Failure of a Reformer Outlet Header

The catalyst tube failure and fire was attributed solely to the fine grain size of the header. Earlier failure was avoided due to design safety factors and, possibly, because of low operating temperatures.

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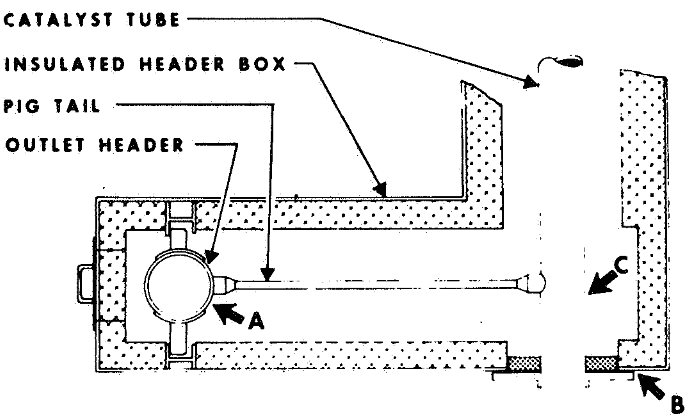


Figure 1. Header and catalyst tube assembly.

Esso Chemical Canada operates a 600 ton/day turbine drive, centrifugal compressor type ammonia plant near Edmonton, Alberta, Canada. Here synthesis gas is manufactured at high pressure using two rows of HK-40 alloy tubes, delivering gas to a bottom mounted Incoloy header through Incoloy pigtail connectors.

The primary reformer consists of two cells. Each cell contains 80 tubes, 3.4 in. I.D. x 0.65 in. A.W. x 47 ft. 5 in. long ASTM-297 HK discharging into a header 44 ft. 6 in. long, 8.625 in. O.D. x 0.800 in. A.W. ASTM spec. B-407-70. The pigtail connection between the tubes and header are straight 3.5 ft. lengths of Incoloy 800 pipe, 1-1/4 in. dia., Sched. 80 ASTM spec. B-407-70. The pigtails and header are enclosed in an internally insulated metal box Figure 1. Design conditions for the header were $1480^{\circ}F$ and 450 lb./sq. in. gauge. The headers are connected to the secondary reformer by an Incoloy 800 transfer line.

The unit was started in the spring of 1969 and had no serious header problems up to the time of failure. By that time, the furnace had been thermally cycled 19 times and had 8,700 hr. of operation. Although creep check readings measured on the Incoloy 800 transfer line had not indicated any problem, no similar readings were taken at the header.

At 8:00 p.m. on October 30, 1970, the header failed during normal operation at 95% of design rate. The resulting fire was quickly extinguished by removing feed gas, and the unit brought down in an orderly manner. The only effect, external to the furnace, was damage caused to the furnace draft instrumentation located immediately adjacent to the damaged cell.

The primary reformer catalyst was oxidized for a period of 12 hr. and the furnace cooled down at the normal rates. Prior to the failure, the control board operator had observed falling east header temperatures for a period of 8- to 10 min. The total change in temperature during this period was $40^{\circ}F$.

The header box was dismantled and the following observations made. Three of the HK-40 tubes had ruptured approximately 6 in. below the bottom pigtail connections. A 3 in. long rupture was measured on the header, and an increase in circumference of 30% adjacent to the rupture was observed. The header had three major bulges. Failure occurred in the bulge that extended 5 ft. long (almost a complete fabrication length between welds). The second bulge measured 1.55% creep 1 ft. long and the third showed 2% creep 1.8 ft. long. The rupture was located immeditely below the pigtail coupling on tube no. 15 at location A on Figure 1. Several other cracks were observed adjacent to the pigtail couplings on either side of the failure. The degree of this cracking decreased in proportion to the amount of creep at the balance of the 5 ft. section.

The ruptured tubes were identified as numbers 14, 15 and 16 in the east cell. Tube no. 14 had vertical split 4 in. long at point C Figure 1. Tube no. 15 had a 7 in. split centered 6 in. below the pigtail, and Tube no. 16 had a 4 in. split 5.5 in. below the pigtail. These ruptures had occurred on the east sector of the tubes. The tube guide bars had been displaced towards the east. and the header box covers had been buckled and distorted.

