Numerical Simulation on Erosion of Drain Valve

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Abstract: In this paper, numerical simulations on Y-type drain valve were carried out using Eulerian-Lagrangian model. The simulation results were verified by the experimental ones. It was found that the droplet velocity close to the sealing surface exceeds the threshold values, resulting in serious erosion. To lower down the extent of erosion, a spool featuring labyrinth discs was proposed. The simulation results showed that the maximum droplet velocity and flow capacity of the drain valve with the labyrinth discs are 46% and 78.2% of the values for the valve without the labyrinth discs, respectively. It can be concluded that the usage of labyrinth discs reduces the erosion significantly and is applicable to serious erosion operating conditions.

Introduction

Steam drain valve is used for drainage [1,2]. During drain-off water, saturated water in the pipeline will form high-speed droplets and hit the internal walls of the drain valve, causing a serious damage of erosion on the valve [3,4]. How to reduce the erosion damage of the steam drain is a main challenge. In this study, one Y-type drain valve from Suzhou Delan Energy Science & Technology Corp. Ltd, was simulated by computational fluid dynamics (CFD) to clarify the erosion position and extent. One method of using Labyrinth disc was firstly proposed in this study to reduce the erosion of the steam drain valve while keeping the flow capacity almost the same.

Physical Model and Numerical Simulation

The diagram of the Y-type drain valve is shown in Fig. 1. In the CFD simulation, the valve entrance and exit were connected with the straight pipes whose lengths are 5 times the diameter of the valve entrance. For simulating the critical flow at the valve outlet, the valve outlet straight pipe was connected with a large container with three openings [5]. The container diameter is 5 times that of the outlet straight pipe. Commercial software CFX with Eulerian-Lagrangian multi flow model was used for simulation. ANSYS ICEM with hybrid meshes was used for meshing. The heat transfer between fluids was ignored and isothermal model was taken. The temperature and the pressure at the valve entrance were set as 300℃ and 9MPa, respectively. The k-ε turbulence model was used with the inlet turbulence intensity of 5%. Droplets were injected randomly at the valve entrance the droplet velocity of 15m s^{-1}. The wall boundary condition is no-slip. The behavior of the particle impacting wall is described by the parallel coefficient and the perpendicular coefficient in CFX. The parallel coefficient value is 1 means complete inelastic collision. Actually, the droplets in the valve collided with the walls and formed a thin film liquid film. Therefore, the parallel and perpendicular coefficients were set to be 1and 0, respectively.

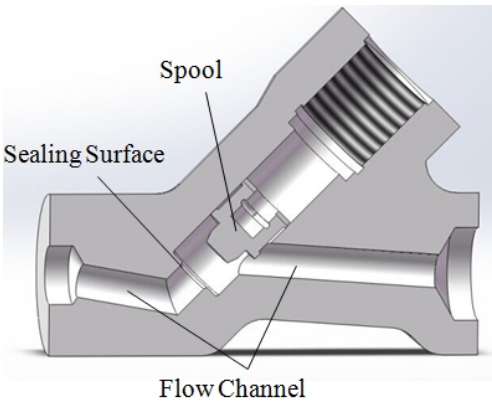


Fig. 1. Structure of Y-type drain valve.

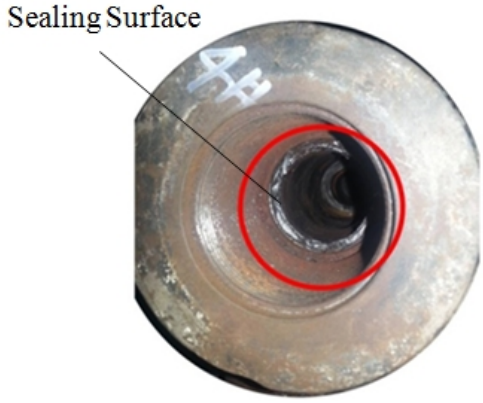


Fig. 2. Erosion of Y-type drain valve.

Results and discussion

The impact of mesh fineness was investigated by comparing the droplet maximum velocity, which has a significant influence on the erosion extent. Three mesh densities have been generated and the number of elements are 80599 (coarse), 598397 (fine) and 2245319 (very fine) respectively. Given the valve opening of 50%, the calculated maximum droplet velocity indicated that there is no obvious difference between fine (34.9 m s^{-1}) and very fine model (33.8 m s^{-1}), but it is different from the coarse one (30.5 m s^{-1}). This indicates that the calculation of the maximum droplet velocity is relatively independent for the fine and very fine models. To minimize computation time, the fine mesh density (598397elements) was chosen for this transient study.

