EFFECT OF ENVIRONMENTAL CONDITION ON VENTILATION RATE OF SPECIAL STANDARD BARS

by

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Original scientific paper
DOI: 10.2298/TSCI1405493M

Standard bar of ventilation is the equipment extensively used in the tobacco industry to calibrate the variety of testing machines. The bar's performance that is usually affected by ambient conditions is numerically studied in this paper. Firstly, the geometry of standard bar is obtained by an optical microscopic 3-D measurement. Then, Solidworks is used to build the 3-D model of standard bar and Gambit is used to mesh the model. Finally, the performance of standard bar under variant ambient conditions is analyzed by Fluent. Compared with the experimental data, the numerical results are found to be quite accurate, and it is found that the ventilation rate increases linearly as temperature rise and decreases non-linearly with the growth of pressure.

Key words: *ventilation rate, standard bar, environmental conditions, numerical simulation*

Introduction

Rate of ventilation is defined as the ratio of the flow rate of air inhaled through an unignited cigarette paper to that inhaled by mouth. The rate of ventilation can tremendously influence the quality of cigarette and consequently becomes one of the key contents in the tobacco industry. The previous studies revealed that the toxic substance in mainstream smoke released by cigarette can be significantly reduced by adjusting the ventilation rate of cigarette [1-3]. Wei *et al*. found that the increment of the ventilation rate of cigarette can improve the filtration efficiency of tip [4]. Adam *et al*. characterized the design variations of filter by using the single photon ionization-time-of-flight mass spectrometry [5].

The ventilation rate of cigarette is a major physical parameter in the cigarette production. Most previous work cared only how the ventilation influences the consequence of the burning cigarette. This paper finds a new path, which study ventilation from the metrological viewpoint. On the market, various ingenious inventions are derived to accurately measuring cigarette ventilation rate with highly accuracy. Such as SVRG-C cigarette ventilation rate instrument, SODIM D49+D49X8. The ventilation rate standard bars have a known and stable value under standard conditions, and then they can be used to calibrate all sorts of the machines. However, their values are usually influenced by the environmental conditions, and the aim of this paper is to computationally study the influence caused by temperature and pressure under the certain rang.

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(a)

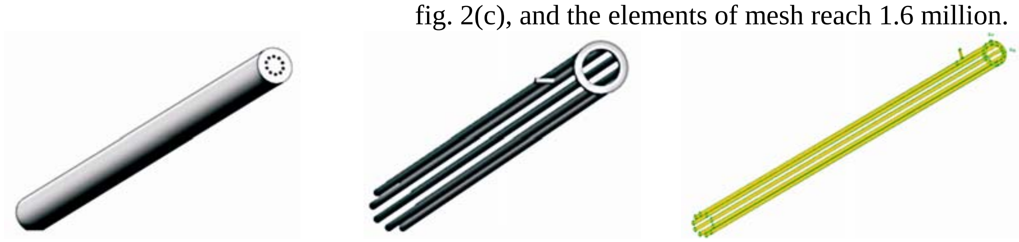
(b)

Figure 1. Schematic view of ventilation rate standard bar

Computational model

The standard bar is a cylinder with ten cylindrical axial capillaries. Several standard bars have one lateral hole, which is usually close to outlet. This paper studies a bar which has only one lateral hole. The schematic diagram of the standard bar is shown in fig. 1. Figure 1(a) is the side view and fig. 1(b) is the end view of the standard bar, from them it can be noticed that the capillaries are arranged in a circle. The capillaries are very tiny, and the side hole is even smaller, which can hardly been identified by naked eyes. So the Optical Gaging products are used to measure their scales to establish the 3-D model of the standard bar.

Figure 2 shows the 3-D model and the domain of fluid modeled by the software Solidworks. Through the software Gambit, the model of calibration equipment is meshed by the structured mesh as shown in fig. 2(c), and the elements of mesh reach 1.6 million.



(a) (b) (c)

Figure 2. The 3-D model, the domain field, and the mesh of ventilation rate standard bar

In numerical simulations, gas flow was assumed to be compressible and steady. The relative humidity is 50%, the range of temperature is 288.15-303.15 K, the ratio of the inlet pressure and outlet pressure is ranging from 0.7 to 1.1, and the operating pressure is defined as $1.01325 \cdot 10^5$ Pa. Governing equations are given by the conservation forms of mass, momentum and energy using the realizable S-A turbulence model.

The experiment showed that two ambient parameters, temperature T and pressure P, seriously affected the airflow characteristics. Rasmussen [6] developed a calculation procedure for these two parameters. By curve fitting R^2 = 99.9%, for temperature, 288.5-303.5 K, for humidity, H, 50% and for pressure, 70-111 kPa, two simplified formula to represent dynamic viscosity η and density ρ covering wide ranges of ambient conditions are:

$$\eta(T, H) = 4.103 \cdot 10^{-6} + 4.587 \cdot 10^{-8} T - 4.944 \cdot 10^{-10} H \tag{1}$$

$$\rho(P, T) = 2.032 \cdot 10^{-1} - 7.137 \cdot 10^{-4} T + 2.281 \cdot 10^{-5} P - 3.728 \cdot 10^{-8} TP \tag{2}$$

Results and discussion

An experiment has been conducted to demonstrate the feasibility and correctness of the numerical simulation. The experiment is carried out in this operation condition: humidity, 53.19%, pressure, 84716 Pa, temperature, 295.13 K. The experimental result shows that the ventilation rate reaches 18.57%, while the numerical simulation results under the same environment conditions is 18.7494%, which means that our numerical simulation is feasible.