Failure analysis

The probable sequence of events is outlined below:

1. The header ruptured under extended creep conditions.

2. The header box was damaged by the force of the

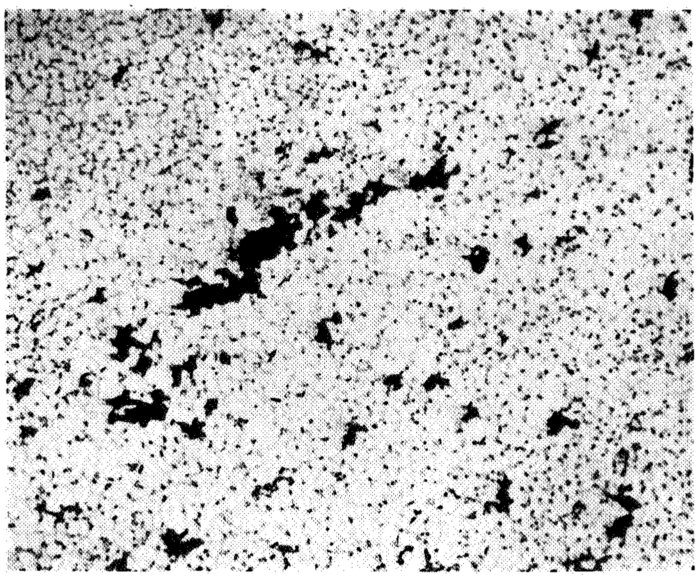


Figure 2. Photomicrograph of header showing integranular cracking.

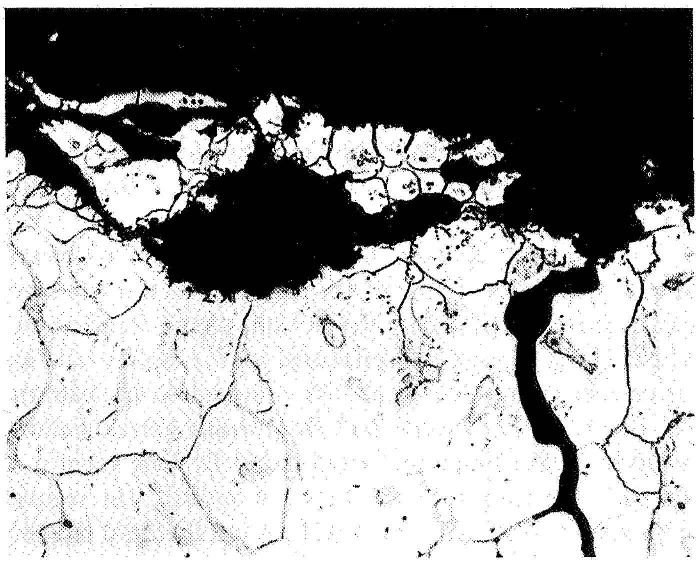


Figure 3. Photomicrograph showing ruptured area of HK-40 catalyst tube.

header enlargement being transmitted through the pigtails to the catalyst tubes.

3. The hydrogen emission from the header rupture came in contact with air being leaked into the header box, resulting in ignition taking place at point B, Figure 1.

4. The fire which followed enveloped the east sector of tubes 14, 15 and 16, causing extremely high tube metal temperatures and, consequently, tube failure.

5. The high tube metal temperatures occurred because flame impingement was directed at the dead zone of the HK-40 tubes.

6. Damage to the tube guide bars came as a result of the combination of flame impingement and creep forces transmitted through the pigtails.

Two independent examinations showed that the Incoloy 800 header failed prematurely in creep rupture because of the fine grain size (ASTM max. 7, min. 10). The catalyst tube failure and fire occurred after the header failure. Metallographic examination of the failed header section showed both extensive intergranular cracking, Figure 2, which is indicative of a creep failure, and a fine grain size which was responsible for the low creep strength.

