Simulation Research on Particulate Matter Filtration of a HVAC Vehicle

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Abstract. In this paper, a HVAC assembly for a domestic automotive air conditioner is studied. The 3D modeling and fluid simulation of the HVAC assembly are carried out. The flow of the gas-solid two-phase flow in a certain concentration of PM 2.5 is studied, including the velocity distribution of the upper surface of the filter element and the trajectories of the internal fluid and particles are analyzed. According to the simulation results, the unreasonableness of the existing HVAC assembly structure is found and the optimization suggestion is put forward.

Introduction

Automotive air conditioning HVAC assembly refers to the unit installed under the dashboard, it has the function of heating, ventilation, air conditioning [1]. In the HVAC system, the air conditioner filter has the main function of filtering and purifying the air outside the vehicle [2]. There are many factors affecting the filter performance of the air conditioner filter, including the ambient temperature, humidity, the type of filter, etc. In addition, the structure of the filter fluid environment is also an important factor [3]. In this paper, HVAC assembly and PM 2.5 as the research object, the internal fluid simulation are conducted.

Establishment of Finite Element Calculation Model

Geometric Model and Meshing

In this paper, 3D modeling software Pro/E is used to model HVAC assembly, the HVAC assembly overall three-dimensional model is shown in Figure 1.

![Figure 1. HVAC three-dimensional model.](image)

Due to the complexity of the model, it needs to be simplified before meshing. After the internal small parts are deleted and modified and the impeller of the fan is simplified, models of different parts are divided into blocks in order to get the more reasonable results of the meshing on quantity and quality. Figure 2 is the meshing model divided in Workbench.
Mathematical Model  \( k - \epsilon \)

The flow in the HVAC assembly of a car air conditioner belongs to the turbulent flow \(^4\). In this paper, the standard two-equation model is used and the governing differential equation is as follows.

Continuity equation

\[
\frac{\partial u_j}{\partial x_j} = 0
\]  \(1\)

Momentum equation

\[
\frac{\partial u_j u_i}{\partial x_j} = f_i - \frac{1}{\rho} \frac{\partial p}{\partial x_i} + \frac{\mu}{\rho} \frac{\partial^2 u_j}{\partial x_j \partial x_i}
\]  \(2\)

Energy equation

\[
\frac{\partial T u_j}{\partial x_j} = \frac{\lambda}{\rho c_v} \frac{\partial^2 T}{\partial x_j \partial x_i} + \frac{\phi}{\rho c_v}
\]  \(3\)

\(k\)  equation

\[
\frac{\partial k u_j}{\partial x_j} = \frac{\partial}{\partial x_j} \left( \frac{v_i}{\sigma_k} \frac{\partial k}{\partial x_j} \right) + v_i s - \epsilon
\]  \(4\)

\(\epsilon\)  equation

\[
\frac{\partial \epsilon u_j}{\partial x_j} = \frac{\partial}{\partial x_j} \left( \frac{v_i}{\sigma_\epsilon} \frac{\partial \epsilon}{\partial x_j} \right) + (c_1 v_i s - c_2 \epsilon) \frac{\epsilon}{k}
\]  \(5\)

where \( \phi, s, v_i \) is

\[
\phi = \mu \left( \frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j} \right) \frac{\partial u_i}{\partial x_j}
\]  \(6\)

\[
s = \left( \frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j} \right) \frac{\partial u_i}{\partial x_j}
\]  \(7\)

\[
v_i = \frac{C_p k^2}{\epsilon}
\]  \(8\)
The main parameters of the above formula $U_i$, average speed(m/s); $P$, pressure (pa); $k$, kinetic energy (J); $\varepsilon$, dissipation; $\rho$, density (kg/m$^3$); $v$, viscosity(m$^2$/s); $C_1$, $C_2$, $C_\mu$, $\sigma_k$, $\sigma_\varepsilon$ are all constants: $C_1 = 1.44$, $C_\mu = 0.09$, $\sigma_k = 1.0$, $\sigma_\varepsilon = 1.3$.

**Boundary Conditions and Model Settings**

After the model is imported into the CFD software FLUENT, the boundary conditions, physical properties, model parameters, etc. need to be set.

Boundary conditions include inlet and outlet boundary conditions and wall boundary conditions. Inlet boundary conditions is selected as velocity inlet, and the value is obtained from the experimental measurements. Outlet boundary conditions is the pressure outlet, due to the connection with the atmosphere, so static pressure is zero $^5$. Blower section is reduced to a closed cylindrical wall, which can be set as a moving wall to simulate the impact on the surrounding fluid. All other fixed boundaries are set as slip-free sheer condition.

