Numerical simulation of the influence of a internally suction type air curtain to refrigerated truck's heat preservation performance

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Abstract. Refrigerated truck as the research object, using the CFD numerical simulation software simulate the dynamic temperature field of refrigerated truck with a internally suction type air curtain, it emphatically analyzes the influence of the export velocity of the internally suction type air curtain to the refrigerated truck's heat preservation performance when door is opened. The results show that the suitable export velocity of the air curtain can improve the insulation performance of the refrigerated truck, but when the export velocity is too large, the opening of the air curtain not only can not improve the heat preservation performance of refrigerated truck, but aggravate the heat and mass exchange between inside cold air and outside hot air. From the perspective of energy saving, researching the best export velocity of air curtain to insure that refrigerated truck has the best heat preservation performance, which will has great significance to the refrigerated truck's energy-saving design.

1. Introduction

Refrigerated truck is an important link of cold chain. According to the characteristics of supply chain in China, refrigerated truck will be frequently opened when use, so the internally temperature of refrigerated truck will has large fluctuation, which is bed for food preservation. In order to solve this problem, the common handling method is setting plastic strip curtain or setting an air curtain at the door.

Air curtain has long been used in the places such as cold store, refrigerated cabinets, in which to cut off large temperature difference between inside air or outside air of the refrigerated trucks. Nan Xiaohong[1] and Foster[2,3]found that air curtain's parameters such as nozzle width, outlet angle, jet velocity have obvious effect on the performance and efficiency of air curtain by numerical simulation. Xu Zhengben[4]discussed the influence factors about the air curtain of the refrigerated cabinets .Liu Jinghui[5] studied the influence of external suction type air curtain to refrigerated truck's heat preservation performance , the results show that there is the best export velocity of air curtain makes the refrigerated truck's heat preservation performance best. Tso[6] used the method of experiment to study the heat and mass transfer characteristics in the body of a refrigerated truck for cases without an air curtain, with a fan air curtain and with plastic strip curtain. The results show that the side door internally suction type air curtain has obvious effect of heat preservation and energy saving. In the domestic, the air curtain was applied to the refrigerated truck in a preliminary stage, this article will do further research about internally suction type air curtain's dynamic temperature distribution and flow field around the truck distribution when the door is opened in a short time.

2. A physical model

Using the refrigerated truck as the research object and establishing a simplified refrigerated truck body physical model, as shown in Fig. 1. The container size of refrigerated truck is 3.1 m $\times$ 1.52 m $\times$1.52 m (length $\times$width $\times$height), the thickness of the carriage wall is 0.15 m, the back door size of refrigerated truck is 1.52 m$\times$ 1.65 m (the back door is opened completely). The simplified model is not considering the influence of the cabin to the refrigerated cabinet, and the 6 surface of refrigerated trucks expose to the environment directly. There is an evaporator inside the refrigerated truck which near the cabin, and the size of the evaporator is 0.41 m × 0.62 m ×0.62 m. The evaporator supplies cold air horizontally towards the back of the body with an average velocity of 3 $m{\bullet}s^{-1}$, the temperature of the cold air is 253 k, and there is an air return inlet at the bottom of the evaporator. A tubular air curtain machine is equipped in the top of the refrigerated truck where upper the back door, the size is 1.52 m × 0.2 m ×0.2 m, and it supplies air vertically towards bottom with a certain velocity. Besides refrigerated truck and air curtain, the computational domain also need to consider the external environment, and the external environment simulation size is 6.1 m ×3.52 m × 3.52 m.

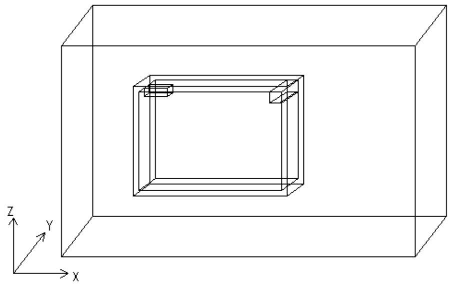


Fig. 1 The simplified model of the refrigerated truck body

3. Numerical methods

3.1. Control equations

In this paper, the study flow field about the refrigerated truck and the external environment is a three-dimensional, unsteady, incompressible turbulent flow included heat and mass transfer process. The process of the core problem is to solve the fluid flow control equations. The heat and mass transfer of the inside cold air with outside hot air satisfied the equation of conservation of mass (1), the equation of conservation of momentum (2), the equation of conservation of energy (3). Turbulence model is κ - ε model, therefore, it also includes the turbulent energy κ equation and the dissipation rate ε equation.

