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Simulation study of a horizontal gas filter

XU Peng[1*], LIU Wei[1], PAN Dan-dan[1], YUAN Xun[2]

1 Key Laboratory of HVAC, Beijing University of Civil Engineering and Architecture, Beijing 100044, China

2. High Pressure Pipe Network Branch of Beijing Gas Group Co. LTD, Beijing 100035, China

ABSTRACT

The solid dust, ammonia sulfide, condensate, water and other liquid substances carried by natural gas in the pipeline transport process do serious harm to the safe operation of pipelines and instrumentation equipment along the way. The performance of the filter installed in the natural gas station and the user entrance is the key to the quality and flow of gas supply. The performance of the filter element changes dynamically with the use. If the filter element cannot be cleaned and replaced in time, the passing efficiency of gas will be seriously affected and the local resistance will soar and the passing flow will drop sharply, thus causing the safety problem of gas supply. In this paper, based on the investigation and analysis of the working condition of natural gas filter in actual engineering, a numerical model of natural gas filter was established, and the flow field inside the filter was simulated by means of CFD tool. The research shows that the change of inlet velocity has a great influence on the filtering effect. When the inlet velocity is about 13 m/s, the filtering effect is the best, reaching more than 96%. Under limited conditions, it is recommended to give priority to the replacement of the lower filter element.

Keywords: gas filter, numerical simulation, flow distribution, filter efficiency

NONMENCLATURE

α	Porosity
C_1	Inertia resistance factor
c_p	Specific heat, J/m³·K
k	Heat transfer coefficient of the fluid, w/m²·s
S_T	Internal heat source of the fluid and the part where the fluid's mechanical energy is converted into heat energy due to viscosity
t	time, s
T	Temperature, K
v_i	The velocity in the I direction, m/s
v	velocity, m/s
ρ	Gas density, kg/m³
η	efficiency

1. INTRODUCTION

With the gradual advance of the air pollution prevention and control action plan of the Chinese State Council, the special gas plan issued in the 13th Five-Year Plan not only points out the direction for the development of the gas industry, but also welcomes the development opportunity of the natural gas industry[1]. In the process of pipeline transportation, natural gas carries solid dust and ash, as well as liquid impurities such as ammonia sulfide, condensate and water[2-3]. These pollutants and impurities do serious harm to the safe operation of pipelines and instruments along the way. Therefore, the filtering device plays an important role in the process of gas transmission and distribution.

According to the Chinese national standard GBT 36051-2018 *Gas Filter*[4], combined with the field investigation of enterprises, this paper studied the main structural parameters and working conditions affecting the performance of the filter by means of numerical simulation for the widely used high and middle pressure horizontal gas filter. Computational Fluid Dynamics (CFD) was applied to simulate the internal flow field of the filter, and the influence of blockage of the filter cartridge at different locations was studied.

* XU Peng, Tel.: +86 10 68331450. E-mail address: xupeng@bucea.edu.cn

2. WORKING PRINCIPLE AND GEOMETRIC MODELING OF HORIZONTAL GAS FILTER

The physical appearance and internal structure of the horizontal gas filter are shown in Fig. 1.

Fig 1 Physical appearance and internal structure of horizontal gas filter

Referring to the relevant provisions of GBT 36051-2018 *Gas Filter*, a horizontal gas filter model with conventional 7-pipe filter elements is constructed, as shown in Fig. 2. The sizes of each part are as follows: DN1(confluence cavity diameter)=900mm, DN2(inlet diameter) =DN3(outlet diameter)=400mm, the number of filter cartridge mesh is 500, the filter cartridge diameter is 260 mm, the length is 1800 mm, and the total length of filter L=2500mm.

The path of gas in and out of the filter: the gas enters from inlet 1 and first hits the hollow support tubes 3 which support the filter elements (to avoid direct impact of air flow on the filter element and damage to the filter material). The larger solid and liquid particles are initially

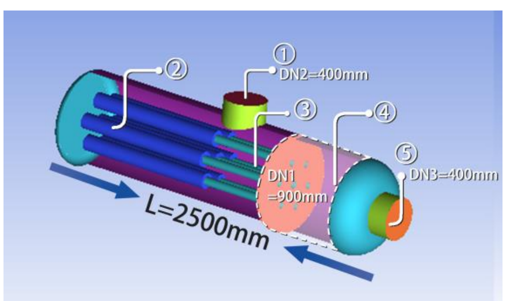

Fig 2 Filter model

separated and sink to the bottom of the container under the action of gravity, and are discharged from the sewage outlet regularly. Immediately afterwards, the gas passes from outside to inside through the coalescing filter element 2, and the solid particles are retained by the filter medium, while the liquid particles coalescence and grow gradually on the inner surface of the filter element due to coalesence of the filter medium. When the droplet reaches a certain size, it will fall off from the inner surface and enter the inner flow passage of filter element 2 due to the impact of airflow, and then enter the confluence cavity 4 through the hollow support tubes 3 connected with the inner part of filter element. In the confluence chamber, the flow section becomes larger and the velocity decreases, and the larger liquid beads are separated by gravity settlement. Finally, the filtered gas flows out of outlet 5.

