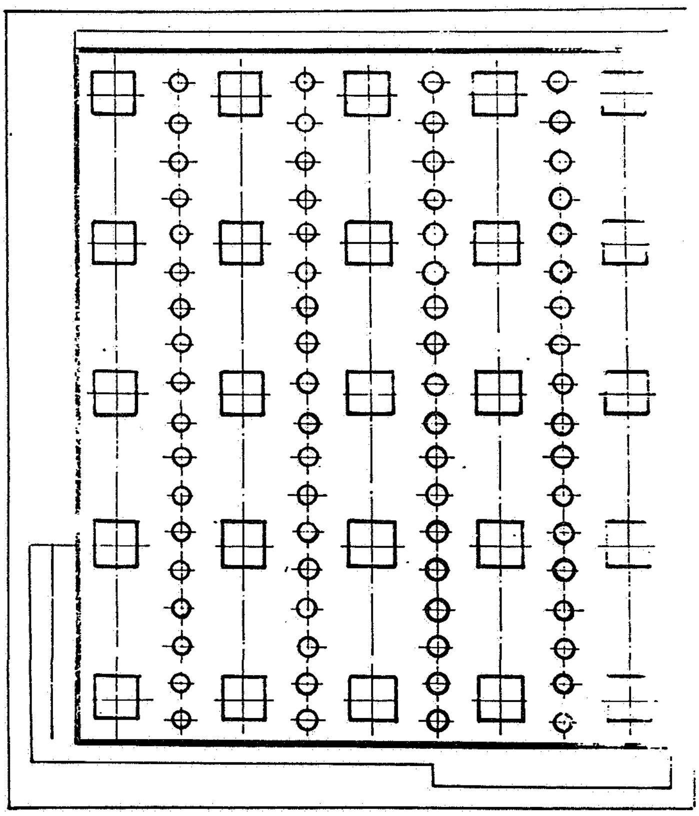


Figure 1. Primary reformer furnace cross section. Circles denote tubes and squares denote burner locations.

inside of the reformer tubes below the top catalyst level.

At the end of July, the plant stopped operating due to the failure of the non-spared turbine driving the induced-draft fan. It was later found that a blade locking screw had worked loose, and as a result the turbine began vibrating.

Steam flow was then reduced and nitrogen admitted to the reforming tubes before condensation temperature was reached. The unit was then held under 200-lb./sq. in. gauge nitrogen pressure while the turbine was repaired. When the plant was ready for restart it was found that nitrogen was blowing out of a crack at the weld where a Type 321 Stainless Steel top flange was attached to one of the HK40 tubes. Then it was seen that all 72 tubes had similar cracks. The material leaking out had produced white streaks down the outside of many of the tubes. This was analyzed to be a sodium salt.

An investigation was started with the assistance of metallurgical specialists. The flanges of all the tubes were opened and inner surfaces tested with dye penetrant. The examination showed that:

1. Nineteen tubes were cracked from ½-in. above and below the top flange weld, which is about 3-ins. beneath the flange. Most of the cracks were vertical but some were circumferential.

2. Fifty-three tubes had cracks at the top weld, and the cracks extended further down.

One badly leaking tube was removed from the furnace and sectioned for its entire length. The cracking was found to extend about 40-ins. down from the top flange. This corresponds to the upper level of the catalyst in the tubes, and is above the fired zone.

The appearance of the cracks suggested stress corrosion. Sections from the cut tube were taken to the Metallurgical Department of the Israel Institute of Technology and the cracks positively identified as resulting from stress corrosion. As a matter of interest the C&P stock of spare brand-new reformer tubes were all checked with dye penetrant, and minor cracks were found around the same top flange weld.

Inasmuch as stress corrosion of austenitic steel requires a strong solution of chlorides or of caustic, attention was directed to the possibility of solids being carried into the reformer from the steam drum. In addition to the solids found on the catalyst in the hot tubes at the beginning of July, solids were also found at various points in the superheated steam main and at the process steam control valve.

The cracking in the region of the flange weld was so severe that no attempt was made to gouge out the cracks and reweld. Instead the tops of all the cracked tubes were cut off and replaced, as follows:

1. Forty-three tubes with cracks below the top weld, had the entire 44-in. cracked length cut out and sections of tube welded in. (see Figure 2, type A repair.)

