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Effect of Air Circulation on Particles Concentration in a Car Compartment in Tropical Country

[1]Mohamad Asyraf Othoman, [2]Mohd Sahril Mohd Fouzi, [3]Shaharin Anwar Sulaiman

[1,2]Department of Mechanical Engineering, Politeknik Ungku Omar, 31400 Ipoh, Perak, Malaysia.
[3]Faculty of Mechanical Engineering, Universiti Teknologi Petronas, Bandar Seri Iskandar,31750, Perak Malaysia.

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ABSTRACT

Particulate matter is one of the most dangerous components in indoor air. Particles are small enough to infiltrate nasal, sinus, and bronchial passages where they can affect passenger's health and comfort. In this work, air quality related to the level particles' concentration PM_{10} in a car's compartment was studied to know how driving conditions and a car's ventilation system can affect air quality. The particle entering the car's compartment through air registers and in the occupants' breathing zone was measured using an aerosol monitor particle counter. It was found that the concentration of PM_{10} achieved maximum value when cars following heavy vehicle in fresh air ventilation mode. The PM_{10} concentration was slightly stable in recirculation mode and gradually increases when driver select fresh air mode. The particulate surrounding air in highly polluted industrial area are not affected the air concentration in the car compartment in leisure driving in fresh air ventilation mode. This study gave an insight on suitable interval for interchange of air recirculation and fresh air modes in order to maintain acceptable level of comfort in a car.

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INTRODUCTION

Particulate matter in a car compartment can be unhealthy. Particles are small enough to infiltrate nasal, sinus, and bronchial passages where they can affect passenger's health and comfort. However, people often spend long time in the automobile during commuting and leisure. Therefore indoor environment in car compartment could be regarded as a kind of residential environment that is equipped with HVAC system (Yokoyama, Iwashita, Yoshinami, Nagayama, & Nakagawa, 2007). Notable characteristics of a car compartment include, for example, sensitiveness to the atmospheric environment and functionality for driving performance.

Study on the quality of air indoor has been very limited; e.g. by Yokoyama *et al*. (Yokoyama, Iwashita, Yoshinami, Nagayama, & Nakagawa, 2007) and Nakagawa *et al*. (Nakagawa, Iwashita, Yoshinami, Nagayama & Yokoyama, 2007). On the other hand, there are plentiful of reports available on study of indoor air quality in buildings; for example in the work by Sulaiman *et al*. (Sulaiman, Isa, Raskan, & Harun, 2013) and Harun *et al*. (Harun, Buyamin, Othman, & Sulaiman, 2013).

Particulate matter (PM) is the word used for a mixture of solid particles and liquid droplets suspended in the air. These particles originate from a variety of sources, such as power plants, industrial processes, and diesel trucks, and they are formed in the atmosphere by transformation of gaseous emissions. Their chemical and physical compositions depending of location, time of year, and weather. Particulate matter is composed of both coarse and fine particles. Coarse particles (PM_{10}) have an aerodynamic diameter between 2.5 mm and 10 mm. They are formed by mechanical disruption (e.g. crushing, grinding, abrasion of surfaces); evaporation of sprays, and suspension of dust. The lifetime of PM_{10} is from minutes to hours, and its travel distance varies from below 1km to 10 km. Praml *et al*. (Praml & Schierl 2000) indicated that particulate concentrations inside vehicles originated from external sources.

The objective this work was to assess the air quality in car compartment as a result of choice of air circulation mode and driving condition. The study was conducted by measuring concentration of particles PM_{10} in a traveling car under tropical weather.

