# EFFECTS  OF  AMBIENT  CONDITIONS  ON  MULTI-CAPILLARY VENTILATION  RATE

by

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*As a major physical parameter for the tobacco industry, the ventilation rate of ciga-rette should be measured reliably. Theoretical and numerical investigation on ef-fects of ambient conditions (e. g., cumulative flux of ozone and additional pressure drop) on the ventilation rate was carried out. It was found that the standards exhib-ited a non-linear airflow component, which explains why additional pressure drop has an effect on the calibrated value, and had low sensitivity to cumulative flux of ozone.*

Key words:  *cumulative flux of ozone, pressure drop, ventilation rate standards*

## Introduction

Cigarette ventilation rate is a major physical parameter for the tobacco industry and should be measured reliably with specific equipment. Standards composed of several glass cap-illary tubes associated in parallel are used to calibrate equipment in different companies. Each ventilation rate standard must have a known and stable value, which is usually calibrated by drawing constant total volumetric flux 17.5 ml/s through it, and the resulting lateral flux is then measured to get its ratio to 17.5 ml/s. Some studies [1-3] revealed that the toxic substance in mainstream smoke released by cigarette can be significantly reduced by adjusting the ventila-tion rate of cigarette. However, ventilation rate values are influenced by the ambient conditions during calibration, *i. e.* by cumulative flux of ozone (CFO) and additional pressure drop, atmo-spheric pressure, $P$, temperature, $T$, and relative humidity, $RH$, of air. While the relations be-tween ventilation rate and the latter three parameters have been well studied [4], how CFO  and additional pressure drop affect ventilation rate will be investigated here.

## Computational model

The standard bar comprised of ten glass capillary tubes with one lateral capillary tube is shown in fig. 1, and the optical gaging products are applied to measure its physical dimension to establish the 3-D model of the standard bar.

As shown in fig. 2, the ten parallel lines represent ten glass capillary tubes with same dimensions, and the vertical line represent one lateral capillary tube. When total air flow flux,

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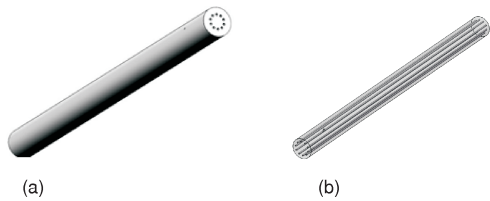THERMAL SCIENCE: Year 2016, Vol. 20, No. 3, pp. 855-857

**Figure 1. (a) physical model and (b) transparent model of ventilation rate standard comprised of ten glass capillary tubes with one lateral capillary tube**
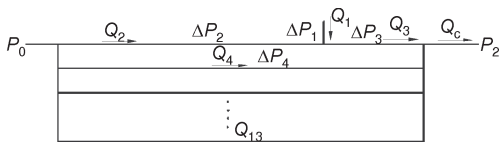


**Figure 2. Schematic model of ventilation rate standard**

$Q_c$, through these tubes, pressure drop, $\Delta p$, will be induced by viscous and inertial resistance, and the relation between the flux through every capillary tubes, $Q_i$, and total air flow flux, $Q_c$, can be expressed:

$$Q_3 \quad 9Q_4 \quad Q_C; \quad Q_1 \quad Q_2 \quad Q_3;$$
$$C_1 Q_1^2 \quad C_2 Q_2^2; \quad C_1 Q_1^2 \quad C_3 Q_3^2 \quad C_4 Q_4^2$$

where $C_1 \quad \dfrac{8\rho}{\pi^2 d_i^4} \quad \dfrac{64}{Re_i} \dfrac{l_i}{d_i} \quad K$, and $K \quad 135$.

Then, $C$ code is programmed and validated to get the gas flow through the ventilation rate standard bar. In the simulations, the fluid was assumed to be impressible gas and steady. The present simulations adopted the following conditions: humidity 60%, pressure 101325 Pa, and temperature 295.15 K. Some experiments showed that two ambient parameters, temperature and pressure, seriously affected the airflow characteristics. Rasmussen developed a calculation procedure for these two parameters [5]:

$$\eta(T,H) \quad 4.103\, 10^{6} \quad 4.587\, 10^{8}\, T \quad 4.944\, 10^{10}\, H \tag{1}$$

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

## Numerical simulation and results analysis

Experiments have been carried out under the standard condition (humidity 60%, pressure 101325 Pa, and temperature 295.15 K) and get the ventilation rate 26.47% for the ventilation rate with specified dimensions, while the numerical simulation results under the same environment conditions is 28.34%, which means that the theory and code are validated and can be used for subsequent numerical simulation.

Figure 3 shows the relation between CFO and absolute deviation of ventilation rate, the data marked with, ▲, shows that result under standard CFO is 17.5 ml/s. However, when CFO has been used for some time, its critical flux maybe changes and vary from 17.0-18.0 ml/s, at the same time, it can be found ventilation rate decreases with the growth of CFO flinearly, but the value of absolute deviation of ventilation rate is almost within 0.3%, which means that although CFO has been used for long time, it can be used to calibrate ventilation rate standards if its critical flux's deviation is less than 0.5 ml/s.
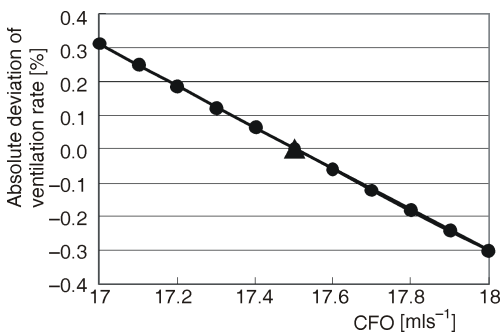


**Figure 3. The relation between CFO and absolute deviation of ventilation rate, here (▲) represents standard CFO 17.5 ml/s, while (●) represents non-standard CFO**

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As shown in fig. 4, the data marked with, ▲, shows that result under standard lateral tube with diameter 0.48 mm and length 1.1 mm, which corresponds the pressure drop 677.974 Pa under the standard ambient conditions. However, when the lateral tube's dimensions' changes, its pressure drop will also change and cause the deviation of ventilation rate from that of standard conditions. When additional pressure drop is in the range from –3 to 3 Pa, it can be found that ventilation rate decreases with the



**Figure 4. The relation between additional pressure drop and absolute deviation of ventilation rate**

growth of additional pressure drop linearly, and the value of absolute deviation of ventilation rate is almost within 0.3%, which means ventilation rate is sensitive to additional pressure drop, and the dimensions of lateral tube are very important parameters and should be protected carefully during experiments.
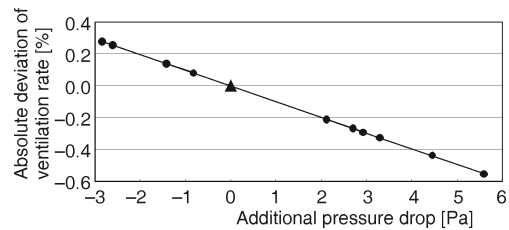
## Conclusion

The ventilation rate of the specified ventilation rate standards is influenced by the ambient conditions including CFO and additional pressure drop. The code based on C language was used to get the value of flux in every capillary tubes. The present numerical results reveal that the simulation method is effective and accurate in calculating the ventilation rate. Moreover, it's found that ventilation rate decreases with the growth of CFO linearly, however, although CFO has been used for long time, it can be used to calibrate ventilation rate standards if its critical flux's deviation is less than 0.5 ml/s. In addition, the ventilation rate is sensitive to additional pressure drop, and the dimensions of lateral tube are very important parameters and should be protected carefully during experiments.

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