Through numerical simulation, the flow rate at the outlet is obtained. Figure 3(a) shows the velocity magnitude in the outlet under standard atmospheric pressure. It can be found that the maximum flow velocity occurs on the capillary which is connected with the lateral hole. The flow rates at other holes are roughly the same. In addition, it can also be found that the largest flow velocity occurs on the center of the capillary. Figure 3 (b) illustrates the contour of pressure on the outlet, and it is much similar to the figure of velocity magnitude at the outlet. It can also be found that the velocity distributions and the internal pressure distributions under different ambient conditions are very similar.

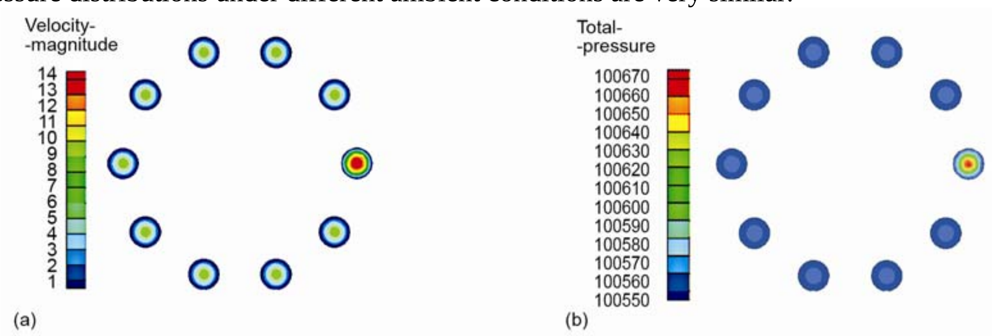


Figure 3. The velocity magnitude in the outlet and the contour of static pressure in the outlet

Twelve points are calculated from 288.15 K-303.15 K. The relationship between ventilation rate and the temperature is illustrated in fig. 4. From fig. 4, it can be found that the ventilation rate of the bar increases obviously with the growth of ambient temperature. Moreover, the ventilation rate V can be represented by a linear equation of temperature T as:

$$V = 3.9143 \cdot 10^{-4} T + 6.0756 \cdot 10^{-2} \tag{3}$$

The relationship between the ventilation rate and the ambient pressure is illustrated in fig. 5 while ambient temperature remains constant. It can be found that the ventilation rate V of the bar decreases obviously with the growth of ambient pressure P. Moreover, the ventilation rate can be represented by an equation of ambient pressure:

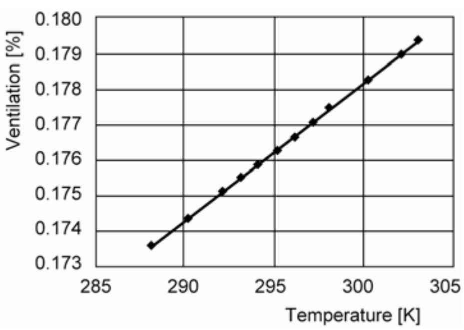


Figure 4. The relationship between ventilation rate and temperature

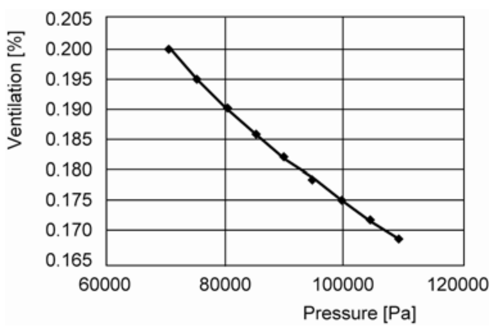


Figure 5. The relationship between ventilation rate and ambient pressure

$$V = 4.62236 \cdot 10^{-12} P^2 - 1.54304 \cdot 10^{-6} P + 0.285106 \tag{4}$$

Conclusions

The performance of standard bar of ventilation is usually influenced by the ambient conditions including temperature, atmospheric pressure, and the present numerical results reveal that the simulation method is effective and accurate in calculating the ventilation rate. Moreover, it's found that the calibration process is sensitive to the ambient temperature and the atmospheric pressure. Two equations expressing the relationship of the ambient conditions and flow rate of standard bar of ventilation have been derived through the numerical simulation. Consequently, the present results are helpful for the research of the influencing factors of ventilation rate.

Acknowledgments

Supports given by the National Natural Science Foundation of China under Grant Nos. 11472260 and 11202203 are gratefully acknowledged.

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Paper submitted: March 20, 2014
Paper revised: April 8, 2014
Paper accepted: July 12, 2014