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Diesel engine calculation of steady state filtration characteristics of metal fibrous felt particulates filter

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Abstract: Metal fibrous felt particulates filter has the advantages of high mechanical strength, long service life, large dust capacity, high filtration accuracy, low resistance loss and high temperature resistance. In order to obtain the influence of structural parameters of metal fibrous felt on the characteristics of steady-state filtration efficiency, the effects of structural parameters of filter material such as porosity, fiber felt thickness and fiber diameter on steady-state capture efficiency under different filtration speeds are theoretically calculated and analyzed by using numerical calculation method. The results show that the structural parameters have an important impact on the steady-state filtration efficiency, which must be controlled within a reasonable range. Reducing the surface filtration speed to less than 0.1m/s can effectively improve the filtration efficiency. This paper provides a theoretical basis for the selection of structural parameters of metal fiber felt filter material, and has important research value.

1. Introduction

Metal fiber felt is mainly used in particulate traps with high performance requirements for filters. Brillant et al. [1], from the vehicle Research Institute of the University of Applied Sciences in Dresden, Germany, conducted a preliminary experimental study on the filtration characteristics, pressure loss and catalytic combustion regeneration characteristics of the folded metal fiber felt particulate trap for off-road four cylinder diesel engine. The research shows that the permeability is 100 times higher than that of wall flow ceramic in clean state.

There are a lot of simulation research on the steady-state and unsteady state capture mechanism of fiber trap on the basis of classical filtration theory. Yang Lin et al. [2] compared and analyzed the rationality of the empirical models of three common filtration mechanisms of single fiber, and compared and analyzed the theoretical calculation error of the capture efficiency of each single mechanism and the influence error of the combined on the total capture efficiency. Saleh et al. [3] carried out three-dimensional simulation calculation on the process, capture efficiency characteristics and pressure loss characteristics of carbon smoke particles captured by thin flat fiber felt, and compared the calculation results with those of one-dimensional model. Balazy et al. [4] used Brownian dynamics method to calculate and study the filtration efficiency of fiber trap for capturing non spherical soot particles, and compared the calculation results with the classical single fiber filtration theoretical model. Przekop et al. [5] used the lattice Boltzmann model to simulate the deposition of soot particles on a single fiber, focusing on the morphology.

Based on the traditional theoretical model of single fiber interception, inertia and diffusion capture, this paper theoretically calculates and analyzes the effects of filter material structural parameters such as porosity, fiber felt thickness and fiber diameter on steady-state capture efficiency under different filtration speeds, so as to provide a theoretical basis for the selection of metal fiber felt filter material structural parameters.

2. Model of metal fiber filter material capture efficiency

In this paper, the capture mechanism of single fiber is systematically studied by using the traditional theoretical model of single fiber interception, inertia and diffusion capture, and the combined capture efficiency of single fiber is calculated. Based on the collection efficiency of single fiber combination, the steady-state collection efficiency model of metal fiber filter material is established.

Using the law of logarithmic transmission, the capture efficiency of metal fiber felt can be calculated after obtaining the combined capture efficiency of single fiber. By integrating the number of particles passed by the unit volume of the filter material, the total capture efficiency of the filter material or filter can be expressed by equation (1):

$$\eta = 1 - \exp\left[-\frac{4\alpha H \eta_S}{\pi(1-\alpha) D_f} \right] \tag{1}$$

Where, η -the capture efficiency; α -the filling rate; H -the thickness of fiber felt; ηS -the combined capture efficiencyt of single fiber; Df -the fiber diameter;

Formula 1 organically connects the micro capture mechanism with the macro capture mechanism In the condition of $\alpha = 0.25$, $H = 0.54mm$, $d_f = 15\mu m$, $T = 473K$,the collection efficiency of fiber filter material for particles with different particle sizes under different filtration speeds is calculated, and the results are shown in Figure 1. Due to the influence of single fiber capture efficiency, the curve change trend is similar to that of single fiber combination capture efficiency, showing a U-shaped distribution, and the filter material capture efficiency is greater than that of single fiber. Comparing the four collection efficiency curves of filter materials under different filtration speeds, it can be seen that with the increase of filtration speed, the collection efficiency of fiber filter materials for small particle size particles continues to decrease, while the collection efficiency of large particle size particles continues to improve, which is consistent with the change trend of single fiber combination collection efficiency, and the change is more obvious in the small particle section. At the same time, it can be found that the most permeable particle size increases with the decrease of filtration rate. Reducing the surface filtration rate is beneficial to the metal fiber filter of diesel engine to capture small particle size particles. Fig. 2 reflects the change of average capture efficiency of different particle diameters of fiber filter media under different filtration speeds. It can be seen that with the reduction of filtration speed, the average capture efficiency of filter media is constantly improving. It can be seen that reducing filtration speed is very beneficial to improving the capture efficiency of filter.

