

Ventilation Characteristics of Modeled Compact Car Part 2 Estimation of Local Ventilation Efficiency and Inhaled Air Quality

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ABSTRACT

In order to evaluate the ventilation characteristics of car interior, a model experiment was performed. Part 1 deals with the air flow properties in a half-scale car model. In this paper, a trace gas experimental method equipped with Flame Ionization Detector (FID) systems is introduced to examine the local ventilation efficiency and inhaled air quality in the car, which was ventilated at a flow rate of 100 m³/h and kept in an isothermal environment of 28°C in the experiment. Here, ventilation efficiency was evaluated by means of the Scales for Ventilation Efficiencies (SVEs), and inhaled air quality in terms of the influences of passive smoke and foot odor was evaluated by means of the Contribution Ratio of Pollution source 1 (CRP1). Therefore, calculation methods using trace gas concentration values were suggested for these indices, which were proposed based on the Computational Fluid Dynamics (CFD) technique. The experimental method will be validated by comparison with the corresponding CFD simulation results. This indicates that the experimental method is precise enough to predict air quality in a car cabin.

1. INTRODUCTION

Air quality in car interior is one of the most important research targets in the field of indoor air quality (IAQ), because our modern personal transport is ever more reliant on various vehicles, and cabins are usually

characterized by their limited, enclosed space and relatively high personal density, conditions which are readily associated with air quality issues. Unfortunately, there are many potential pollutant sources in a cabin, such as volatile organic compounds (VOCs) from the materials, contaminants from passengers and their preferences, and pollutants taken in through the ventilation system. Consequently, it is highly possible for IAQ problems to arise in such cabins, and may even be more harmful than usual indoor environments in buildings^[1]. Therefore, it is necessary to ensure efficient ventilation and sufficient capacity to remove such pollutants from inside the cabin.

Many researches have been performed in regard to IAQ problems in cabins, and CFD simulation is a useful tool in these studies, thanks to its ease of operation, short development period and lower cost compared to experimental methods^[2]. However, the heating, ventilation, and air-conditioning (HVAC) system is always designed to optimize the thermal and air environments by utilizing a non-uniform distribution of the flow field for a cabin^[3]. In such non-uniform environments, to accurately examine the ventilation conditions and air qualities throughout the whole cabin, experimental examination is surely the most reliable means. Mathur^[4] investigated the tailpipe emissions entering into the vehicle cabin to improve indoor air quality. However, there have been few experimental studies to measure local ventilation efficiency, and inhaled air quality for passengers. This

also means that there is a lack of effective experimental data to validate the CFD simulation results at present. Accordingly, a trace gas experimental method using FID systems was introduced to measure the local ventilation efficiency and passengers' inhaled air quality in this paper.

The local ventilation efficiency will be evaluated by SVEs^{[5] [6]}, and inhaled air quality will be evaluated by CRP1^[7], respectively. Because both of the indices were initially proposed based on CFD techniques, the corresponding calculation methods using the concentration values of the trace gas were suggested for these indices. In this paper, the experimental method was applied for a half-scale car model ventilated with an airflow of 100 m³/h at 28°C, to investigate the local ventilation characteristics in the cabin under isothermal conditions. The experimental results were validated by the corresponding CFD simulation methods. Additionally, horizontal and vertical distributions of SVEs were estimated by CFD.

2. EXPERIMENTAL METHOD

2.1 OUTLINE OF CAR MODEL

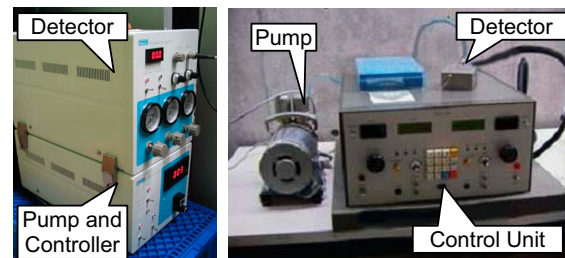
The scale model as shown in Figure 1, which was provided by the Society of Automotive Engineers of Japan (JSAE), was used in the experiment. The model is made of transparent acrylic resin and measures 1,450 mm × 700 mm × 900 mm. For more details, refer to Part 1. There were four seats: a driver's seat, front passenger seat, rear seat 1, and rear seat 2 in the cabin. It had four supply openings and two exhaust openings. The supply openings were front-mounted with dimensions of 60×50 mm² (W×H). The exhaust openings were side-mounted rearward with dimensions of 50×100 mm² (W×H). Every opening was connected to orifice tube with blower at its foot to control the flow rate.