The HVAC assembly of fluid and discrete phase for the physical parameters set fluid and solid to maintain the default parameters, respectively, air and aluminum. Next, the inlet of the particulate matter is set to select anthracite particulate matter, when it comes to the gravity sedimentation of atmospheric particulate matter, the general take the particle density of 2000kg / m$^3$, the other parameters by default $^6$.

The filter part is set as porous zone, the viscous resistance coefficient and inertial resistance coefficient can be calculated by the filter pressure-drop wind speed test $^7$. Calculated by the correlation formula, the viscous resistance coefficient and inertial resistance coefficient are $2\times10^7$ and 800 m$^{-1}$ respectively.

**Analysis of Simulation Results**

**The Inlet Velocity Distribution of the Filter**

The uniform distribution of the inlet velocity of the filter can effectively improve the service life and filtration efficiency of the filter $^8$. Therefore, the velocity profiles of the upper surface of the filter at three inlet wind speeds are output in this paper, as shown in Fig. 3~5. In order to facilitate the comparison of the distribution of the three cases the degree of uniformity, the display of the range set to the same value, the velocity of the cloud are displayed in the range of 4 m/s.

![Speed distribution at the weed speed 0.9 m/s.](image1)

![Speed distribution at the weed speed 1.4 m/s.](image2)
Figure 5. Speed distribution at the weed speed 1.7 m/s.

Observe the velocity distribution of the upper surface of the filter corresponding to the three kinds of air inlet velocity. As the inlet air velocity increases, the unevenness of velocity distribution is magnified. In all three cases, there is a long section of low velocity zone to the right of the filter velocity profile (corresponding to the air intake side of the model). As a result, an area of the filter cannot be effectively utilized, the area with greater speed impact can be damaged more rapidly, and its dust growth rate will be much larger than that in the low speed area, so that the overall performance of the filter decline \([9]\).

**Flow Field and Particle Movement in HVAC**

Select the inlet velocity of 1.7 m/s situation and analyze the flow and particle trajectory of the internal movement at this wind velocity. It can be seen from the Fig. 6 and Fig.7 that there are vortices below the air inlet (above the filter), in front of the middle connecting section, and near the air outlet. The air flow rate is low and the flow becomes cluttered. Due to the driving of the air flow, the basic movement tendency of the particles is the same as that of the air fluid and remains in the swirling zone.

At the same time, the eddy current into the air inlet is the cause of the uneven velocity distribution of the air inlet of the filter.

Figure 6. Flowing trajectory line in HVAC.

Figure 7. Particles trajectory line in HVAC.
Structure Optimization Recommendations

From the analysis of the flow field and particle trajectories, there are three obvious swirling zones in the existing HVAC. On the one hand, the existence of eddy current area will consume the flow energy, reduce the air volume of the air conditioner and increase the power consumption of the whole vehicle\(^{[10]}\), on the other hand, it also causes the no uniformity of flow, especially the eddy flow in the inlet section makes the velocity distribution of the filter inlet not Ideal, the retention of particulate matter, resulting in low utilization of the filter and dust distribution unevenly. Therefore, we propose the following improvements to the three unreasonable structures in the hope of obtaining better liquidity.

1) For the structure of the inlet section can consider two kinds of optimization ideas. On the one hand, the angle of the air inlet can be adjusted under the installation space permitting. The air inlet of the existing structure is substantially perpendicular to the surface of the filter so that the vortex flow is formed. It is suggested to reduce the angle between the two surfaces to make the flow more stable. On the other hand, a diversion device can be added to the wall between the air inlet and the filter to assist the air flow to the filter inlet face and achieve greater and more uniform velocity

2) The middle connecting section can be considered to change the original cross-section structure form, cut the runner within the allowable range, and remove the part generating the vortex. For the connection rigidity problem, the connecting arm can be added outside the runner to improve the section stiffness.\(^{[11]}\)

3) The vortex generated in the outlet section is mainly due to the complexity and distortion of the channel shape. It may be considered to change the position of the outlet so that the airflow can be blown perpendicularly to the outlet and minimize the curve encountered in the flowing process

Conclusion

In this paper, by finite element simulation and experiment, the distribution of fluid and particulate matter inside a HVAC structure of a certain automobile is studied. In order to improve the performance of the filter, the eddy current problem of the existing flow is found, and the optimization proposal of the structure is put forward.

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