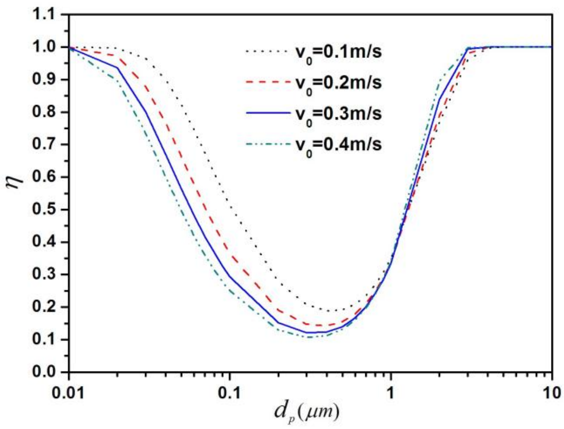

Fig.1 The total collection efficiency of metal fibrous felt vs. particulate diameter

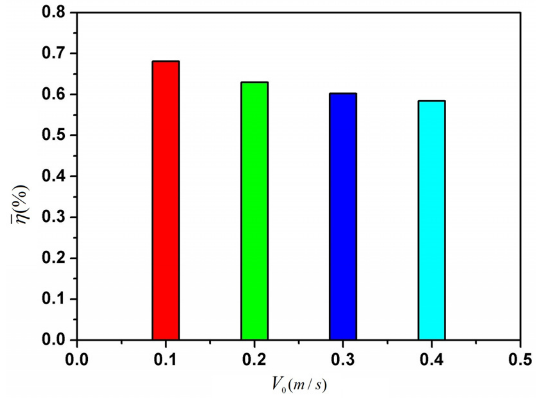

Fig.2 The average collection efficiency of metal fibrous felt with different V_0

The with H-type main steel beams and steel channels, lightweight precast panels set upon the steel skeleton, shear keys connected to the main steel beams and post-pouring concrete layer.

3. Effect of filling rate on capture efficiency

The filling rate of metal fiber felt studied in this paper varies from 13% -28%. When the fiber diameter is taken as 15 μm and the fiber felt thickness is taken as 0.54mm, the collection efficiency of fiber filter materials with filling rates of 10%, 15%, 18%, 20%, 23%, 25%, 28% and 30% at different filtration rates is calculated. The average value of the combined collection efficiency of particles with different particle sizes of a single fiber is taken. The calculation results are shown in Figure 3, It can be seen that with the increase of the filling rate of metal fiber felt, the capture efficiency increases nonlinearly, but the growth rate is decreasing. After the filling rate is greater than 25%, the influence of the filling rate on the capture efficiency is no longer significant, and the capture efficiency cannot be improved by blindly increasing the filling rate. Comparing the change curves of four different surface filtration rates, it can be found that the other three curves are basically the same except that the filtration rate of $V_0 = 0.1m/s$ is significantly higher than the other three curves. This is because as the filtration rate decreases, the diffusion capture efficiency increases, while the inertia and interception capture efficiency decrease. The average capture efficiency $\overline{\eta}_s$ changes little when V_0 changes in the range of 0.2 ~ 0.4m/s. However, when V_0 decreases to $0.1m/s$, the diffusion capture efficiency increases sharply, while the inertia interception capture efficiency decreases slightly, resulting in rapid increase, resulting in the increase of filter material capture efficiency. If the filtration speed is reduced to $0.1m/s$, the collection efficiency of filter material can be effectively improved.