The erosion of the Y-type drain is shown in Fig. 2. After one month operation of the valve, serious erosion can be found at the positions close to the sealing surface. Such erosion resulted in an obvious leaking during the valve's operation. For the simulation of the Y-type drain valve, the droplet trajectory at the valve opening of 100% is demonstrated in Fig. 3. The maximum droplet velocity appears at the positions close to the sealing surface, which is in a good agreement with the actual result as shown in Fig. 2. Kenndy et al. studied the threshold of droplet velocity regarding the erosion of carbon steels. The threshold value is about 120 m s^{-1} [6]. That is, when the droplet velocity exceeds the threshold valve, erosion occurs. The erosion rate can be roughly estimated following Equation (1) [7]. Where, W is the weight loss of carbon steel; V and V_{th} are the droplet velocity and threshold velocity, respectively.

$$W \propto (V - V_{th})^{2.5} . \tag{1}$$

As shown in Fig. 3, the maximum droplet velocity is around 170.3 m s^{-1}, which is higher than the threshold vale, indicating the presence of serious erosion. It should be noted that at the actual valve operation, the droplet in the steam impacts on the valve interior wall and form a thin liquid film. This liquid film slips form the wall and is carried by the steam, subsequently forming droplets. In the simulation, this complicated behavior can not be accurately described. The droplet at a high velocity just collided with the valve wall and disappeared. However, for the calculation of the maximum droplet velocity and the corresponding position, our simulation method is correct enough. In addition, for a conventional power plant, the saturated water in the pipeline inevitably contains fine particles which were formed by the oxidation of the metal material by high-temperature steam during the plant running. Several groups collected the water samples of boilers to analyze the particle size distributions. The results indicate that the particles size is concentrated less than 100 μm [8,9]. The damage of the material heavily depends on the concentration and size of the micro-particles contained in the saturated water. When the micro-particle size is more than 6.5 μm, the grinding of micro-particles not droplet erosion is the main failure cause [10]. In this case, the V_{th} decreases significantly. Therefore, for the real application of the Y-type drain valve, the droplet

velocity should be reduced to a value that remains far below the V_{th} of 120 m s^{-1} to guarantee a long operation life of the valve.

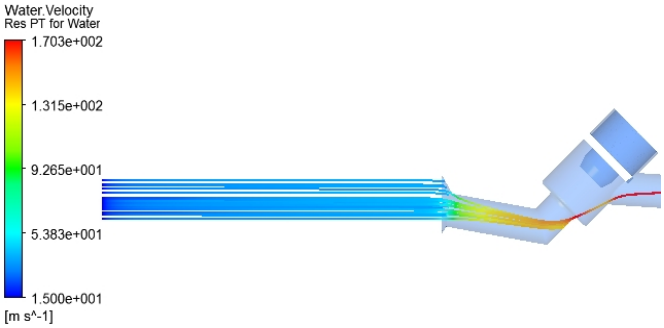


Fig. 3. Droplet trajectory contour at100% valve opening.

To this end, a labyrinth disc was proposed in this study. The diagram of the flow pattern is illustrated in Fig. 4. On a single disc, there are several concentrically circular channels which were broken evenly. When the fluid flows across the disc from the inner channel to the outer one, the fluid is firstly divided into two flows at one channel. Then, the two flows undergo a head-on collision at the adjacent channel and forms one flow. The flow division and collision are repeatedly until the fluid exits form the disc. The main philosophy is that the reduction of the droplet velocity by the head-on collision of droplets not by the collision between droplets and valve walls. Several labyrinth discs were boned and form as one spool by diffusion bonding. As shown in Fig. 5, a solid valve stem is installed inside the central passage of the formed spool. The valve opening is controlled by the movement of the valve stem.

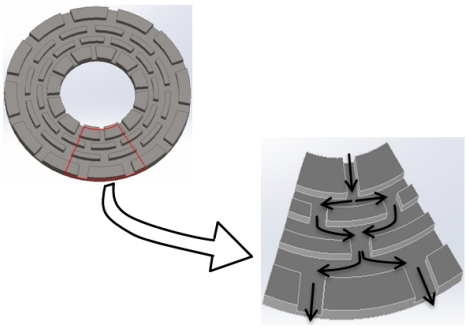


Fig. 4. Labyrinth disk and diagram of its flow pattern.