Figure 1. Half-scale car model

2.2 OUTLINE OF FID SYSTEMS

The trace gas concentration was measured using two kind of Flame Ionization Detectors (FID) respectively. One was a TCH-2A made by Technica Co., Ltd. and the other was an R5033 made by Ohkura Riken Co., Ltd. as shown in Figure 2. These FIDs measure the concentration of organic gases by detecting the electrical current of negative ions generated ($\text{CH} + \text{O} \rightarrow \text{CHO}^+ + \text{e}^-$) during incineration (oxidation), the amount of which is proportional to the quantity of carbon atoms included in the gas. THC-2A is characterized for its response time of just 1 ms, because it has a sampling device together with the detector, and its sensitivity ranges from 10 ppm to 10,000 ppm. Its response can be used to measure the age of the air and the residual lifetime of the air using the step-down method^{[8] [9]}. However, it may have a considerable influence on the flow field when placed in the cabin due to natural convection caused by the high temperature of the detector and its size. On the other hand, R5033, whose detector is in the instrument body, can only measure using the steady state or constant method, because it samples the gas through a tube. However, it can take samples with little influence on the flow field. Its sensitivity ranges from 10 ppm to 10,000 ppm.



a) R5033

b) TCH-2A

Figure 2. FID systems

3. ITEMS AND METHODS OF MEASUREMENT

The trace gas concentration was measured to evaluate the local ventilation efficiency and inhaled air quality as follows:

1. Age of air for each supply opening (SVE3*)
2. Contribution ratio of each supply opening (SVE4)
3. Residual lifetime of air for each exhaust opening (SVE6*)
4. Contribution ratio of each exhaust opening (SVE5)
5. Contribution ratio of pollution source 1 (CRP1)

Moreover, the overall age of air (SVE3) and overall residual lifetime of air (SVE6) were calculated from the results of the above terms.

Trace gas was discharged at a rate of 8 l/min into the orifice tube connected to a supply opening in order to calculate SVE3* and SVE4. The gas was sufficiently mixed with the air by a fan and flowed into the model. The gas concentration was measured at the points where

passengers breathe, using the step-down method for SVE3*, and the constant method for SVE4. Then SVE3 was calculated from the results of the two. They were calculated using Equations (1), (2) and (3).

$$SVE3_{X,i}^* = \int_0^{\infty} \frac{C_X(t)}{C_X(0)} dt \quad (1)$$

$$SVE4_{X,i} = \frac{C_X}{C_s} \quad (2)$$

$$SVE3_X = \sum SVE3_{X,i}^* \cdot SVE4_{X,i} \quad (3)$$

In the case of SVE6* and SVE5, the trace gas was generated at a rate of 4 l/min at the seated breathing position and measured concentration at each exhaust opening. SVE6* was measured using the step-down method and SVE5 using the constant method. SVE6 was calculated from the results of the two. They were calculated using Equations (4), (5) and (6).

$$SVE6_{X,i}^* = \int_0^{\infty} \frac{C_e(t)}{C_e(0)} dt \quad (4)$$

$$SVE5_{X,i} = \frac{C_e \cdot Q_e}{C_X \cdot Q_X} \quad (5)$$

$$SVE6_X = \sum SVE6_{X,i}^* \cdot SVE5_{X,i} \quad (6)$$

Additionally, the influence of passive smoke was examined, assuming that a smoker was on the car. Case 1 assumes that the driver smokes, while Case 2 assumes that the passenger in rear seat 1 smokes. It was assumed that the cigarette smoke traced the airflow, and the tracer gas was generated at a rate of 4 l/min at the position of the smoker, and the gas concentration was measured at the other seats. In this experiment, the influence of buoyancy from the cigarette's heat and that of the weight of the smoke particles were not taken into account. In order to examine the inhaled air quality, the CRP1 of the gas was calculated by Equation (7).