The fine grain size of the header was solely responsible for the component failure and fire. Incoloy 800 used for components where resistance to creep is vital should be coarse grained and have the properties of Grade II material as specified in Code Case 1325. Data taken from a supplier's product bulletin showed that if a stress was chosen to cause failure in 100,000 hr. at 1,425°F, and if fine grained Grade I material was used in error, creep failure would occur in less than 2,000 hr. These data demonstrate the detrimental effect of the fine grained structure and help to explain the early failure of the header. Earlier failure was avoided due to inherent design safety factors, and possibly due to lower operating temperatures. Photomicrographs of the HK-40 catalyst tubes showed that they ruptured because of overloading. Figure 3 shows the tube O.D. where the failure originated. The metal had seen temperatures in excess of 2,100°F in the areas where the fire occurred.

A complete inspection of the transfer line ASTM B-407 Incoloy 800 Grade II, carried out at this time indicated anticipated creep rate only.

As an outgrowth of the header-pigtail assembly inspection, a significant fault was noted. There was gross misalignment at the pigtail to coupling welds resulting in root cracks in the fillet weld. A gap of 1/16 in. between the coupling and pigtail end is required to provide for differential thermal growth during startup, and shrinkage in the weld joint during fabrication.

Repair

A 67 in. length of header was cut out and replaced with two pieces of Incoloy 800, Grade II material. The section of header replaced was extended beyond the original welds because fine cracks were found in the welds. These cracks appeared a short distance into the parent metal and were removed by grinding. Cracking was also found on the surface of the header beyond the section removed. The cracking pattern was spider web in nature, in an area containing many circumferential grooves. These grooves were caused by the use of a steady rest during the original machine bevelling for welding. It is believed that there was sufficient work hardening of this area to cause the cracks. This area was ground out and built up with Incoweld "A" rod, ground flush, and dye checked.

New couplings were welded to the new header sections using Inco-weld "A" manual stick. Each coupling was ground after welding and dye checked. Header welds were completed by using back-up rings. TIG with Inco 82 filler metal was used for the first three passes, and Inco-weld "A" manual stick for the remaining. Root passes and finished welds were dye checked. One hundred per cent radiography

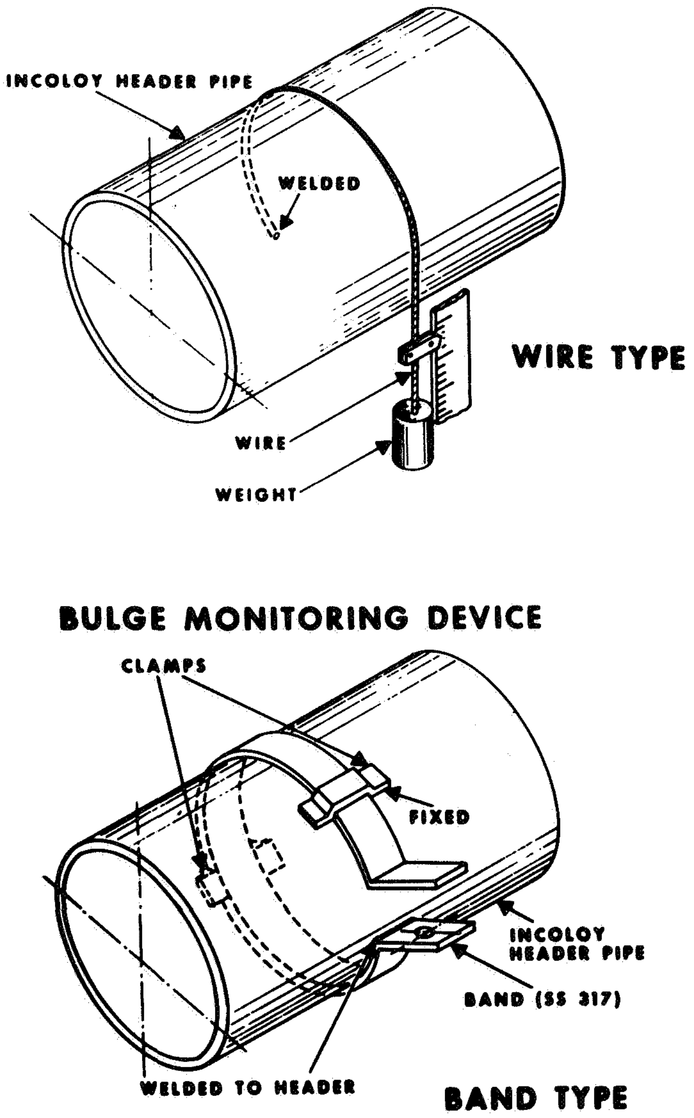


Figure 4. Creep monitoring devices.

