Unsolved Questions in the Analysis of Failure of Aluminium Alloy Component in an Air Separation Apparatus

R. CHANDRASHEKAR
Corrosion Engineer (TS), The Fertilizers Corporation of India Ltd., Gorakhpur-273 007.

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FAILURE of aluminium alloy piping occurred in an air separation apparatus after 8000 running hours, causing heavy down-time of the equipment and losses of utilities and production. Failure analysis was carried out, with the aid of ultrasonic thickness measurement, sectional and surface metallography and corrosion experiments. A repetition of the failure after another 9000 running hours and a third failure after 3000 more hours of running could not be prevented. From the three failures, the thoughts regarding failure analysis were modified to such an extent that after the third failure, the picture became unclear. While remedial measures have been initiated to forestall further failures, the reasons for the failure are, as yet, unknown. The paper sets out a description of the system, the failures encountered, failure analysis carried out and the development of thoughts and poses the unsolved problem relating to the causes of failures.

HEAVY leakage was observed from the cold box of an Air Separation Apparatus (ASU) and pearlite (insulating material) was seen coming out from conditioning case safety valves. It was suspected that some cracks may have developed in the vessels/pipe lines inside the cold box and a shut-down of the ASU was taken. After de-rime with nitrogen and removal of pearlite, the cold box internals were inspected.

A puncture of about 20 mm diameter was found near the weld seam of the aluminium alloy piping. After repair patch-welding, the ASU was put back into service.

This failure had caused a down-time of 21 days of the equipment, accounting for a loss of production of Rs 20,00,000 and loss of utilities of Rs. 3,75,000. Since the losses were of such high magnitude, it was essential to make a thorough analysis of the failure and evolve effective measures to prevent recurrence of further failures.

Though a sincere effort was made at failure analysis, the solution evaded us and the failure repeated twice more in the next two years. It is the endeavour of this paper, therefore, to place on record the data available, the approach to failure analysis followed and pose the unsolved question to the scientific community for analysis.

Description of the system : The system essentially consists of a set of 4 Reversing Heat Exchangers (RHEs). These are plate-type heat exchangers, with 2 paths, path A and path B. Atmospheric air enters through one of the paths and is cooled by cold impure nitrogen passing out through the other. When air gets cooled in the RHE, components like CO_2, ammonia and moisture are condensed and retained in the RHE. To remove these components, a switching valve operates every 8-9 minutes, so that the paths of air and nitrogen are interchanged, and the impure nitrogen CO_2, ammonia and moisture that had condensed in the RHE. Thus the RHE acts as a regenerator in addition to a plate-type heat exchanger.

Figure 1 shows schematically the RHE and the switching valve. The RHE is connected to the switching valve through 2 aluminium alloy piping, 300 mm dia, 3 mm thick and about 1150 mm long (of which about 500 mm of piping is inside the cold box and about 650 mm on the outside). These piping are called the "warm legs" of the RHE and the temperature in these is near atmospheric. The material of construction of these warm legs is aluminium alloy 5052 (2.5% Mg, 0.45 Fe+Si, 0.15-0.35 Cr, rest Al) and welding carried out by aluminium alloy rod A 5083-BY (4.5%Mg, 0.4 Fe, 0.4 Si, 0.1-0.3 Mn, 0.05-0.025 Cr, 0.15 Ti, rest Al), to obtain mechanical properties of 18-22 Kg/mm^2 TS, 7 Kg/mm^2 YS and 20% elongation.

The geometry of the system and location of failures are also depicted in Fig. 1. The design

parameters of the system are: Design Pressure = 5 Kg/Cm^2; Design Temperature = −200°C to +80°C; Air entry temperature 43°C at 3 Kg/Cm^2 and 8250 NM^3/hr flow per leg; Nitrogen exit 29°C at 0.2 Kg/cm^2 and 5200 Nm^3/hr flow per leg. The flow velocities encountered in these aluminium piping are less than 1 m/Sec.