Corresponding Author: Mohamad Asyraf Othoman, Department of Mechanical Engineering, Politeknik Ungku Omar, 31400 Ipoh, Perak, Malaysia.
E-mail: masyraf@jkm.puo.edu.my

2. Methodology:

Test with driven automobile was conducted using the experimental automobile on the road. The vehicle under testing is a sedan car with an estimates compartment volume of 3 m^3. The condition of concentration particles PM_{10} in the car compartment were measured when the car is used in the city (commuter driving) and sub city (leisure driving), in Ipoh, Malaysia, where the weather is all year round hot and humid. The distance also covered institution, city and sub city, industrial and highly polluted industrial area and was approximately 70 km at an average speeds 50 km/h for commuter driving and 80 km/h for leisure driving. The outside average temperature during the test is 33.6°C and relative humidity 52%, which was held between 16.00 hr and 18.30 hr in the month of March.

In this testing, the car was occupied with two people, including the driver. The set point temperature of the car compartment's air-conditioner was set at 25°C. The average supply air flow rate from each of air-conditioner outlets, located on the dashboard, was measured to be 3.8 m^3/min. Two ventilation modes were selected; i.e. 100% recirculation mode and intermittence of recirculation and fresh air modes. The car window keep closed while driving and the measuring instrument DUSTTRAK II Model 8532, with concentration range up to 150 mg/m^3 was placed on the middle of the front seat about 35 cm from the floor. The data was analyzed by the software provided by the instrument's manufacturer.

Different than centralized air-conditioning systems for buildings, which allow slight fresh air intake for return air system, most car air-conditioning systems do not allow such feature while in recirculation mode. Consequently, under the air recirculation mode the car interior would experience accumulation in the content of hazardous gas due to exhalation by the occupants in the fully confined space.

The different modes tested in this study are shown in Table 1. Also shown in Table 1 are the durations and actual times of the tests. Commuter driving refers to the condition during city driving when the automobile tends to frequently stop and slow due heavy traffic. The intermittence test refers to regular switching between fresh-air mode and re-circulation mode. The intermittence mode started with fresh air at 16.00 hrs and followed by switching to recirculation and 100% fresh air at a 15 and 10-minute interval. The total duration for commuter intermittence test was 60 minutes. Leisure driving refers to that when the automobile frequently have constant acceleration with speed average 70 km/h. During this period, re-circulation mode was selected for the first 30 minutes, and then fresh air mode was selected. The total duration for leisure intermittence test was also 60 minutes. The particle's concentration was also measured when the car was driven from low to highly polluted industrial areas within 30 minutes under two modes of ventilation; i.e. fresh air and recirculation.

Table 1: Test conditions.

Ventilation	Test	Duration (minutes)	Time
Intermittence	Commuter:		
	a. Recirculation	15	16.00 hr – 17.00 hr
	b. Fresh air	10	
	c. Recirculation	10	
	d. Fresh air	10	
	e. Recirculation	15	
	Leisure:		
	a. Recirculation	30	17.30 hr – 18.30 hr
	b. Fresh air	30	
100% Fresh air	a. Commuter	30	15.37 hr – 16.07 hr
	b. Leisure	30	
100% Recirculation	a. Commuter	30	16.40 hr – 17.10 hr
	b. Leisure	30	

RESULT AND DISCUSSION

A. PM_{10} concentration for intermittence of recirculation and fresh air mode of commuter driving:

The particle's concentrations of PM_{10} as function of time on 27 March 2013 are drawn in Fig. 1. This figure includes the scatter data when the experimental automobile was followed the traffic flow and variety traffic condition. At the beginning of the recirculation mode, the PM_{10} concentration was stable and slightly decreased because the car was still in static condition. When the car stared moving at 16.04 hrs, the concentration started to fluctuate rapidly until the fresh air mode was selected. The maximum value recorded was 0.12 mg/m^3. At between 16.15 hr until 16.25 hr, the air ventilation was set to 100% fresh air mode. The concentrations started to increase rapidly to a maximum value of 0.229 mg/m^3 then decreased to minimum value 0.098 mg/m^3. The high dust concentration was probably related to the large number of traffic during peak hour especially heavy vehicle such as truck and bus.

The recirculation mode was selected again at between 16.25 hr and 16.35 hr and the concentration was rapidly decreased then fluctuated until fresh air mode was selected at 16.35 hr. At between 16.45 hr and 17.00 hr the concentration was slightly decreased because the automobile decelerate heading to institution area.