$$\frac{\partial \rho}{\partial t} + \nabla(\rho U) = 0 \quad (1)$$

$$\frac{\partial(\rho u)}{\partial t} + U \bullet \nabla(\rho u) = \nabla(\mu \nabla u) + S_u + \nabla P \quad (2)$$

$$\frac{\partial(\rho T)}{\partial t} + U \bullet \nabla(\rho T) = \nabla(\frac{\lambda}{C_P} \nabla T) + S_T \quad (3)$$

Where the ρ is the air density ($kg{\bullet}m^{-3}$), U is the air velocity ($m{\bullet}s^{-1}$), $U = u\vec{i} + v\vec{j} + w\vec{k}$, S_u is the generalized source term, P is the pressure (Pa), T is the temperature($^{\circ}C$), λ is the coefficient of thermal conductivity of the air($W/(^{\circ}C{\bullet}m)$), c_p is the specific heat at constant pressure of the air, S_T is the source term.

3.2. Numerical method and meshing

In order to adapt to the requirements in this paper, the numerical method use SIMPLE algorithm, and also because the air is incompressible fluid in simulation, so considering the Boussinesq hypothesis, and considering buoyancy lift and gravity. With hexahedron mesh, the mash is localized encryption near the evaporator calculation domain and the air curtain calculation domain, encryption parts of the grid size is 0.04 m, other parts of the grid is divergent sparse distribution, so that the calculation precision and the accuracy of solution can be ensured .

3.3. The boundary conditions

In this numerical model, the influence of the internally goods to the flow field is ignored, and also regarding all walls of refrigerated truck as an adiabatic walls. This is a transient process of the simulation, and the time is 1 min. The calculating temperature of refrigerated truck is 253 k, the evaporator air velocity is 3 m/s, the calculation temperature of outside environment air is 303 k .Outside environment area boundary conditions are the outflow boundary condition. For all the wall boundary conditions, the velocity is handled to without sliding conditions, the wall temperature values of the refrigerated truck is according to the temperature of air in the refrigerated truck.

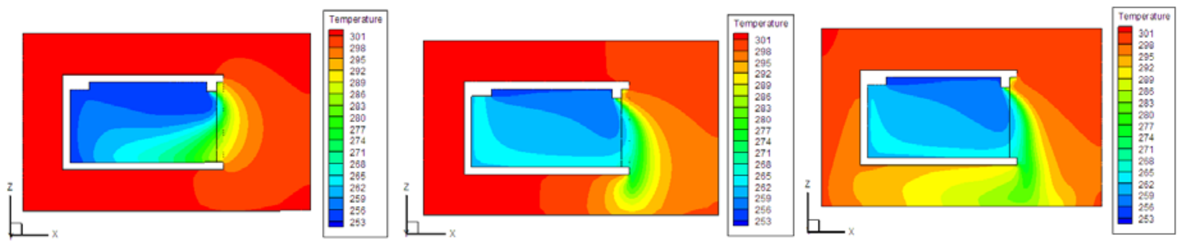
4. The simulation result and analysis about the dynamic temperature distribution of the refrigerated truck

4.1. The dynamic temperature distribution in cases that without an air curtain, an air curtain with a velocity of 0.5 $m{\bullet}s^{-1}$, 3 $m{\bullet}s^{-1}$.

In order to observe expediently, intercepting Y = 0.76 m plane to analyze the temperature distribution internally the refrigerated truck.

