THE EFFECTS OF AMBIENT CONDITIONS ON THE CALIBRATION OF AIR FLOW PLATE STANDARDS

by

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The volume flow rate measured by air flow plate is influenced by the ambient conditions during the calibration. A series of numerical examples are conducted for the relationship and the outcomes demonstrated that the calibration is quite sensitive to the atmospheric pressure and the ambient temperature, but insensitive to relative humidity. The experiment model has been applied to calibration results with wide ranging ambient conditions. In conclusion, the results of this study demonstrate the benefits to calibration data of minimizing the effects of ambient conditions.

Key words: *air flow plate, ambient condition, numerical simulation*

Introduction

The permeability of cigarette paper is a major physical parameter in the cigarette production. In the process of testing permeability of cigarette paper, equipments calibrated with volume of flow standards must be used and the reliability of measurement is vital. Benson and Hawk [1] devise a small flowrate device to measure the micro flow rate. Kim *et al.* [2] studied the critical flow nozzle both by the computational and experimental way. The standards are a series of air flow plates; each of them is an iron plate with a hole in the center. Each plate must have a known and stable value defined under standard conditions. Based on the original model shown in fig. 1, numerical simulations had been done to find the relationship between the flowrate and ambient conditions.

Computational model

The picture of plate and fixture are showed in fig. 1. Figure 1(a) is the two-dimensional size of the fixture; fig. 1(b) is the original model of the fixture and fig. 1(c) shows the model of plate. Fluent, a common CFD software, has been adopted to simulate the gas flow through the calibration equipment. In the simulation, the fluid was assumed to be ideal-gas which is compressible and steady. The present simulation adopted to the following conditions: the relative humidity is 50%, the range of temperature is 15 to 30 °C, 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. The governing equations are given by the conservation forms of mass, momentum, and energy using the realizable S-A turbulence model. An UDF program

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(a) (b) (c)

Figure 1. Picture of air flow plate and fixture

had been written and adopted to calculate the internal flow field of calibrating progress which would be more close to the actual situation.

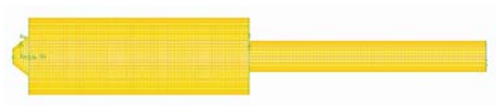

Figure 2. The mesh of flow field

Through the GAMBIT software, the model of calibration equipment has been meshed by structured mesh method and the mesh distribution is displayed in fig. 2. The elements of mesh reach 35 million. The flow field, where has drastically changed, is meshed refined.

The experiment showed that two ambient parameters, temperature T and pressure P, affected the airflow characteristics seriously. Rasmussen [3] has developed a calculation procedure for these two parameters from which, by fitting (R2 = 99.9%), we deduced two simplified formula to represent dynamic viscosity η and density ρ covering wide ranges of ambient conditions in the participating laboratories: for temperature, 15-30 °C, for humidity, H, 50%, and for pressure, 70-111 kPa:

$$\eta(T, H)[\mathrm{Pa\cdot s}] = 4.103\cdot 10^{-6} + 4.587\cdot 10^{-8}\cdot T[\mathrm{K}] - 4.944\cdot 10^{-10}\cdot H[\%] \tag{1}$$

$$\rho(P,T)[\mathrm{kgm^{-3}}] = 2.032\cdot 10^{-1} - 7.137\cdot 10^{-4}\cdot T[\mathrm{K}] + 2.281\cdot 10^{-5}\cdot P[\mathrm{Pa}] - \\ - 3.728\cdot 10^{-8}\cdot T[\mathrm{K}]\cdot P[\mathrm{Pa}] \tag{2}$$

Referring to gas dynamics, it can be found that the flow field is much similar to a convergent nozzle [4]. Using the stagnation phenomenon theory, the model's correctness can be tested and verified [5]. The mass flow rate of the ideal one-dimensional and isentropic fluid flowing through a nozzle is given by:

$$m_{\max} = \sqrt{\frac{K}{\mathrm{R}T_0}}P_0 A_1 \left(\frac{2}{K+1}\right)^{\frac{1}{2}\frac{K+1}{K-1}} \tag{3}$$

$$u_1 = a_{cr} = \sqrt{\frac{2K}{K+1}\mathrm{R}T_0} \tag{4}$$

where u_1 is the velocity where the radius is the minimum. The analytic model is only valid for the critical flow (at Mach number equal to 1), the maximum mass flow rate depends on the stagnation pressure (P_0) and the stagnation temperature (T_0).These values must be expressed in absolute units. A_1 is the area of throat, R is 287 J/kgK, the ideal gas constant, and K is the adiabatic index, 1.4 for the air.