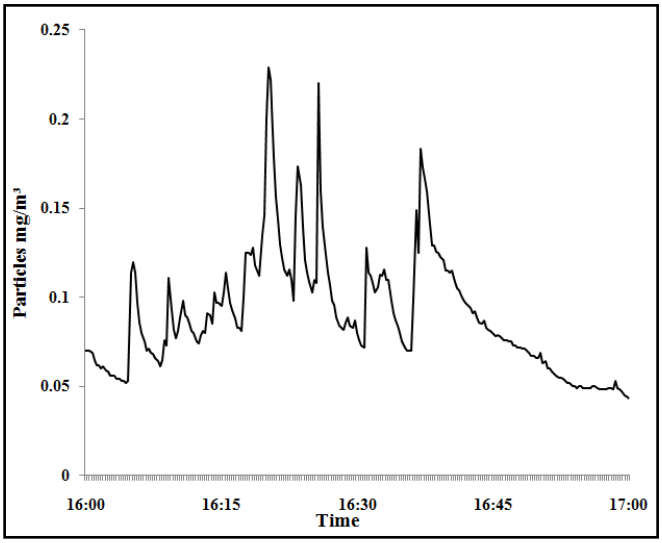

Fig. 1: The particle's concentration of PM_{10} as a function of time on 27 March 2013 in commuter driving.

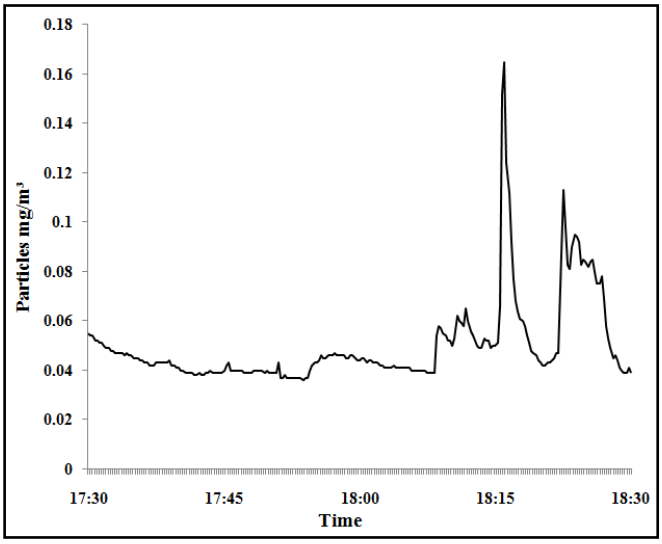

Fig. 2: The particle's concentration of PM_{10} as a function of time on 26 March 2013 in leisure driving.

B. PM_{10} concentration for intermittence of recirculation and fresh air mode of leisure driving:

It is shown in Fig. 2 that the particle's PM_{10} concentration was 0.055 mg/m^3 at the start of the test. During the first 30 minutes in recirculation mode, the particle's concentration was slightly decreased and stable in range of 0.04 mg/m^3 to 0.06 mg/m^3. This was most probably because the car was driven at a constant acceleration and this caused the particles in the car compartment to be less scattered and HVAC system also continuously filtering the air in the automobile compartment.

At between 18.00 hr and 18.30 hr, is a fresh air mode. In the beginning the concentrations of particles is stable then was tending to increased and decreased gradually. At time 18.15 hr the value was rapidly increased and achieved maximum concentration value 0.165 mg/m^3 due the testing automobile follow the heavy vehicle that emitted high concentration of particles from exhaust gas. Then the PM_{10} dust concentration decreased 0.042 mg/m^3 at 18.20 hr when driver applied the brake to increase the gap of the car from heavy vehicle because the unpleasant smell of exhaust smoke.