$$CRP1 = \frac{C_{in} \cdot Q_{in}}{C_p \cdot Q} \times 100 \quad (7)$$

When calculating CRP1, it was assumed that the passengers breathe at a rate of 8 l/min. ^[10]

In the same way, foot odor from the driver was assumed, and the influence that the odor had on the other passengers' breathing was examined. The location of respiration and source of foot odor are shown in Figure 3.

4. OUTLINE OF EXPERIMENT

The experiment was carried out in August 2006, in a climate chamber at the Institute of Industrial Science, the University of Tokyo. Figure 4 illustrates a simplified scheme of the experimental system using the step-down method with TCH-2A.

The total flow rate was set to 100 m³/h. The model volume was about 0.706 m³, therefore the air exchange rate was about 142 h⁻¹. Each supply opening was adjusted to supply 25 m³/h, and each exhaust opening was adjusted to exhaust 50 m³/h. The temperature of the supply air was kept at 28 °C.

The trace gas used in this study is ethylene (C₂H₄). We prefer C₂H₄ as the trace gas mainly because of its similar density to air ^{NOTE1}. For the tracer gas method with R5033, the measurement time was 2 minutes (1,200 data), which was averaged overall. When using TCH-2A, the measurement time was 2 minutes (12,000 data), which was averaged overall.

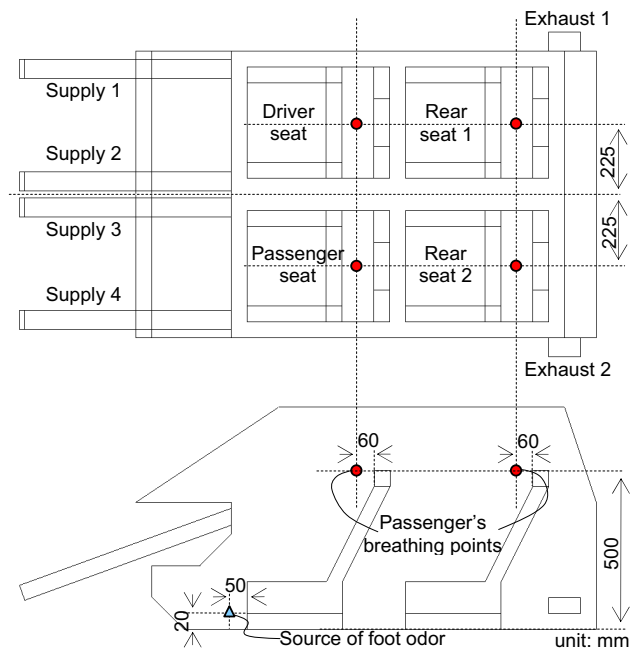


Figure 3. Measurement points for ventilation efficiency

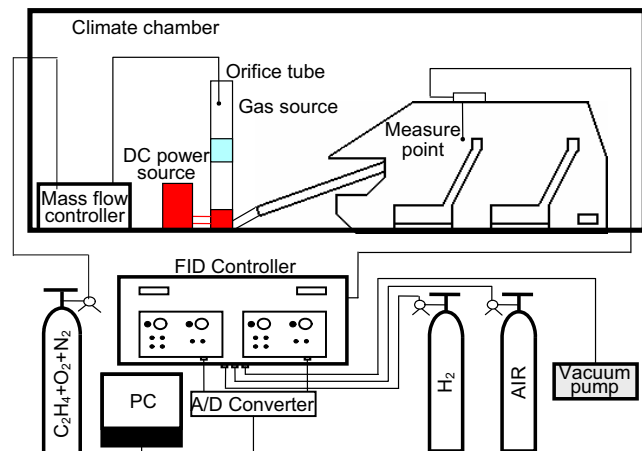


Figure 4. The experimental set-up (Case for measurement of SVE3*)