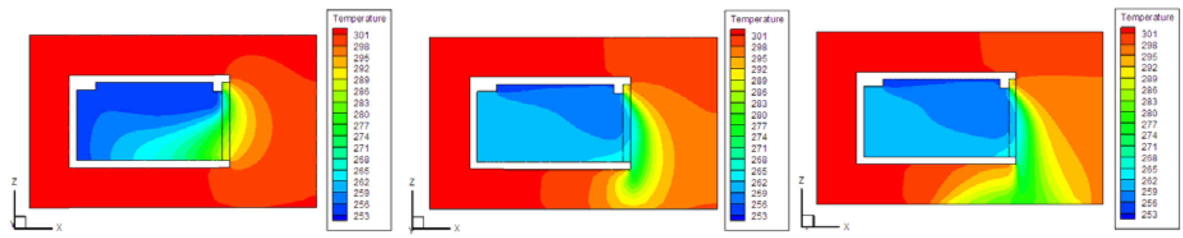
From Fig. 2 (a1), (a2) and (a3), we can see that in all three cases, the temperature near the bottom area of the refrigerated truck's door is higher than other areas when the door just opened. This is because on the one hand, part of the cold air's temperature rise for heat and mass transfer with the outside high temperature air. On the other hand, cold air with a certain velocity rolled and absorbed outside high temperature air into the truck, that caused temperature of the bottom air of the truck rose. In addition, from the Figure.2 ,we also can see that, in all three cases, in the 40 seconds and 60 seconds ,the average temperature of the truck is higher than it in 10 seconds; When the air curtain with an velocity of 0.5 $m{\bullet}s^{-1}$,the average temperature of the air in refrigerated truck is lowest ,and the temperature distribution is also more uniform compared with other two kinds of circumstances. This indicated that air curtain with a velocity of 0.5 $m{\bullet}s^{-1}$ can make refrigerated truck has a good heat preservation performance. But when the air curtain with a velocity of 3 $m{\bullet}s^{-1}$, the average temperature is even higher than the case without an air curtain. So when air curtain with an improper velocity, the air curtain not only cannot make refrigerated truck with a good heat preservation performance, but aggravate the heat and mass transfer between inside cold air and outside hot air, and then the average temperature rapidly rise.

(1) The dynamic temperature distribution in case that without an air curtain



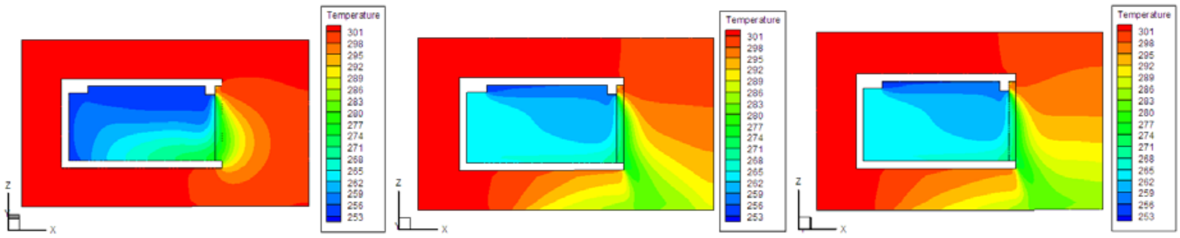
（a1）10s （b1）40s （c1）60s

(2) The dynamic temperature distribution in case that the curtain with a velocity of 0.5 $m{\bullet}s^{-1}$



（a1）10s （b1）40s （c1）60s

(3) The dynamic temperature distribution in case that the curtain with a velocity of 3 $m{\bullet}s^{-1}$



（a1）10s （b1）40s （c1）60s

Fig. 2 The dynamic temperature distribution for the cases that without an air curtain , and an air curtain with a velocity of 0.5 $m{\bullet}s^{-1}$ and 3 $m{\bullet}s^{-1}$.

4.2. The impact analysis about the velocity of air curtain to the refrigerated trucks heat preservation performance

The size of the velocity of an internally suction type air curtain has a great influence on the refrigerated truck's heat preservation performances. When cold air blow out from the outlet of air curtain, some outside hot air will be rolled and absorbed ,and mix with inside cold air and then return to the inside refrigerated truck. The greater the velocity is the more hot air will be rolled and absorbed from the outside world. But when the velocity is less than the best velocity, jet flow of air curtain cannot completely closed the door, so there is a best velocity about air curtain.

As shown in Fig. 3 is the change curve that average temperature of the air in the refrigerated trucks with the change of the time under different air curtain velocity. We can see from the Fig. 3 that with the increase of air curtain export velocity, the average temperature of the air in the refrigerated trucks firstly decreased, and then increased, when the velocity of the air curtain is greater than 2 $m{\bullet}s^{-1}$, the average temperature of the air in the refrigerated trucks even more high than the cases without air curtains, in that case the air curtain completely out of action effect.