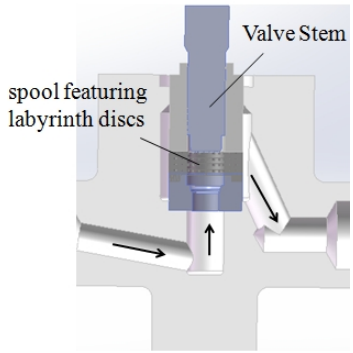
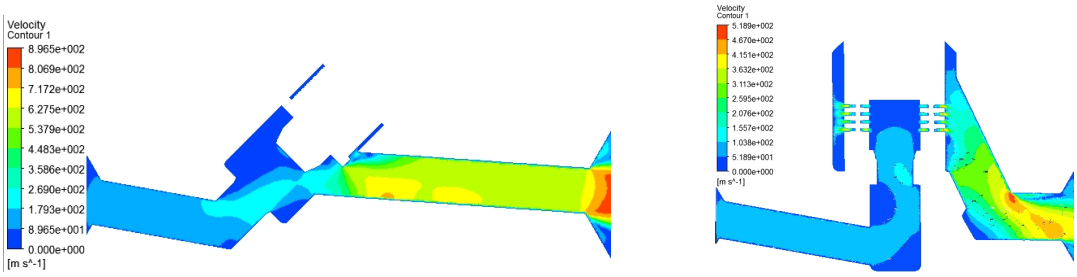


Fig. 5. Structure of labyrinth drain valve.

As shown in Fig. 6, the maximum gas velocity is 518.9 m s^{-1} for the valve with the labyrinth discs, accounting for 57.9% of that for the valve without labyrinth discs. It can be seen from Fig.7 that the maximum droplet velocity is 78.6 m s^{-1} in the case with labyrinth discs, 46% of that without labyrinth discs. Therefore, the spool featuring labyrinth discs can effectively reduce the valve erosion by the collision of droplets. The flowrate is 1.8 kg s^{-1} for the case with labyrinth discs, which is 78.2% of that without labyrinth discs. The reduction of the flow capacity is acceptable considering the design margin of the actual drain valve. The fabricated drain valve with the labyrinth discs was operated in a power plant and exited an excellent anti-erosion activity. This drain valve has performed well for one year and is now running. So, the spool featuring labyrinth discs is a good anti-erosion design. The disadvantage is the fabrication cost of such spool is high, indicating that its reasonable application is limited to serious erosion conditions.



(a) (b)

Fig. 6. Gas phase velocity of the drain valves without (a) and with labyrinth discs (b).

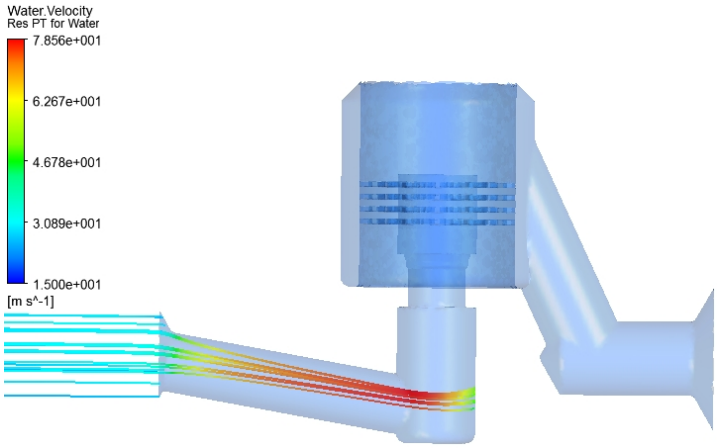


Fig. 7. Droplet velocity inside the drain valve with labyrinth discs.

Conclusions

(1) For a conventional Y-type drain valve, the droplet velocity close to the sealing surface exceeds the threshold values, resulting in serious erosion.

(2) The maximum droplet velocity and flow capacity of the drain valve with the labyrinth discs are 46% and 78.2% of the values for the valve without the labyrinth discs, respectively. For the usage of labyrinth discs, the erosion can be reduced significantly and meanwhile the decrease in flow capacity is acceptable.

(3) The usage of labyrinth discs is applicable to serious erosion operating conditions.

References

[1] Wenjun Xu, Jinzhu Xu, Dong Qiao, et al. Ineer Mongolia Electric Power, 2011, 29 (6) : 66-67. In Chinese.

[2] Hutchison J W. Isa, 1976.

[3] Zhen Li, Yongquan Xiao. HV&AC, 2005, 35(2):126-128. In Chinese.

[4] Wang Y, Xing J, Ma S, et al. Corrosion Science, 2016, 104: 260-268.

[5] Wang Z J, Yu X H, Ze X F, et al. Mechanics and Mechatronics Proceedings of the 2015 International Conference on Mechanics and Mechatronics, Shanghai, ICMM2015, 2016: 284-293.

[6] C.F. Kennedy, J.E. Field. Journal of Materials Science, 2000, 35:5331-5339.

[7] Orna M, Ruml Z. International Conference on Erosion by Liquid and Solid Impact, 5th, Cambridge, England. 1979: 23.

[8] Dai L, Yu M, Dai Y. Wear, 2007, 262(1): 104-111.
[9] Campos-Amezcua A, Gallegos-Muñoz A, Romero C A, et al. Applied thermal engineering, 2007, 27(14): 2394-2403.
[10] Wanli Xu. Beijing: Tsinghua University, 2010: 15-22. In Chinese.