Failure analysis of corroded and cracked flare tip of material SS310 in phase 12 gas refinery of South Pars Gas Complex

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Abstract

The flare system collects hydrocarbon gases released from relief valves during upset conditions, process venting during start-up and also blow down gas during normal shutdown and emergency conditions. So, having an intact flaring system is one of the most fundamental requirements in gas refineries in order to have gas production continuity, specially in emergency flaring during unexpected shut downs. Since AISI310 stainless steel grade has a good resistance against high temperature oxidation and hot corrosion, it has been used extensively in the fabrication of most flare tips in refineries. In this paper the failure analysis of cracks and corrosion-like failure on medium pressure flare tips which was occurred after short period of being in service will be discussed. In order to investigate root causes of the failure, some samples taken from cracked and corroded areas and metallographic analysis conducted. Results of microscopic examinations containing SEM, EDS and micro hardness measurements revealed intergranular corrosion due to the occurrence of chromium depletion around the grain boundaries. Diffraction pattern of XRD examination on the burned parts of the pilot indicated high levels of oxygen which can be the consequence of high temperature oxidation. Small distance between high and medium pressure flare tips and consequent flame impingement due to predominant high speed wind direction and retention rings improper design concluded as root causes in this kind of failure.

Key Words: Flare tip; SEM; XRD; EDS
Introduction

A flaring system is provided in a refinery or petrochemical plant to ensure the safe and efficient disposal of relieved gases or liquids. The disposal fluids are collected in a flare header and routed to the flare. A properly operating flare system is the critical component to prevent a plant disruption from turning into a disaster. A flare is expected to operate twenty-four hours a day and must be in service for several years without a need to shut it down and it shall always be available for flaring whenever a plant disruption occurs [1].

Failure of flare tips in oil and gas refineries has been reported in previous works [4].

Proper design, operation and maintenance of emergency flaring systems are extremely important [1-6].

There are several types of flare structures within the refinery. Flare system in refineries of South Pars Gas Complex is a derrick supported structure and for each phase of the refinery there are three different flaring systems as following:

- HP flare system (Sonic Flare) which mainly receives high pressure flared gas from relieving devices such as PSV\(^1\) and BDV\(^2\) that are activated in pressures above 1 barg [7].
- MP flare system (Subsonic Flare) which mainly receives acid gas from process units and medium pressure flared gas from relieving devices such as PSV\(^3\) and BDV\(^4\) that are activated at pressures in the range of 0.3 to 1 barg [7].
- LP flare system(Subsonic Flare) which mainly receives low pressure flared gas from relieving devices such as PSV's that are activated at the pressures below 0.3 barg and equipments operating at atmospheric pressure and also receives disposal gas where the back pressure is maintained very low [7].

Main components of each flare system are as following:

- Flare header lines
- Knock-Out drums
- Flare stack

HP and MP flare tips have been installed on a common stack and with a very small distance of about 15 centimeters from each other as shown in Fig.1.

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\(^1\) Pressure Safety Valve
\(^2\) Blow Down Valve
\(^1\) Pressure Safety Valve
\(^2\) Blow Down Valve
Flare tip design consists of pilots that are required to establish and maintain proper ignition and stable combustion. This equipment must control the combustion process for the specified relief conditions and shall produce the desired combustion efficiency and act as a continuously operating pilot to provide ignition energy and light the flared gases. In case of pilots failure, unburned hydrocarbons and other toxic gases could be released to atmosphere and pollute the environment or cause explosion or other safety issues. Liquids of flared gases from process units shall be removed sufficiently to prevent poor combustion and burning liquid droplets. AISI 310 stainless steel is a commonly used material in fabrication of flare tips because of its high resistance against high temperature oxidation and hot corrosion. Flare tips material must be resistant against flame impingement that could occur at low rates of flared gas. It should be noted that most reported failures of pilots is due to low relief gas flow rates, because in this condition the pilots are most subjected to the detrimental effects of flames impingement [1].

Based on above mentioned issues, the integrity of flaring system is of extreme importance in refineries and petrochemical plants. The present paper investigates the root causes of failures which was occurred on HP & MP flare tips and pilots in one of the gas refineries of South Pars Gas Complex located in south of IRAN. The flare system was less than three month in service and flame blow down was observed during its operation. Sections were taken from crack containing regions and also burned parts to conduct analyzing methods in order to assess the root causes of failure. By considering the results of SEM, EDS and microhardness measurements besides the design conditions of high and medium pressure flare tips and predominant high speed wind direction, it was concluded that a combination of many factors contributed to this failure.

Fig.1 HP and MP flare tips located on same structure with a very small distance
**Observations**

After a very short period of first flaring in commissioning of a newly constructed gas refinery in SPGC, flare system took out of service and closed visual inspection conducted. As illustrated in Figs. 2 and 3, some cracks on flare tips observed and severe ovality of the tip was obvious. Arrows indicate the location of cracks on MP flare tip. It is obvious from the picture that refractory of combustion chamber has been damaged.