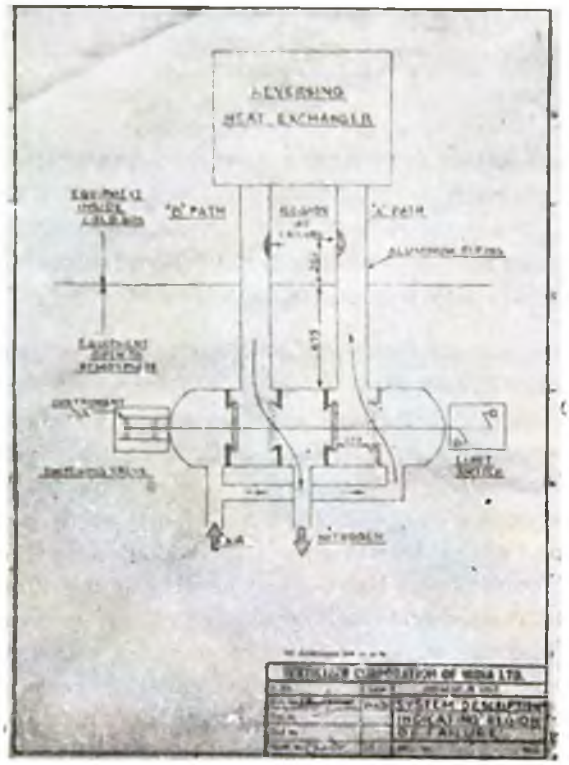


Fig. 1. Description of the system showing approximate configuration

Description of Failures: Fig. 2 is a photograph of the failed portion showing the inside surface of the pipe and a hole of about 20 mm diameter. Fig. 3 is a sketch showing the failures as they occurred on the first two occasions and also indicating the thicknesses.

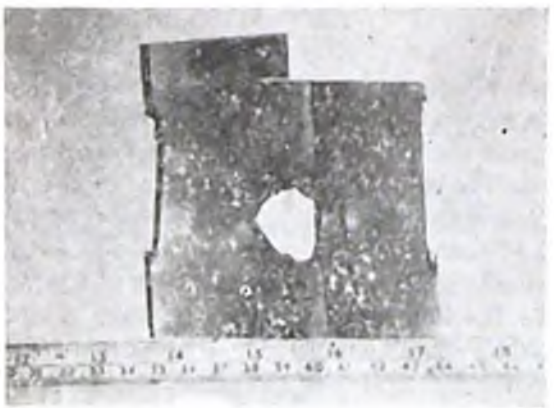


Fig. 2. Photograph of failed portion, showing inside surface of piping. Note grinder marks on weld seam and pipe

Basically, failure occurred in the form of a hole or holes in the aluminium alloy piping. Failures invariably were adjacent to the verticle weld seam and located in the middle portion of the piping inside the cold box and on the side where the warm legs faced each other (See Fig. 1). The thickness of the piping, as measured by an ultrasonic thickness gauge, showed general thinning around the failed portion and helped us in estimating the amount of repair patch-welding required. The individual failures are described below.

Failure No. 1: Failure occurred after 8,00 running hours adjacent to the weld seam, in RHE-3, A path. The thickness of piping had reduced to 1.5 mm near the irregular edged 20 mm diameter hole that had developed. A patch plate 120 mm × 140 mm × 3mm thk. was welded on after cutting out the failed portion the photograph of which is shown in Fig. 2. A scratch of about 25 mm length was observed in the B path at a place exactly opposite to the region of failure in path A. This scratch appeared to be of mechanical nature and was welded with A 5083-BY electrode.

Failure No. 2: This failure occurred after about 17000 running hours and in RHE 4, B path. Two holes 20mm dia and 8 mm dia were found on either side of the weld seam. As in the first failure, the edges of the holes were irregular (See Fig. 3). A verticle crack was also observed along the weld seam in Path A at about the same height. The thickness measurements made by the ultrasonic thickness gauge gave values of 1.7 mm. The holes were repaired by patch welding and the crack in the B path was also welded, as in failure 1.

Failure No 3: The third failure of ASU occurred after 20,000 running hours and was manifest in A and B paths of RHE-3. Ultrasonic thickness measurement indicated that while path A could be repaired by patch welding, patch B had thinned down to such an extent that the pipe had to be replaced. The holes in path A were therefore repaired by patch-welding and path B was replaced by a newly fabricated 5052 piping. When the piping taken

out from path B was inspected, it was found that there was white staining on the inside, on the side of failure, indicative of higher corrosion rates on this side, possibly due to seepage of condensate

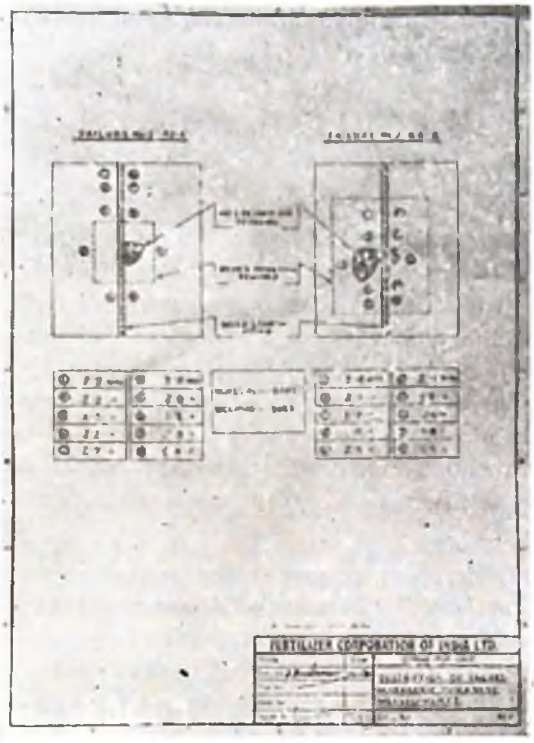


Fig. 3. Description of failures 1 & 2, with readings of ultrasonic thickness measurement

Development of thoughts and failure analysis : As part of failure analysis, the following investigations were carried out : (a) Ultrasonic thickness testing near regions of failure (b) Sectional metallography of piece cut out from failure, (c) Surface metallography of the inside surface of piping and (d) Corrosion tests in a 5 per cent aqueous solution of ammonia.