Results and discussion

Two flux points were calculated. Through numerical simulation, the flowrate in the field was obtained. Figures 3(a) and (b) shows the velocity magnitude of air flow plate when the ratio of the ambient pressure to standard atmospheric pressure is 0.7 and 1, respectively. From fig. 3 it can be found that the largest flow velocity occurred on the outlet of the air flow plate. The closer the upper wall, the smaller the speed was. There are dramatic changes at the exit. Comparing to the pressure ratio is 1; the velocity was higher when the pressure ratio is 0.7. But it can also be found that the velocity distributions under these two different ambient pressures are very similar.

Figures 4(a) and (b) show the contour of static pressure in the flow area when the ratio of the ambient pressure and standard atmospheric pressure is 0.7 and 1, it can be seen that at each inlet of the flow field, the pressure drop was small and at the outlet, the pressure drop was sharp. The distinct pressure gradient in the outlet indicated that the pressure loss was mainly produced by the mutations tube. Moreover, the internal static pressure distributions of two situations were consistent.

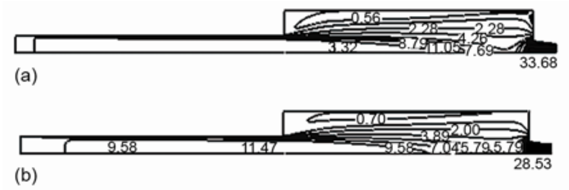

Figure 3. The velocity magnitude in the flow field

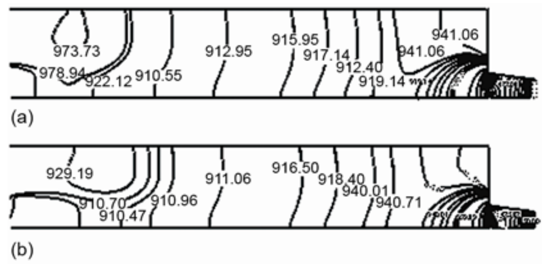

Figure 4. The contour of static pressure in the flow field

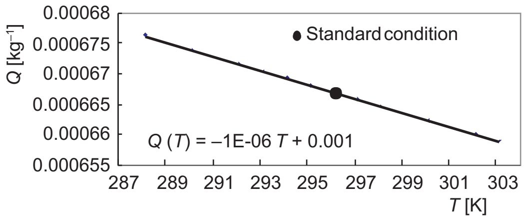

Figure 5. The relationship between mass flow and temperature

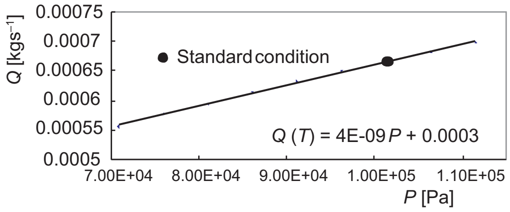

Figure 6. The relationship between mass flow and ambient pressure

Twelve points were calculated from 288.15 K to 303.15 K. The relationship between mass flowrate and temperature is illustrated in fig. 5. From fig. 5, it can be found that the mass flowrate in the outlet decreased obviously with the growth of temperature setup in inlet and outlet. Moreover, the mass flow could be represented by the linear equations of temperature: $Q(T) = T{\cdot}10^{-6} + 0.001$. Also, the point under standard condition is also on the straight line.

Nine points were calculated and the relationship between mass flow rate and ambient pressure is illustrated in figure 6. The temperature of inlet and outlet was maintained a fixed value. It can be found that the mass flow rate in the outlet increased obviously with the growth of ambient pressure. Moreover, the mass flow rate could be represented by the linear equations of ambient pressure: $Q(T) = 4\text{P}\cdot10^{-9} + 0.0003$. The point under the standard condition is also on the straight line.

Conclusions

The flowrate of air flow plate is influenced by the ambient conditions including temperature, relative humidity of air, and the atmospheric pressure. The present numerical results reveal that the simulation method is effective in calculating the mass flowrate. Moreover, we also find that the calibration progress is quite sensitive to the atmospheric pressure and the ambient temperature, but insensitive to relative humidity. Consequently, the present results are helpful for the research of the influencing factors of flow rate.

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