![Fig. 2](image1.png)

*Fig. 2 Top view of MP flare tip showing cracks on the flare tip and damage of combustion chamber*

![Fig. 3](image2.png)

*Fig. 3 Crack on the flare tip and its location*
As seen in Fig.4, there are several individual retention rings which have been welded to internal surface of the flare tip. These retention rings keep the flame focused in center of the flare tip. In most flare tip designs, the retention ring is fabricated as an integral part while in a case which is discussed about it is fabricated in several parts which had been welded to the flare tip’s internal surface. Arrows indicate the space between adjacent retention rings which cracks had been initiated from this region.

**Fig.4** top view of flare tip indicating several retention rings which welded to internal surface of the flare tip

As illustrated in Fig. 5, morphologies of high temperature oxidation and hot corrosion observed on combustion chamber of MP flare tip.

**Fig.5** probable high temperature oxidation and hot corrosion on combustion chamber of MP flare tip
**Investigation**

Specimens cut out from the crack containing region in order to conduct metallurgical examinations and also samples was taken from the burned parts of pilot to analyze the chemical composition. Fig.6 indicates crack's growth route on a sample after surface preparation and etching under the light microscope.

![Fig.6 SEM image from cracks propagation route showing Intergranular morphology](image)

The contrast difference in some areas in Fig.6 might be due to different phases on the metallic structure. So, in order to assess this issue, microhardness measurements were performed across the line from two adjacent grains containing crack between them but there were no significant difference in hardness numbers. Fig.7 Shows a grain which was selected and chemical analysis at point A within the grain boundary and also point MATRIX inside the grain was examined by Energy Dispersive Spectroscopy (EDX) to determine elemental composition at these points. Elemental composition of the points MATRIX and A have been shown in Figs.8 and 9, respectively.

![Fig.7 SEM image of selected points in grain boundary and within the grain to be analyzed](image)
**Fig. 8** EDX Spectrum at point MATRIX within the grain

**Fig. 9** EDX Spectrum in the grain boundary at point A
The quantitative analysis at points A and MATRIX has been shown in table1, and it is obvious that chromium content within the grain boundary is about 7% more than its content inside the grain.

**Table1 Elemental analysis at Points A and MATRIX**

<table>
<thead>
<tr>
<th>Element</th>
<th>Cr</th>
<th>Ni</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt % at point A</td>
<td>30.41</td>
<td>13.68</td>
<td>47.81</td>
</tr>
<tr>
<td>Wt % at point MATRIX</td>
<td>23.35</td>
<td>17.70</td>
<td>48.96</td>
</tr>
</tbody>
</table>

In order to have a better and more reliable assessment, line scan analysis was carried out by scanning electron microscope at 25 points on a line across the grain boundary of two adjacent grains. Result of line scan examination has been shown in Fig.10.

*Fig.10 elemental analysis by Line scans method within two adjacent grains*

The quantitative results of line scan and also elemental analysis results done by energy dispersive spectroscopy (EDX) which have been shown in table2 revealed that chromium depletion and probable formation of chromium carbide has been occurred in grain boundaries in areas subjected to flame impingement. Since this intermetallic compound has a brittle structure, so because of thermal stresses imposed during flame impingement, cracks could be initiated from grain boundaries and propagated with an intergranular pattern.
Energy Dispersive Spectroscopy (EDX) results of burned parts of pilot has been shown in Fig.11.

**Fig.11** EDX spectrum taken from burned part of pilot

**Table 2** Elemental composition of burned part of pilot

<table>
<thead>
<tr>
<th>Element</th>
<th>Wt %</th>
<th>Atm.%</th>
</tr>
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<tbody>
<tr>
<td>O</td>
<td>20.50</td>
<td>46.24</td>
</tr>
<tr>
<td>Si</td>
<td>2.14</td>
<td>2.75</td>
</tr>
<tr>
<td>Cr</td>
<td>26.91</td>
<td>18.68</td>
</tr>
<tr>
<td>Mn</td>
<td>2.02</td>
<td>1.33</td>
</tr>
<tr>
<td>Fe</td>
<td>42.31</td>
<td>27.34</td>
</tr>
<tr>
<td>Ni</td>
<td>5.71</td>
<td>3.51</td>
</tr>
<tr>
<td>Mo</td>
<td>0.41</td>
<td>0.16</td>
</tr>
</tbody>
</table>
**Conclusion**

Energy Dispersive Spectroscopy (EDX) from the burned part of pilot indicated high peak of oxygen which could be due to high temperature oxidation during flame impingement on the pilots. Other elements were consistent with the material of the pilot.

Line scan across the line from one grain to its adjacent grain indicated that the content of chromium within the grain boundary has been decreased significantly which can be a sign of chromium depletion and probable formation of chromium carbide which could experience crack due to its brittle structure in compare with the virgin structure of the material.

Flame impingement was clearly seen during flare's operation and high temperature oxidation observed on pilots and combustion chamber of MP flare tip.

Since all the cracks on the flare tips had been occurred in front of the retention ring slots, it was concluded that because of not having uniform expansion between individual retention rings and flare tip material the cracks initiated in front of slots and propagated consequently.

The small distance between MP and HP flare tips as one of the main root causes in this failure which can impose flame impingement from one flare tip to another. Because of installation the flare stack at beach there are always cross winds with high speeds on flare tip so that the flame blow down and in most of time the flare tip is in fire. This condition can create hot corrosion or high temperature oxidation on flare tip and its components.
References


