EVALUATION OF STAINLESS STEEL PLATES OF HEAT EXCHANGER DAMAGE

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ABSTRACT
An attempt has been made to unravel the exact reasons for premature damage of stainless steel plates of plate cooler used as plate heat exchanger (PHE) to cooling down the temperature of process water using normal cooling water. Analysis suggested that as a result of presence of some factors such as, harmful corroded element such as chloride ions from cleaning solution and probably water, in addition to accumulated residual stresses caused by water pressure, heavy deformation at protuberance shape and probably over tightening of cooler plates had led to the failure due to Stress Corrosion Cracking (SCC) failure.

Keywords: Plate heat exchanger, Damage, stainless steel 316, stress crack corrosion.

INTRODUCTION
Plate heat exchangers (PHE) have many uses in different industries such as, fertilizing plants, milk revival, pre-heater, cooler, heater, regeneration and etc. The Plates Heat Exchanger (PHE), as shown in Fig. 1, is composed of corrugated thin alloy plates, which are hung between top and bottom guide bars. The plates are compressed by tightening bolts in between the frame plate and pressure plate until metal-to-metal plate is reached and a channel is formed. The manner in which the gaskets are fitted enables alternative flow channels to be created and heat transfer to pass from one side of the plate to the other. The alternative channels maximize the heat transfer surface in compact manner. Therefore, it can produce the most effective performance from the compact size (Sunders AED, 1988 and Pearce N, 2001).

The heat exchanger is thermally designed to the required operation and service supplied. The product, flow rates and required temperature are used to find the required plate arrangement based on the surface area and allowed pressure drop. Usually, the PHE total heat co-efficiency is 3 to 10 times greater than the shell and tube heat exchanger (Pearce N, 2001).

316 Stainless steel is a candidate material for manufacturing of PHE's plates due to having its corrosion resistance properties in cooling water but the parameter of normal cooling water determine the overall corrosion stability of plate heat exchanger such as temperature, pH, conductivity, hardness, alkalinity as well as sulphate, nitrate and most importantly Chloride ion concentration (Georgiadis MC, 2000 and K.M Dean, 2010).

This paper details the study carried out on twelve stainless plates of PHE having some cracks after three years in service and recommends certain measures to be taken in term of cleaning material, operation practice to prolong the life of these plates.
modes of Failure

Cooler plate heat exchanger

Main feature of a heat transfer plate

Fig.1 - Illustrating diagram for construction of cooler plate heat exchanger.

BACKGROUND INFORMATION

In this study the PHE has set of 132 plates made of 316 stainless steel. These plates are used as heat exchanger to cooling down the temperature of process water using normal cooling water. The plates cooler are separated from each other by a gasket. It is reported that, after three years in service, twelve of total 132 plates have some cracks. During the operation and as the result of improper cooling due to scale formation in the plate, it was necessary to perform chemical cleaning with materials containing acid and zinc chloride several times and the last time was done by injection of Nitric acid to remove the scale. During the plant shut down all the plates were changed and during cleaning process cracks were visually observed in some plates.

Two pieces from two different failed plates were investigated to study the cause of the failure. Table 1 shows the actual operating condition for cooler plate. It is also reported that, during the operation, the maximum temperature for process side outlet side was raised until 113°C.
Table 1 - Operation condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>Process side</th>
<th>Cooling side</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>inlet</td>
<td>outlet</td>
</tr>
<tr>
<td>Normal Operating</td>
<td>95</td>
<td>80</td>
</tr>
<tr>
<td>Temp.(°C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Actual Temp.(°C)</td>
<td>104</td>
<td>80</td>
</tr>
<tr>
<td>Normal Operating</td>
<td>10.0</td>
<td>9</td>
</tr>
<tr>
<td>Press.(bar)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Actual Press.(bar)</td>
<td>15</td>
<td>3.6</td>
</tr>
</tbody>
</table>

**EPERIMENTAL PROCEDURE AND RESULTS**

**Visual inspection**

The general view of the plates cooler is presented in Fig.2. It is clearly obvious that there was no mechanical damage. It is also noticed that the cracks are located near to circumference of the opening holes at each plate and around the areas which were subjected to high deformation stresses during manufacturing using die pressing process as shown in Fig.3. Moreover, it is also noticed that there is corrosion losses.