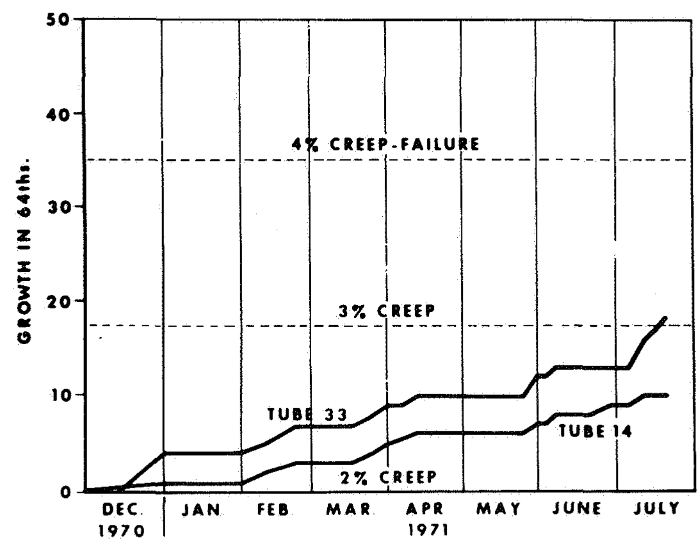


Figure 5. Plot of header creep as measured by monitoring devices.

was used on the two final position welds. All welding was satisfactory except for one 1/4 in. crack on one position weld. This was ground, rewelded and x-rayed.

Because of the weather conditions at the time of repair (0^{o} - to $+30^{o}$F), heated enclosures were provided. The time required to complete the repairs was four days.

To insure even flow distribution throughout the catalyst tubes after this upset, the pressure differential on all tubes in no. 1 cell were measured and 11 tubes were recharged with new catalyst. The criteria for recharging was 10% deviation from the mean pressure drop value. The same check was performed on no. 2 cell and, as a result, catalyst was replaced in three tubes.

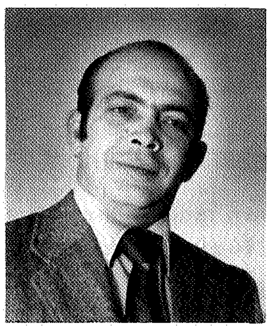
Post-failure operating precautions

Bulge monitoring devices were installed as shown in Figure 4 at the two remaining bulges. Two types of devices were adopted, the wire type and the band type. The band type was found to be of real value. Header creep was measured and recorded on a weekly basis with results, as shown in Figure 5. Surface thermocouples were installed at eight locations. Additional inspection ports and necessary access platforms were installed to improve visual inspection of the header and pigtails. Approximately one month after the failure, the header box covers were removed, the headers were measured, and a comparison made with the creep gauges.

The following measures were adopted to increase surveillance of furnace operation:

1. Complete optical pyrometer surveys of the tubes, pigtails, tube supports, and headers were scheduled once per week, in addition to the normal visual and pyrometer checks performed by the operators. These checks were also repeated immediately after rate changes.

2. Maximum header temperatures were specified at 1,420^{o}F where the original design had called for 1,480^{o}F. The header pressure was lowered to the lowest pressure as limited by the suction of the synthesis compressor. Subsequent creep measurements indicated that, even at 1,400^{o}F header creep accelerated. As a result, furnace outlet temperatures were reduced to the 1,370^{o}F – to 1,380^{o}F range. Higher steam to gas ratios were used to maintain lower temperatures. Ratios before the failure were 3.7- to 4.0, and 4.0- to 4.3 after. Methane slippage increased from 9- to 10%, to 10- to 12%. #



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