Fig. 4 described the change curve that average temperature of the air in the refrigerated trucks with the change of different air curtain velocity. From the Figure 4, we can see that when air curtain with the velocity of 0.5 $m{\bullet}s^{-1}$, the average temperature of the air in the refrigerated trucks is lowest , is about 259.8 K, so in this case ,the best export velocity of the air curtain is about 0.5 m/s.

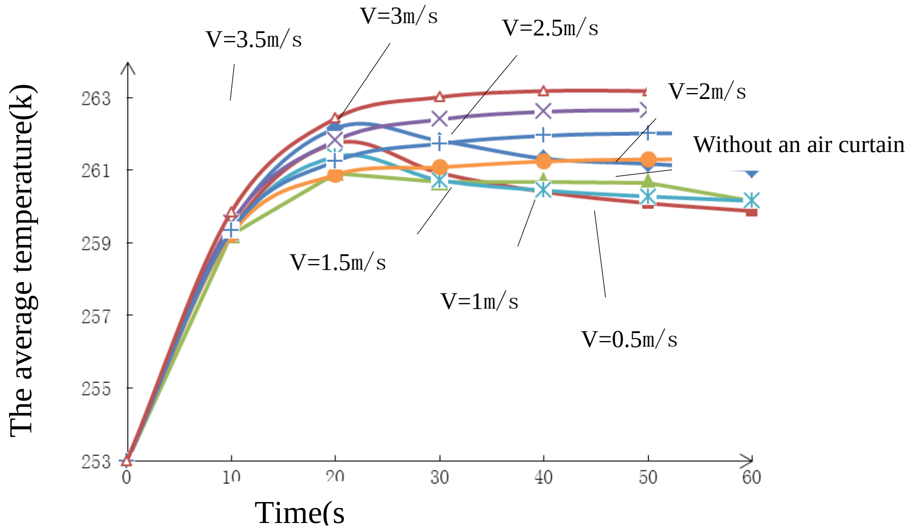


Fig. 3 The change curve that the average temperature of the air in the refrigerated trucks changes over time under different air curtain velocity

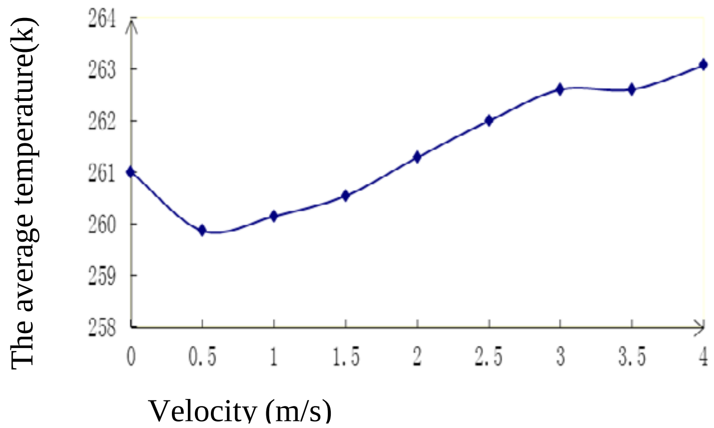


Fig. 4 The change curve that average temperature of the air in the refrigerated trucks with the change of different air curtain velocity

5. Conclusion

Through the simulation analysis about dynamic temperature distribution in the refrigerated truck of without an air curtain, with an air curtain and different air curtain export velocity, shows that when air curtain's velocity is suitable, the air curtain can make refrigerated truck has a good heat preservation performance, and the velocity of the air curtain had a great influence on the refrigerated truck's heat preservation performance.

1. When the refrigerated truck's door is opened, in the case of without air curtain or with an air curtain, average temperature of refrigerated truck increases rapidly at first, then the rate of increase slow down, and finally tends to a stable value.

2. When the refrigerated truck's evaporator is opened, and there is an air curtain with a suitable velocity, then the average temperature of the refrigerated truck rose slowly than the case without an air curtain. Finally the stable temperature is also lower than the case without an air curtain, and the temperature distribution internally of the refrigerated truck is also more uniform. When the velocity of the air curtain is suitable, the air curtain can make refrigerated truck has a good heat preservation performance.

3. When the velocity of the air curtain is higher than a certain value, air curtain open not only can not improve the heat preservation performance of refrigerated truck, but aggravate the heat and mass transfer between inside cold air and outside hot air.

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