2. Nineteen tubes were repaired by cutting off the cracked section and moving the flange down about ¼-in. (See Figure 2, type B repair.)

3. Ten tubes were replaced by the available spare tubes on site.

All 62 repaired tubes had their flanges machined to a slip-on type and were then rewelded. The tube sections

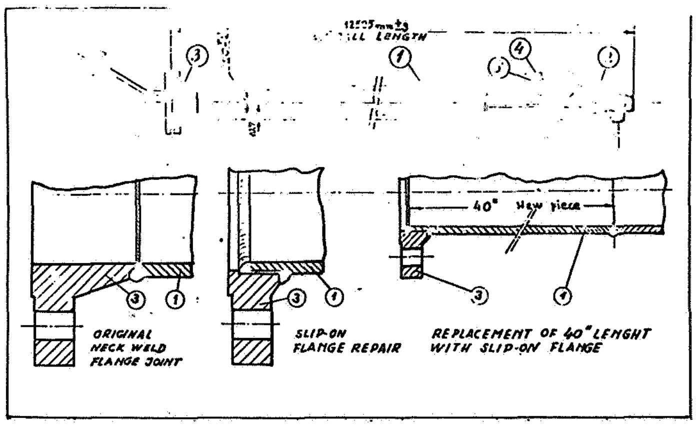


Figure 2. Primary reformer tube repairs: types A and B.

used for the repair were taken from the bottom part of the 10 replaced tubes. It should be explained that the plant is at some distance from tube suppliers, thus repairs had to be made with material available on site. Inconel 82 argon-root welding and Inco-weld "A" arc weld was used for welding. All welds were inspected by dye penetration and radiography.

The lines between the steam drum and inlet reformer tubes were then carefully flushed clean of any solid deposits.

At this stage it was impossible to determine which of the boilers (ammonia plant or off-site main boiler) had been the prime cause of deposits in the tubes and on the catalyst.

It was decided to install a continous sodium monitor for analyzing steam purity during boiler load fluctuations, start-ups, and shutdowns. The instrument ordered is a Electronic Instruments Ltd. Model 8990 cation sodium monitor. Meanwhile a daily routine for laboratory analysis by conductivity and atomic absorption spectrophotometer was adopted.

More emphasis was put on conditioning the make-up water (phosphate control) even though the boiler TDS was running around 40 ppm and most similar boilers are operating with a TDS as high as 2000. Provisions were also made to avoid a rapid drop in steam pressure when off-site steam was imported during shutdowns.

Following the repair, the plant was put back on line and appeared to run satisfactorily until November, 1972. At that time a gas leak developed at the top flange of one of the tubes. The leak got progressively worse and the tube became overheated. We tried to nip off inlet and outlet pigtails and had the interesting experience of having the inlet carbon steel pigtail break completely apart.

The plant was shut down for repairs. After it went back on line, leaks were noted near the top flange weld on 14 tubes. Ten of the leaking tubes were those replaced in August which still had the original 18-8-Ti weld neck flange at the top of the tube. Circumferential cracks running around the edges of the weld were found, with some longitudinal cracks running across the weld. These cracks were also confirmed as being caused by stress corrosion cracking.

Further investigation showed evidence that liquid water could have found its way into the reformer tubes through leaking steam control and block valves.

Table 1. Analysis of sodium in steam exit of steam drum

Date	mg./liter, Na^+ condensed steam
Oct. 22, 1971	2.3
Nov. 3, 1971	6.0
December 12, 1971	1.2
March 24, 1972	5.6
April 1, 1972	5.6
May 12, 1972	2.2
June 21, 1972	1.4
Sept. 24, 1972	3.6
Oct. 5, 1972	0.9
Oct. 18, 1972	4.0
Nov. 7, 1972	0.9
Dec. 4, 1972	0.9
Feb. 26, 1973*	not detectable
March 8, 1973	<0.1
March 18, 1973	<0.05
March 25, 1973	not detectable
March 29, 1973	not detectable

*Plant restart.

Laboratory analysis by conductivity meter on snap steam samples was found unreliable. It also became evident that something was seriously amiss in the steam drum system. By careful monitoring the existing cracks on the affected tubes both visually and ultrasonically, the plant was kept on line until January 15, 1973, when the annual turnaround was scheduled.

