Failure analysis of heat pipe in hydrogen production unit

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Abstract. After two months of service, the heat pipe of hydrogen production unit bulged and fractured. The observation and measurement of the deformation of the pipeline was performed. The failure mode of heat pipe was analyzed by observing the macro and micro morphology of the fracture surface, and by Energy Dispersion Spectrum (EDS) analysis. Through the analysis of the metallographic structure of the pipeline, it is found that the pearlite is seriously spheroidized, which indicates that the pipeline has failed under long-term overheating working condition.

1. Introduction

Since the start-up of hydrogen production unit in a refinery, the inlet temperature of induced draft fan has been on the rise. The measured overheating data of air preheater during full load operation of the unit are shown in Table 1. It can be seen from the data in the table that the flue gas temperature at the outlet of air preheater rises from 204 °C on July 6, to 274 °C on September 13, showing an upward trend. The air temperature decreased from 287.5 °C on August 3 to 274 °C on September 13.

During the operation of the unit, the flue gas temperature at the inlet of the air preheater has not changed greatly, and the amount of medium pressure steam generated by the preheating boiler has not changed greatly. However, the flue gas temperature at the outlet of the air preheater has always been on the rise. In addition, the air temperature at the outlet of the air preheater is also decreasing. Therefore, it indicates that some heat pipes of the air preheater have failed. After the heat exchanger was shut down and opened, it was found that part of the heat pipes had broken, and plastic deformation and bulged phenomenon occurred. The material of heat pipe is 20G steel.

| Parameter                        | Position | Unit   | Measured Value |
|----------------------------------|----------|--------|----------------|
| Natural gas feed FI4201          | Nm³/h    |        | 18030.1        |
| Outlet temperature of air preheater TI4422 | °C      | 145    | 204.1           |
| Temperature after air preheating TI4423 | °C      | 300    | 283.0           |

Table 1. Monitoring data sheet for full load operation of hydrogen production unit.
2. Observation and detection of failure heat pipe

2.1. Macroscopic observation of failure heat pipe
The macro picture of fracture of the fractured heat pipe (hereinafter referred to as heat pipe 1) is shown in Fig. 1. The overall plastic deformation of the heat pipe at the crack is relatively large. The diameter of the fracture is Φ 82mm, while the original diameter is Φ 60mm. The thinnest part of the pipe wall is 1.2mm, while the original wall thickness should be 4mm. The thinning rate is as high as 70%. The fracture is perpendicular to the tube axis, and the wall thickness at the fracture has different degrees of thinning. The maximum thinning point is located at the position where the heat pipe is connected with the outer wall heat sink, and the fracture surface here is relatively flat. According to the law of material fracture, the crack should start from the largest wall thickness reduction. Fig. 2 shows the macro picture of the bulged but unbroken heat pipe (hereinafter referred to as heat pipe 2). The pipe diameter at the maximum deformation is up to Φ 71.5mm, and the circumferential crack perpendicular to the axis has been found at the connection position between the maximum deformation of the pipe wall and the heat sink.

![Figure 1. Macro photo of broken heat pipe.](image1)

![Figure 2. Macro photo of bulge of heat pipe.](image2)

2.2. Microscopic observation and energy spectrum analysis of fractured heat pipe
The plastic deformation near the fracture surface of heat pipe 1 is very large, and the thickness of the thinnest part is only 30% of the original wall thickness. There is a thick and dense covering on the
fracture surface, and the result of EDS is iron oxide. The oxidation layer is the thickest at the thinnest part, which proves that the fracture started from here. The energy spectrum analysis results at the fracture source are still iron oxides, and the results are shown in Fig. 3. No corrosion products such as S and Cl are found, which proves that the fracture of heat pipe is not caused by corrosion. The oxide on the fracture surface was cleaned with weak acid. After cleaning, the fracture was observed under scanning electron microscope. It was found that the fracture surface presented intergranular fracture morphology (see Fig. 4).

![Figure 3. Fracture EDS results.](image)

![Figure 4. Intergranular morphology of fracture.](image)

3. Observation on metallographic structure of heat pipe
Take the transverse section near the maximum local deformation position of heat pipe 2 for metallographic observation, and compare with the transverse metallographic structure far away from the deformation position. The transverse metallographic picture of the part with the largest deformation is shown in Fig. 5. The microstructure is ferrite + pearlite. The grain deformation is elongated and the pearlite is severely spheroidized. This shows that the heat pipe at the deformation position works at a high temperature of more than 450 °C for a long time. The transverse photos far
away from the plastic deformation position are shown in Fig. 6. Pearlite is slightly spheroidized, but it can be seen that the original microstructure of the material is the normal metallographic structure of 20G steel.

The hardness of transverse section of heat pipe 2 without plastic deformation was tested. The results show that HV = 151 ~ 158, which meets the requirements of GB8162-87 for mechanical properties of 20G steel at room temperature.

4. Analysis and discussion
The fracture energy spectrum analysis results show that the fracture of heat pipe has nothing to do with corrosion. The metallographic examination results and hardness test results at the position where plastic deformation does not occur show that the heat pipe material meets the requirements, and the failure has nothing to do with the material.

The severe plastic deformation of the heat pipe and the pearlite spheroidization at the deformation position indicate that the material has been working at high temperature for a long time and the temperature is above 450 °C. The lamellar pearlite in the material gradually spheroidizes under the driving force of the reduced surface energy at high temperature, which makes the phase interface of
carbides decrease and the strengthening effect of interface, which makes the mechanical properties of the material deteriorate seriously, especially the yield strength at high temperature. The characteristics of intergranular fracture also indicate that the fracture of heat pipe occurs in high temperature environment, and then the fracture is oxidized to form dense high temperature oxide layer.

Under the action of internal pressure, the tube wall with performance degradation will expand due to plastic deformation, which will further reduce the strength at the thinning position. Finally, under the action of axial force formed by internal pressure and thermal stress caused by temperature difference between inside and outside the tube, cracks will appear at the stress concentration position where the thinning is the most serious and connected with the heat sink. After the crack is generated, it will continue to expand under the action of stress until it can not bear the internal pressure.

5. Conclusion
The plastic deformation and fracture of heat pipes are caused by some heat pipes working at high temperature higher than 450 °C for a long time.

It is suggested to find out the cause of long-term overheating operation of hydrogen production unit as soon as possible, strengthen the temperature monitoring of each part in the system working process, and take timely measures under abnormal conditions to prevent the occurrence of heat pipe failure accident.

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