![Fig. 2 - General view of the cooler plates after chemical cleaning](image)

**Dye penetrant testing (PT) and chemical analysis**

The damaged plates showed also crack, pitting and corrosion losses areas as detected by dye penetrant testing (PT) as shown in Fig.4. The chemical composition done on the received specimen of the damaged plates is confirmed with the standard 316 stainless steel as given in the data sheet received.
Metallographic examinations

Metallographic examinations were conducted on cut pieces from the damaged cooler plates. Figure 5 shows the macro-photographic appearance of the damaged area using the stereoscope. It can be noticed that there are some pitting corrosions around the cracks and at other places as well. The crack started its initiation at the pitting area. Moreover, it is also
noticed that there are some small corrosion spots on the plate near the crack and petting areas. Figure 6 shows the nature of the crack propagation of a specimen taken at the damaged area of cooler plate. There is a distinguished main crack propagated in the matrix with small hair cracks are branched like a tree. The figure indicates also that there are several other cracks had initiated at the same area.

The cracked area was investigated in the as polish surface condition at high magnification using optical microscope. Figure 7 shows branching of cracks, the main crack is not uniformly propagated and it has small branches. The microstructure of the etched surface of the specimen taken near the crack area is shown in Figs. 7a and 7b, which reflects that the morphology of the crack resembles the intergranular stress corrosion cracking (IGSCC) nature (Metals Handbook ASM Vol. 11 and 13).
The micrograph near the cracked area shows partly recrystallized austenite grains, carbide particles, and remnants of twinning (slip bands) while the matrix is austenite as shown in Fig. 8a. This structure is typically cold worked and annealed structure (Metals handbook ASM Vol. 17).

In order to investigate the effect of cold working process during the manufacturing of the plates on the mechanical characteristics at each part of the deformed plate according to the degree of deformation which was applied on the plate, microhardness measurements were done on several locations at the plate. The hardness measurements away from the cracked area (which were exposed to heavy deformation during manufacturing to create curved shapes on the plate) is in the range of 187-205 Hv, and the hardness values at similar location but near the tip of the crack is decreased to 157 Hv as the result of stress release due to the occurrence of the crack at this area as shown in Fig. 8a. While the hardness measurement at flat areas far from cracked area is 164 Hv, this area was exposed to much less deformation stresses during the manufacturing process of the plate as compare with the curved cracked area. The microstructure at the flat area shows normal annealed structure with less twinning i.e. less residual stresses, as shown in Fig. 8b (Metals handbook ASM Vol. 17)
Scanning electron microscopy and scale characterization

Scanning Electron Microscope (SEM) was used to examine the cracked area from the damaged cooler plate. It has shown a typical intergranular stress corrosion cracking behavior as shown in Fig. 9 (Metals handbook ASM Vol. 17).

Due to the chemical cleaning of the cooler plate before receiving the investigated specimens, no corrosion product could be obtained for chemical or x-ray analysis. However, some precipitates from the cooling water of other cooler plates were removed, in order to be examined by X-Ray Diffraction (XRD). The results showed the presence of Calcite (Ca CO₃) and silica SiO₂. No indications for any other corrosion products could clearly be detected.

DISCUSSION

It was reported that the cooler plates were cleaned several times using chemical solution which contained chloride compound. In last few cleaning processes, both of the concentration of the cleaning solution and the duration of the cleaning time were increased. Therefore, it can
be deduced that the austenitic stainless steel cooler plate has failure due to exposure to chloride containing solution during chemical cleaning for several times and each time the concentration of the harmful element, chloride ions was increased. The cracks were developed at the protuberance shape which reflected the highest hardness values as a result of heavy deformation during manufacturing process causing relatively high residual stresses. The Chlorine ions replaced oxygen/hydroxide ions in the protective layer. Usually the cooler plates are tied together; sometimes they are over-tightened to eliminate a leakage situation, then cooler plates would have a permanent stress. Moreover, the damaged area is located at protuberance place at the sheet. This area is expected to have residual stress as indicated from both microstructure and hardness measurements at damaged area. This condition creates good atmosphere to cause the intergarnullar stress corrosion cracking. Also, results of XRF for water cooling precipitates showed presence of silica and calcite which promoted localized pitting at high flow rate and water pressure.

CONCLUSION

It can be concluded that as a result of presence of some factors such as, harmful corroded element such as chloride ions from cleaning solution and probably water, in addition to accumulated residual stresses caused by from water pressure, heavy deformation at protuberance shape and probably over tightening of cooler plates had lead to the failure due to Stress Corrosion Cracking (SCC) failure.

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