3. NUMERICAL MODEL AND MESH GENERATION

3.1 Mathematical model and boundary setting

The fluid medium discussed in this model is CH_4, and the total pressure and temperature change are relatively small, so the solid wall can be considered as adiabatic. The medium density in the whole model is constant, and the turbulence model is defined as *k*-ε equation. SIMPLE algorithm was used for pressure-velocity coupling, and the convergence accuracy of each variable was 1×10^{-6}. The pressure term, momentum, turbulent kinetic energy and turbulent dissipation rate all adopt the high precision second order windward discrete scheme.

Define filter inlet 1 as velocity-inlet, outflow 5 as free outflow, wall of model, and filter elements 2 as porous-jump.

3.2 Governing equation

The flow process in the filter satisfies three governing equations, i.e. conservation of mass, conservation of momentum and conservation of energy.

Mass conservation equation:

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x_i}\left(\rho \upsilon_i\right)=0 \qquad (1)$$

Momentum equation:

$$S_i=-\left(\frac{\eta}{\alpha}\upsilon_{\mathrm{i}}+\frac{1}{2}c_1\rho\left|\upsilon\right|\upsilon_{\mathrm{i}}\right) \qquad (2)$$

Energy conservation equation:

$$\frac{\partial(\rho T)}{\partial \mathrm{t}}+\mathrm{div}(\rho\upsilon T)=\mathrm{div}\left(\frac{\mathrm{k}}{c_p}gradT\right)+S_T \qquad (3)$$

3.3 Division of ICEM CFD grid

Designing a reasonable and high-quality grid is the prerequisite to ensure the calculation accuracy and solve the problem, and is an important step in the simulation process. ICEM CFD was used to mesh, because of tetrahedral mesh grid adaptability is strong, can better filled with complex geometry, this model adopts tetrahedral mesh division, the priority to encrypt and adjustment on the border of the grid number, the higher quality of structured grids, division of the grid are shown in Fig. 3 below. Basically meet the required accuracy requirements of the discussion.

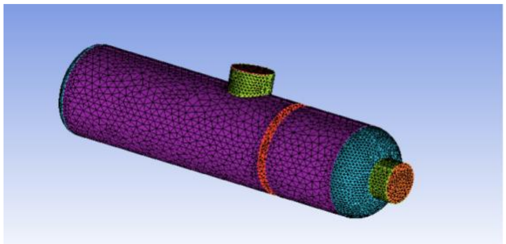

Fig 3 Model meshing diagram

3.4 Model validation

Li Baisong[5] used DOS (dioctyl sebacate) as the experimental medium to conduct an experimental study on the gas-liquid separation performance of natural filter by weighing method. The effects of surface filtration rate of the filter element, average particle size of the droplet and liquid content of the gas on the separation performance of the filter were studied. Experimental parameters are shown in Table 1 below.

Table 1 Setting of variables in the experiment

Liquid content of gas (g/m^3)	Average particle size of droplet (μm)	Surface filtration rate of filter element (m/s)
18.5	20	0.06-0.10
11	5-30	0.10
8-18.5	20	0.10

The parameter filter efficiency in the filter separation performance is selected to verify the accuracy of the model. The filter efficiency refers to the ability of the filter or core to trap a particular test particle. Calculate according to formula (4).

$$\eta = 1 - \frac{\text{Number of particles that escape}}{\text{Number of particles emitted}} \quad (4)$$

The turbulence model was set as the K- ε equation, and the SIMPLE algorithm was used for the pressure-velocity coupling. The pressure term, momentum, turbulent kinetic energy and turbulence dissipation rate all adopted the highly accurate second-order upwind discrete scheme. When 4000 particles were injected into the calculation domain for numerical simulation, the number of escaping particles was 156, 152, 132 and 120 when the surface filtration velocity of the gas was 0.06 m/s, 0.07 m/s, 0.08 m/s and 0.10 m/s, respectively. The corresponding filter efficiencies were 96.1%, 96.2%, 96.7% and 97.0%, respectively. The calculation results are shown in Figure 4. The deviations between the simulated and experimental values of filter efficiency were 2.9%, 2.9%, 3.0% and 2.8%, respectively. The maximum deviation is 3.0%, and the overall trend is consistent. With the increase of the gas surface filtration velocity, the filtration efficiency gradually increases. The low simulated filtration efficiency is mainly due to the relatively idealized model setting. In the actual process, other factors may play a role in promoting the filtration of impurities, so it will be slightly less than the experimental value. On the whole, the deviation between the simulation results and the experimental data is small, and the prediction results are relatively reliable.

