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Investigation on failure process and structural improvement of a high-pressure coal water slurry valve

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ABSTRACT

The failure mechanism of a high-pressure coal water slurry valve in the coal chemical industry was investigated in this paper. Severe erosion wear was found on the valve spool, which threatened the safety and reliability of the unit. The mechanism was initially clarified by analyzing the technical process, operational condition and micro-morphology of corroded surface. Moreover, the failure process of valve spool is researched and the corresponding structural improvement was proposed via computational fluid dynamics (CFD) methodology. The numerical simulation was performed by using actual running and fluid physical parameters. The results showed that the serious erosion wear was both found on the valve spool and valve bushing. Specially, the maximum erosion rates locate on the top of spool head. The numerical results are in good agreement with the actual failure morphology, then the numerical calculation is verified. The improved structure of valve spool and downstream pipeline is proposed. The field test proved that the erosion wear of valve spool was significantly reduced, thus the service life of the valve was extended.

1. Introduction

The technology of coal gasification and liquefaction has been widely applied in the coal chemical bases of China in recent years [1]. The thinning and leakages of pipes and equipment caused by the particle erosion wear have become a considerably difficult problem in the coal chemical industry. In the coal water slurry valve, for the transportation of solid – contained slurry with the high velocity, the service life of valve spool ranges from 4 months to 6 months. It is known that erosion wear is affected by the flow pattern, solid particle characteristics, material performance, particle impact process and so on [2]. Therefore, the failure analysis and structural improvement of valves should be conducted by considering all the factors mentioned above.

The CFD methodology has become an important tool in predicting erosion wear of valves. A lot of efforts have been made to predict the multiphase flow erosion. Peng et al. [3] used liquid film and droplet velocity to replace the mixture velocity implemented in empirical models for annular flow. Their work was aimed at providing assistance to industry not only performing the qualitative but quantitative CFD erosion analysis. Parsi et al. [4] calculated the erosion wear in slug/churn flows by using the volume of fluid (VOF) model. Barton et al. [5] proved that the CFD methodology can accurately predict erosion rate by comparing with the experiment data. In order to ensure the accuracy of erosion prediction in the multiphase flow environment, the numerical model and

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method should be modified and verified. Chen et al. [6] investigated the impact of a stochastic particle rebound model [7] on erosion of elbows and plugged tees. Experiments confirmed that a stochastic rebound model is required in simulations to give a reasonable estimate of erosion rate and pattern in a plugged tee. Zhang et al. [8] found from simulations that accounting for the rebound at the particle radius helps avoid nonphysical impacts and reduces the number of impacts by more than one order-of-magnitude for small particles due to turbulent velocity fluctuations. Messa GV et al. [9] found the combination of Euler–Euler and Euler–Lagrange models can considerably reduce the computational burden for particle tracking and wear estimation. And, the objective of their work was to investigate how the erosion estimates are affected by the different sub-models and parameters of a CFD-based wear prediction model [10], providing guidelines for increasing the reliability of the estimates. Particularly, a simple approach was developed, which allows relating the useful lifetime of the valve to the integral erosion ratio of its most vulnerable component [11]. Based on the verification of a semi-empirical material removal model, Wang et al. [12] employed the multi-objective genetic algorithm to mitigate the erosion wear. An empirical wear mass loss model was adopted by Wallace et al. [13] to characterize the erosion wear behavior in the valves with simple and complex structure. The results revealed that the model can accurately predict the flow rate and erosion region. In the coal water slurry valve, the particle erosion occurs in the cavitation process. The process makes the flow regime more complex and the erosion wear is difficult to be predicted. Although many structural optimizations and surface hardening technology [14–16] have been applied in the manufacture of valves, the effective is still limited.

In this paper, the failure mechanism of high-pressure coal water slurry valve was initially clarified by analyzing the technical process, operational condition and micro-morphology of corroded surface. The actual working condition, physical parameters and valve structure were used in the numerical simulation. Then the failure mechanism of valve was revealed and the influence of failure process on the erosion wear of valve spool was discussed. Finally an improved valve structure was proposed and the effectiveness was proved by actual filed test.

2. Failure description

2.1. Technical process

The process flowchart of coal water treatment unit is shown in Fig. 1. The high-temperature coal water comes from the central of gasifier and the bottom of carbon scrubber. Once it passes through the high-pressure coal water slurry valve, the pressure is reduced to 0.8 MPa. Finally, it will enter into the high pressure flash tank. In the flowing process, the gas – liquid – solid flow is formed. The inlet and outlet pressures of valve are 6.5 MPa and 0.9 MPa, respectively, and the working temperature is 246 °C. In the full open state, the pressure difference is 6.33 MPa, and the maximum flow rate is 48.9 m^3/h. The operational parameters of the valve are detailed in Table 1.

The fluid properties in the valve are detailed in Table 2. The outlet of slurry valve is connected with the high-pressure flash tank, thus the downstream pressure of valve is the same as that in the tank. A large amount of vapor phase will be produced during the flow process, resulting in the rapid increase of mixture velocity. Simultaneously, the high concentration of solid particles in the multiphase

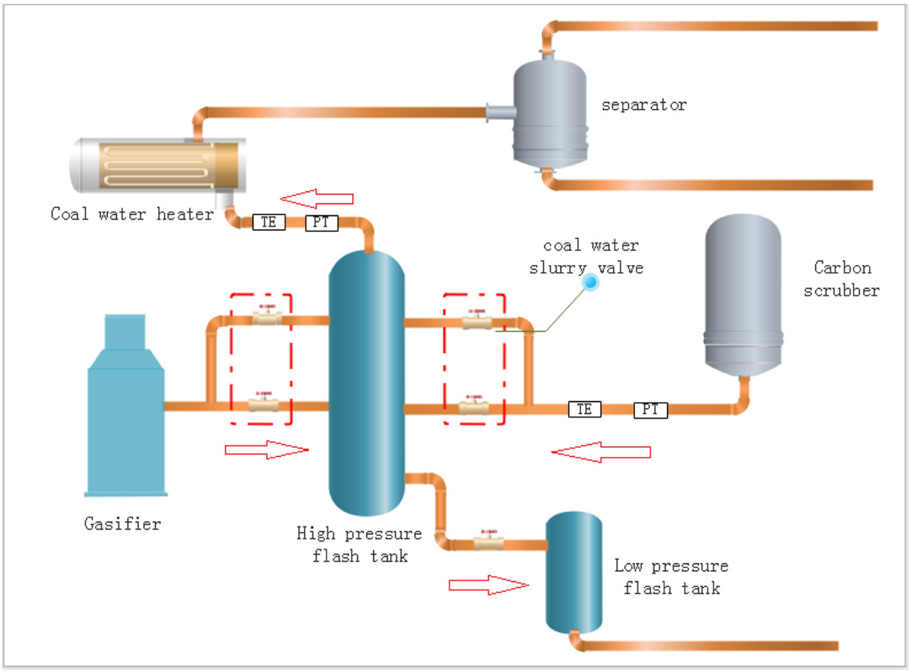

Fig. 1. Process flowchart of coal water treatment unit.