C. PM_{10} concentration for 100% fresh air mode of commute and leisure driving:

It is shown in Fig. 3, the PM_{10} concentration when the automobile is drive in 100% fresh air in commute and leisure driving. In beginning the concentration is low due automobile is start from institution area then was rapidly increased when the automobile enter the sub city area. The large number of traffic and following heavy vehicles is a factors the concentration reached 0.246 mg/m^3. This can be proofed from the sample data as Fig. 4 that was measured from surrounding air area that the data was achieved 0.246 mg/m^3. The concentration's value of surrounding air is in range 0.110 mg/m^3 and 0.184 mg/m^3.

The vehicle was heading the industrial and highly polluted area with leisure mode and the concentration of PM_{10} that have been measured are at between 0.102 mg/m^3 and 0.155 mg/m^3. Even though, the sample data that have been measured from the surrounding area of industrial showed the surrounding air concentration are pretty high in range between 0.166 mg/m^3 and 0.405 mg/m^3 such as shown in Fig. 5. The value of the concentration between inside and outside automobile compartment are quite different regarding to the HVAC system that has the filter to extract the particle even though the fresh air mode is used. Besides, while the automobile has been static such as waiting for someone, the concentration in the automobile compartment was increased slightly high.

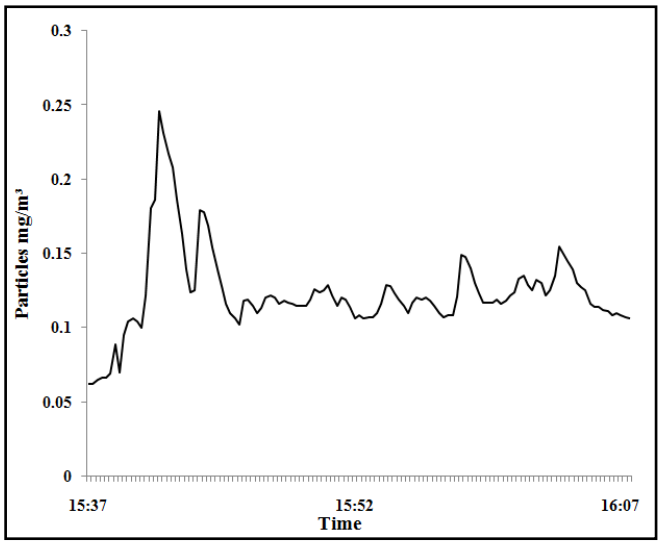

Fig. 3: The particle's concentration of PM_{10} as a function of time on 28 March 2013 in 100% fresh air mode.

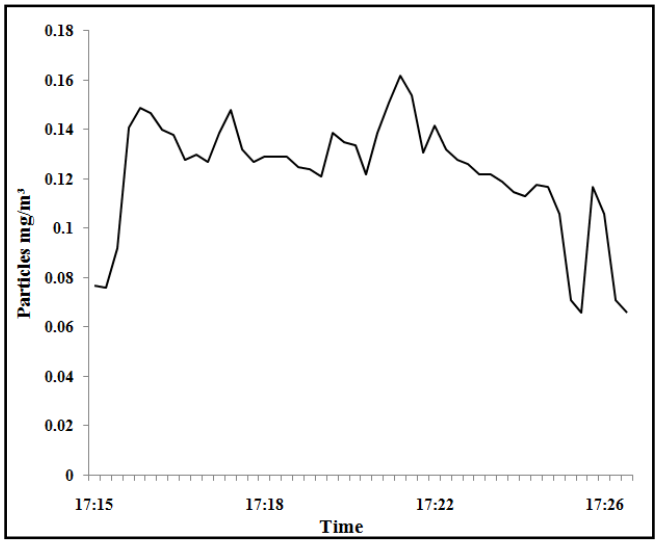

Fig. 4: Surrounding PM_{10} concentration for sub city area.