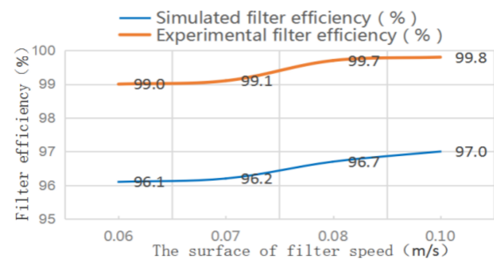

Fig 4 Comparison of simulated and experimental values of filter efficiency

4. NUMERICAL SIMULATION RESULTS AND ANALYSIS

4.1 Residual analysis

Before the simulation study, the residual analysis and calculation were carried out. The unit series of residual curve is generally set as 10^{-3}. According to this default series, each parameter gradually tends to be stable after 500 steps of iteration, indicating that the above parameter setting is correct and the equation has a solution.

4.2 Impact of inlet velocity

There is a certain relation between inlet velocity and gas surface filtration velocity. The number of filter core mesh of each filter set in the model is 500, the outer diameter of filter core is 260 mm, the length is 1800 mm, and the filtration accuracy is 20 m. The total number of mesh holes in this model is about 8.2×10^7. When the gas surface filtration rate is 0.1m /s, the filter inlet velocity is about 12.3m/s.

In order to further analyze the influence of inlet velocity change on internal airflow distribution, inlet velocity was set as 11 m/s, 13 m/s and 15 m/s respectively. The section y=0 inside the filter was selected as the analysis plane to obtain the contours of velocity inside the filter under different inlet velocities, as shown in Fig. 5.

Due to the internal structure of the filter, the upper element position is prone to vortex. Its position is also consistent with the fact that the clogging near the end cover is more serious in the actual maintenance process.

The velocity distribution around the filter element varies with the inlet velocity. If the inlet velocity is too high, it will lead to the penetration of large particles, thus reducing the filtering effect. Moreover, with the increase of inlet velocity, vortexes will form in the position shown

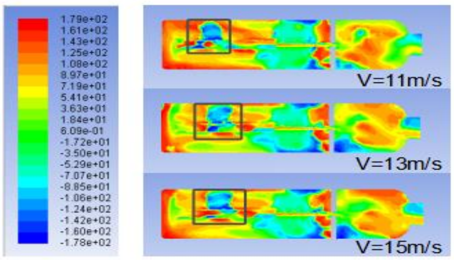

Fig 5 Velocity distribution under changing inlet velocity

in Figure 5, and the formation of vortexes will also increase the resistance. However, as a whole, the velocity distribution of airflow around the filter element is uniform and relatively small, which is conducive to better filtering of the gas. To a certain extent, the filtering effect will become worse with the increase of speed. After a series of value simulation, it is found that the best effect is to keep the inlet speed around 13 m/s.

4.3 Impact of filter element position

To further analyze the impact of different filter elements locations on velocity distribution, the inlet velocity was first set as the optimal velocity mentioned above at 13 m/s. Then, the porosity of the filter core at the top, middle and bottom was set to 0 respectively, and the section y=0 inside the filter was selected as the analysis plane. The contours of different velocity distributions was shown in Figure 6.

As can be seen from Fig. 6, when the bottom filter element is blocked, the velocity distribution of the upper part remains the same. Therefore, when the pressure difference between the front and rear of the filter reaches a certain value, the filter element can be partially replaced. Give priority to replace the middle and lower filter elements and keep the upper filter elements. This idea is verified. The porosity of the upper part of the filter element was distinguished from that of the lower part of the filter element. Then, DPM in Fluent was used again to track the particles. The results showed that the actual filtration efficiency was maintained above 95%, thus fully

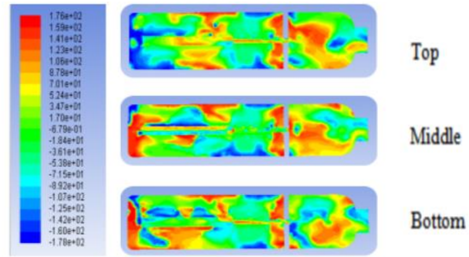

Fig 6 Velocity distribution of filter clogging in different locations

reducing the operating cost while ensuring the filtration effect.

5. CONCLUSIONS

The gas filter faces very complex gas source temperament and operating conditions in the actual use process. For gas transmission lines and large stations, the number of internal filter elements can be up to 100, and the internal flow field is very complex. In the process of use, factors such as maintenance cycle of stop gas and open cover and cost of cleaning and replacement should be taken into consideration. In places with poor temperament, the bottom filter element will be buried by sundry and fail during operation, leading to deformation of the top filter element due to pressure difference suction. In this paper, only the numerical simulation under the ideal working condition is done, and the reliability of the simulation model is verified by comparing with the experimental results, and some preliminary conclusions are drawn, which lays a certain foundation for the subsequent simulation research closer to the actual working condition.

1) The fact that the porous media model simulating the working condition of gas filter achieved high agreement with the experimental test results for the filter efficiency, proposes a method for the numerical study of gas filter.

2) A large inlet velocity of gas filter can ensure smooth flow of airflow into the filter, but obvious local eddy will be generated inside the filter. In the actual operation, the inlet speed is suggested be controlled at about 13 m/s, which helps to achieve better filtering effect.

3) Considering the operation cost in actual projects, the lower and middle filter elements could be replaced preferentially when replacing the filter elements.

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