Ultrasonic thickness testing revealed (See Fig. 3) that there had been thinning down of piping and that failure was not abrupt. Sectional metallography confirmed the normal structure of 5052 and also that the welding was defect-free. Surface metallography of the inside surface of piping gave evidence of corrosion attack on the inside surface as seen by pitting and general corrosion.

Corrosion tests carried out on 4 samples 20 mm × 2) mm × 3 mm cut out from the failed piece (Fig. 2) in 5% aq. solution of ammonia over 14 days gave the following corrosion rates : 0.153, 0.073, 0.103 and 0.077 mm/yr, with an average value 0.101 mm/yr and maximum rate of 0.153 mm/yr. These values compare well with the value of 0.167 mm/yr quoted by the manufacture, as given in Table I.

On the basis of these experiments, it was concluded that the material was of proper specifications and failure could have occured due to one of the following reasons :

(a) *Fabrication Defect :* The weld seam had been ground from the inside. As seen from Fig. 2, the grinding had inadvertantly extended beyond the weld seam and some portion of piping had also been ground off. Such regions where grinding had extended to the piping, would experience high surface stresses and consequently accelerated corrosion would occur at these places, leading to failure.

(b) *Erosion :* From the configuration of the switching value and the RHEs (See Fig. 1), the incoming air may preferentially erode the inside

TABLE 1

Corrosion Rates of Metals in Aqueous Ammonia, mm/yr

(Room Temp. test, 14 days duration, conducted by M/s Kobe Steel Ltd)

Material	% Ammonia							
	0.01	0.05	0.10	1	5	10	20	25
Aluminium 99.8	0.000	0.007	0.036	0.056	0.244	0.418	0.103	0.132
Aluminium 99.2	0.001	0.015	0.031	0.023	0.596	0.650	0.203	0.031
Al Alloy 3003	0.002	0.018	0.064	0.133	0.770	0.650	0.203	0.032
Al Alloy 5052	0.002	0.003	0.001	0.015	0.167	0.105	0.036	0.000
AISI 304	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C Steel	0.031	0.001	2.0	3.0	2.0	2.0	6.0	0.197
Copper	0.001	0.002	0.020	0.093	0.107	0.172	0.102	0.000

surfaces of warm legs, However, from a calculation of the distances involved, it is seen that there is but little change in the direction of air flow. Also, the flow velocity of less than 1 m/Sec makes erosion an unlikely.

When a second failure occurred, again near the weled seam and with a crack along the weld seam, our reasoning that a fabrication defect was responsible for the failure, gained credence. In addition, the fact that the incoming air contained upward of 3 ppm of ammonia against the specified value of less than 1 ppm made us think that this was the cause.

However, when the third failure occured, we were made to change our thinking drasticaliy. For one, there were no extension of grinding mark at regions of failure. Secondly, cracking had occurred along the weld seam without any apparent thinning of the portion of piping. A new observation was made there was staining on the inside surface (about 60° of pipe) in the direction where failure had taken place. This made us think that the corrosive attack may be taking place not during the air-in cycle, but during the nitrogen-out cycle, when the condensed CO_2, ammonia and moisture are all taken out of the RHE through the warm legs. These perhaps seep down prefenatially on one side and cause failure at region where the temperature becomes about 30-35°C. Cracking was possibly due to stress corrosion cracking caused by air, moisture and salts in the intake air.

Remedial measures taken : Though the reasons for failure could not be unequivocally established, the following remedial mesures have been taken :

The ammonia content of the intake air has been reduced by commissioning of a new air-intake tower in an ammonia-free zone.

(b) Patch-weld strengthening of all legs likely to fail is planned.

(c) Action has been initiated to replace the warm legs of RHEs by thicker (6 mm) piping.

Remnants of the problem : As yet, the reasons for the failure of the ASU have not been estabilshed. It is essential that this problem is solved satisfactorily, since there are quite a number of ASUs in India using the Alex type Reversing heat exchangers. The cause, whether a fabrication defect, erosion, stress corrosion cracking, or any other phenomenon, needs to be identified so that the reliability of such air separation apparatuses is ensured.

Conclusions : Frequent failures in aluminium piping of an air separation apparatus have caused heavy down-time of the equipment and losses of production and utilities. Failure analysis carried out has been inconclusive. The problem, alongwith all the data available so far, is set out, so that the learned reader may throw light on the problem and arrive at a solution.

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