The plant was shut down according to schedule. Inlet pigtails and flanges of the cracked tubes were opened and inspected. Solid deposits were again found at the tube inlet. The same deposits were found everywhere in the lines between steam drum and reformer tubes. Laboratory analysis showed the solids were almost entirely sodium salts. (See Table 1.)

A representative of the steam drum supplier was invited to witness this shutdown and to recheck the design of the steam drum and steam drum internals. With his assistance, we hope we have found the cause of and the solution to the problem.

Cause of the problem

There is a single steam drum with three water circuits: one to the convection section (flue gas) and two to two waste heat boilers (make gas) between the secondary reformer and the high temperature shift converter. Design evaporation rate is 30 ton hr. In the contractors design (Figure 3), the steam-water mixture from the flue gas and make gas boilers enters the drum via a baffle box and from there into cyclones, where steam and water are separated. A chevron dryer was to be provided to reduce TDS in exit steam to 1 ppm when boiler TDS was 2500, regardless of the action of the cyclones.

In the steam drum as built (Figure 4), the steam water mixture from the boilers enters at the bottom of the drum without baffling. The steam rising from the water surface

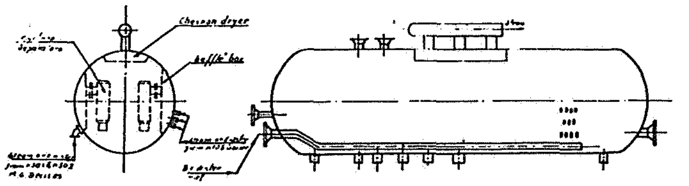


Figure 3. The steam drum as per contractors design.

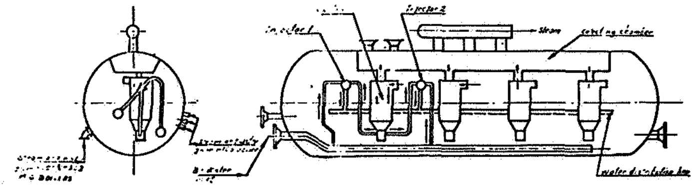


Figure 4. The steam drum as it was built.

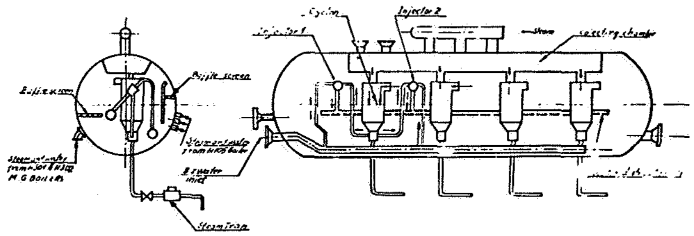


Figure 5. The steam drum as redesigned and modified.

passes into the flared entries of the cyclones and is deflected first downwards and then upwards by cylindrical baffles into the outlet box. Water accumulates at the bottom of the cyclones and is aspirated out by the feedwater injectors, two injectors for each cyclone.

The causes of carryover with this design are presumed to be:

1. The absence of effective baffling around the steam/water inlet. This means that the water level is very disturbed and water is splashed into the cyclone entries.

2. Steam/water inlets from make gas boilers are located directly opposite cyclones 3 and 4. This means that water can easily be splashed into them.

3. According to the injector operating diagram, the injectors do not evacuate the water from the cyclone bottom at low capacity plant operation. The water level in the cyclones rises and is drawn up into the steam outlet box. A similar situation exists at start up and shut down when boiler feed water inflow stops because of high water level.

4. Injector malfunction may be caused by pluggage.

Six measures were then taken to solve the problem:

1. All cyclones were tested for tightness and the injector operation as also checked.

2. Steam traps were installed for each cyclone, to evacuate water at low steaming rates.

3. A secondary separator was installed between the steam drum and the superheater.

4. Horizontal perforated baffle plates were installed above steam/water inlets from boilers, to avoid splash.

5. Isokinetic sample points were provided on steam lines for sodium monitoring.

6. Continous sodium electrode monitor was put in operation.

The plant was restarted in February, 1973, and the steam sodium content was found to be less than 0.1 ppm. (See Table 1.)

As of this writing we have had no further episodes of reformer tube or steam drum problems. Final drum design is shown in Figure 5.

Acknowledgement

I would like to thank C & P for granting permission to publish this article and to my colleagues for their help in its preparation. #

FUCHS, J.