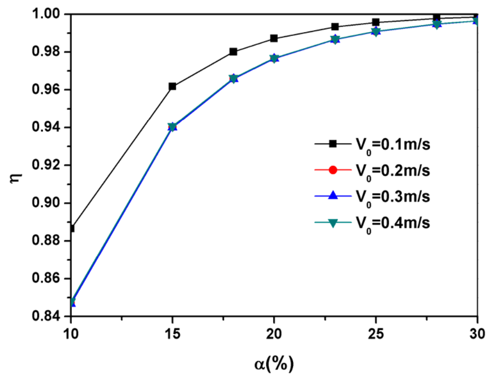

Fig.3 The collection efficiency of metal fibrous felt vs. α

4. Effect of fiber felt thickness on capture efficiency

The thickness of fiber felt is one of the factors affecting the collection efficiency. When the filling rate is 25% and the fiber diameter is 15 μm, the collection efficiency of fiber filter materials with fiber felt thickness of 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0mm under different filtration rates is calculated. The calculation results are shown in Figure 4. It can be seen that the collection efficiency increases nonlinearly with the increase of metal fiber felt thickness, and H is in the range of 0.1~0.5mm, The growth rate of capture efficiency is fast, but the growth rate is decreasing. After the thickness is greater than 0.5mm, the influence of thickness on capture efficiency is no longer significant. Comparing the change curves of four different filtration rates, it can be found that the other three curves are basically the same except $V_0 = 0.1m/s$ they are significantly larger than the other three curves. The reason is the same as the effect of filtration rate on the capture efficiency of different porosity, which will not be repeated here.

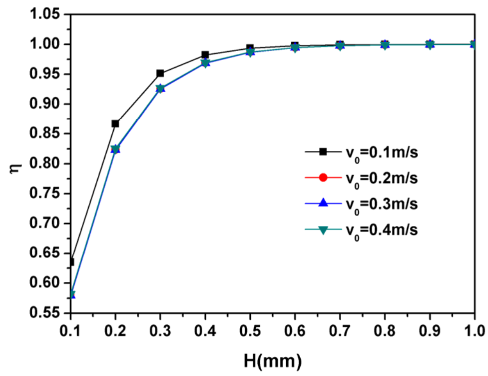

Fig.4 The collection efficiency of metal fibrous felt vs. thickness of the felt

5. Effect of fiber diameter on capture efficiency

When the filling rate is 25% and the thickness of the fiber felt is 0.54mm, the fiber diameter of the fiber felt is 3, 5, 8, 10, 15, 20, 25, 30, 35 and 40 μm respectively. The calculation results are shown in Fig. 5. It can be seen that the collection efficiency decreases nonlinearly with the increase of the fiber diameter of the metal fiber felt, because when the filling rate and the thickness of the fiber felt are unchanged, The fiber length per unit area is inversely proportional to the square of the fiber diameter, that is, the larger the fiber diameter is, the smaller the fiber length per unit area is, which leads to the reduction of fiber filter material capture efficiency. In the range of D_f>15μm, the reduction rate of capture efficiency is faster and increasing. In the range of D_f<15μm, the effect of fiber diameter on capture efficiency is no longer significant. Comparing the four curves under different filtration rates, it can be found that the other three curves are basically the same except $V_0 = 0.1m/s$ the capture efficiency is significantly greater than the other three curves. The reason is the same as the effect of filtration rate on the capture efficiency of different porosity, which further proves the importance of reducing the filtration rate to the following.

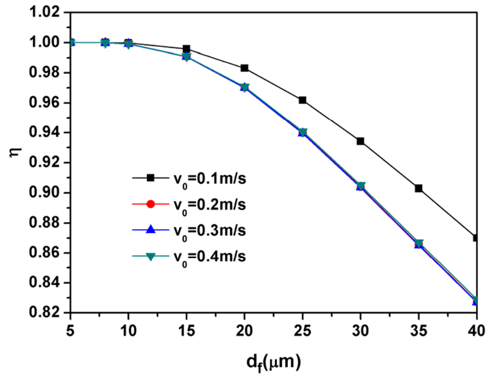

Fig.5 The collection efficiency of metal fibrous felt vs. diameter of fibre

6. Conclusion

Based on the filtration efficiency of a single metal fiber calculated by the traditional single fiber interception, inertia and diffusion capture theoretical model, this paper theoretically calculates and analyzes the effects of filter material structural parameters such as porosity, fiber felt thickness and fiber diameter on the steady-state capture efficiency under different filtration speeds. The research shows that the capture efficiency increases nonlinearly with the increase of metal fiber felt filling rate, but the growth rate decreases, When the filling rate is greater than 25%, the effect of filling rate on capture efficiency is no longer significant. With the increase of H, the capture efficiency increases nonlinearly. When H is in the range of 0.1 ~ 0.5mm, the capture efficiency increases rapidly, but the growth rate is decreasing. When the thickness is greater than 0.5mm, the influence of thickness on the capture efficiency is no longer significant. With the increase of the fiber diameter of the metal fiber felt, the capture efficiency decreases nonlinearly. In the range of D_f>15μm, the capture efficiency decreases faster and the reduction speed is increasing. In the range of D_f<15μm, the effect of the fiber diameter on the capture efficiency is not significant. Reducing the filtration rate below 0.1m/s can effectively improve the capture efficiency of filter material. The research results provide a theoretical basis for the selection of structural parameters of metal fiber felt filter material.

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