Engineering Failure Analysis 55 (2015) 115–130

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Failure analysis of a high pressure differential regulating valve in coal liquefaction

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ARTICLE INFO

Article history:
Received 9 January 2015
Received in revised form 11 April 2015
Accepted 12 May 2015
Available online 21 May 2015

Keywords:
Failure analysis
Coal liquefaction
Regulating valve
Cavitation erosion
Particle erosion

ABSTRACT

Under harsh working conditions-high pressure differential, solid concentration and high velocity of a regulating valve in coal liquefaction, the valve plug damages easily. Its longest service life is less than 2000 h, which seriously affects the running safety. Failure analysis of valve plug is conducted via computational fluid dynamics (CFD) by using the actual physical parameters. The results show that the damage of valve plug results from a synergistic effect of cavitation erosion and abrasion. Two cavitation regions exist on the wall of valve bushing and plug, and a high-speed reflux appears on the plug head where the pressure is higher than the saturation pressure. Driven by the reflux, the cavitation bubbles and solid particles move toward the plug head, thus the most severe cavitation erosion and abrasion occur on the plug head because of the bubbles collapse and particle impacts. The decrease of valve opening tends to aggravate the valve plug damage caused by the combined effects of cavitation erosion and abrasion. Compare with the actual corrosion morphology, the accuracy of failure analysis is verified.

0. Introduction

Coal liquefaction is a technology changing the state of raw coal from solid into liquid through a series of chemical processing under harsh working conditions-high temperature, pressure, particle concentration, etc. [1]. A high differential pressure regulating valve is used for adjusting the liquid-level of high temperature and high pressure (HTHP) separator and controlling the pressure differential between the HTHP separator and high temperature and intermediate pressure (HTIP) separator. Own to harsh working conditions, failures of regulating valves easily occur with less than three months service life. That seriously affects the running safety of coal liquefaction.

In order to extend the service life of regulating valves, material upgrading and surface strengthening are main methods to improve the abrasion resistance. Several valve models are manufactured and tested in laboratories or pilot plants to realize the structural optimization and improvement. Streamlined flow channels are proposed by Charles [2] to enhance material loss tolerance and abrasion resistance. A report summarized by Krishnan indicates that the service life of regulating valve has increased from several hours to more than 100 days by using the proposed method [3]. Using synthetic diamond and wolfram carbide (WC) as abrasion resistant components, the longest running time of the valve developed by NEDO in Japan is approximate 1000 h in pilot plants [4]. Own to high cost of experiments, numerical simulation is suggested as a necessary method to obtain inner flow characteristics for further failure analysis and structural optimization [5,6], which has

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http://dx.doi.org/10.1016/j.engfailanal.2015.05.004
1350-6307/

been utilized by many researchers [7–9]. However, there are lack of numerical analysis on cavitation erosion and particle erosion of high pressure differential regulating valves.

In this paper, Schnerr–Sauer cavitation model [10] is used in calculating cavitation flow characteristic in the regulating valve under actual working conditions (involve pressure differential, structure, medium and material properties of the valve plug). On this basis, erosion rate distributions of valve plug at typical openings are obtained by using discrete phase model (DPM) and erosion model. The computational results agree well with actual damage morphologies and characteristics, verify the accuracy of present numerical simulation.

1. Failure description

1.1. Technical process

The process of coal liquefaction is shown in Fig. 1. The regulating valve locates at the bottom of the HTHP separator, plays a role in adjusting the liquid level of the HTHP separator and segregates the HTHP separator and HTIP separator. The inlet and outlet pressure of the regulating valve are 19.0 MPa and 3.0 MPa respectively, and its operation temperature is 415 °C. The medium passes through the valve is liquefied oil, and its composition is similar to petroleum hydrocarbons. The fluid physical properties are shown in Table 1.

1.2. Valve structure

Fig. 2 shows a structural schematic diagram of the regulating valve, mainly contains the valve stem, plug, seat, bushing and body. Among them, the plug is a movable element to adjust the flow rate; the stem is used to connect the plug and actuator for realizing the location of plug; the seat is an element engaging with the plug to cut off the flow when the regulating valve is totally closed; the bushing is used to prevent the body from damage. WC is used as manufacturing material of the seat and bushing, and 316L stainless steel is used as base material of valve plug and steam. WC is coated on the plug surface of 316L by High Velocity Oxy-Fuel (HVOF) spraying with adhesive bond of Co. The thickness of WC–Co coating is 500 μm. And the chemical composition and material properties of WC–Co is listed in Table 2.

For the changes of working conditions, load fluctuation or plug damage of the regulating valve, the relative position of valve plug and seat need to be adjusted during the operation. Therefore, the valve opening is also changed for altering flow resistance, regulating flow rate, compensating load disturbance and eventually maintaining the liquid level of HTHP separator in set range. Fig. 3 shows that valve opening varies from ranges of 40% to 60% according to the run-time.

1.3. Failure description

Because of high pressure differential between inlet and outlet pressure, solid particles concentration and high velocity, failures of regulating valve occur easily. Its current service life is less than three months, which seriously affects the safe operation of enterprise (see Table 3). Fig. 4 shows the damage morphologies of valve plugs in different maintenances. It can be seen from Fig. 4a that there are obvious erosion pits on the surface of arc segment of plug head in early stage when the valve opening is about 60%. Through comparing Fig. 4b with Fig. 4a, it can be concluded that the damage process of valve plug develops from head to root. Fig. 4c shows that most surface material of valve plug has been removed with 40% valve

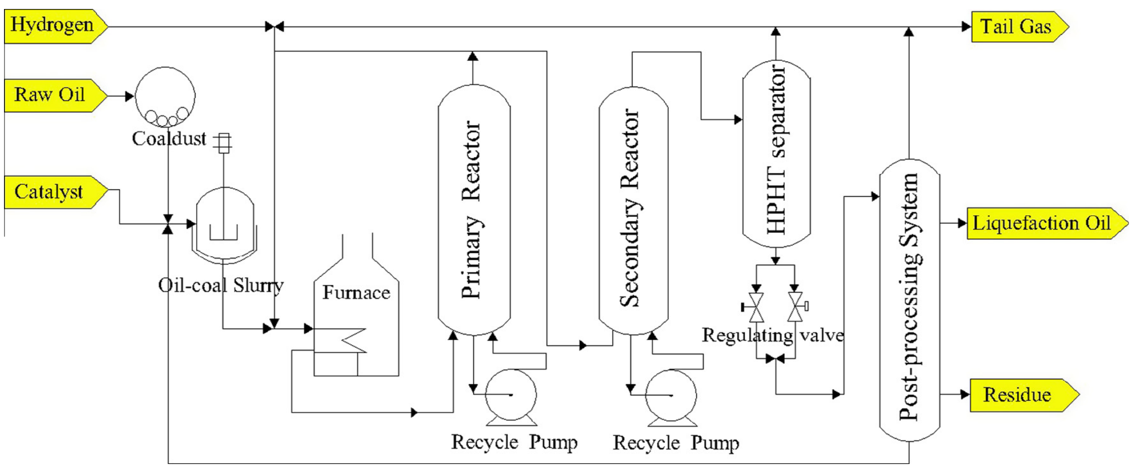

Fig. 1. Process diagram of direct coal liquefaction.