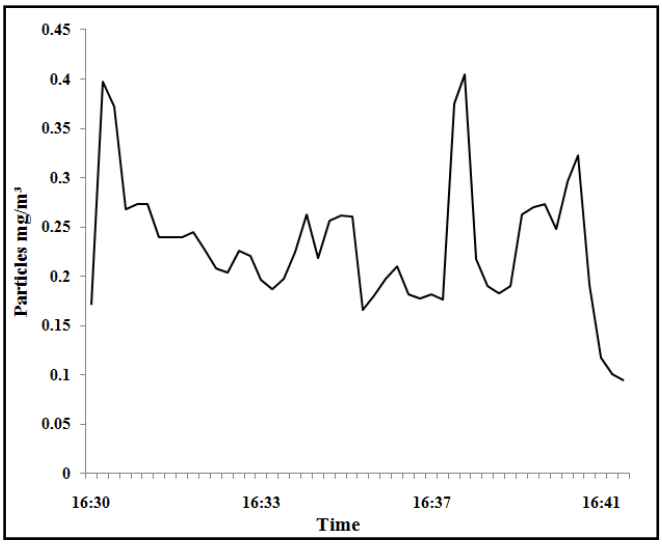

Fig. 5: Surrounding PM_{10} concentration for highly polluted industrial area.

D. PM_{10} concentration for 100% re-circulation mode of commute and leisure driving:

As shown in the Fig. 6, the 100% recirculation mode recorded the concentration start with 0.09 mg/m^3 than was slightly decreased and stable because HVAC system continuously filtering the air in the automobile compartment.

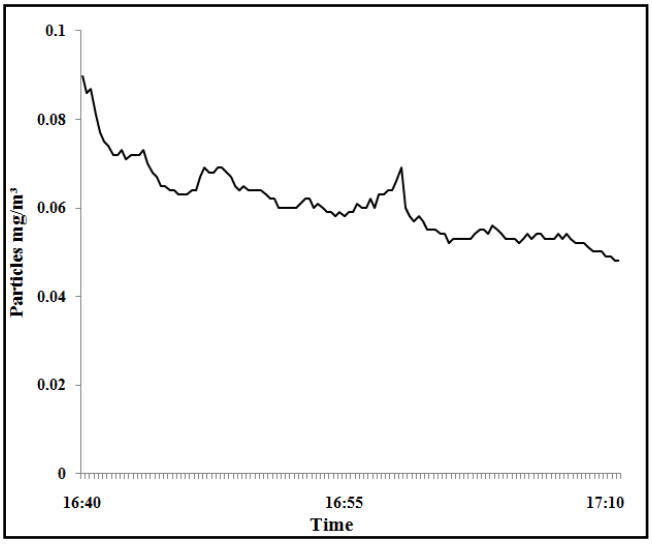

Fig. 6: The particle's concentration of PM_{10} as a function of time on 28 March 2013 in 100% recirculation mode.

Conclusion:

A study on particle's concentrations of a car's compartment was conducted, while the vehicle was traveling on roads. The study was important in assessing the suitability of air condition vis-à-vis passengers' comfort and health. From the study, the following conclusions are made:

- The PM_{10} concentration was observed to be low in the car compartment when ventilation with re-circulation air and fresh air at the start of every journey would be acceptable for healthy indoor environment.
- The rise of PM_{10} concentration can be as high as 0.229 mg/m^3 in just 5 minutes after changing from full recirculation to 100% fresh mode in commuter driving. This implies that 100% fresh mode would result to unhealthy indoor condition. To some extent, this could be a factor contributing to poor drivers' alertness in long distance journeys, apart from fatigue.
- For leisure driving, the PM_{10} concentration was slightly stabled in recirculation mode and gradually increases when driver select 100% fresh air mode then concentration values rapidly increase when testing automobile follow heavy vehicle transport.

- The particulate surrounding air was not affected the air concentration in the car compartment in leisure driving. The concentrations will tendency increase when the vehicle stops at traffic light or waiting because the particle tends to penetrate trough the small cavity of car's compartment.

One important recommendation for passenger's that automobile compartment ventilation is set to intermittence of recirculation and fresh air mode (mixed mode) when leisure driving and use recirculation mode in commuter driving.

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