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TEMPERATURE INFLUENCE ON TOTAL VOLATILE COMPOUNDS (TVOCs) INSIDE THE CAR CABIN OF VISIBLE LIGHT TRANSMITTANCE

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ABSTRACT

In the automotive industry indoor air quality or Vehicle Indoor Air Quality (VIAQ) are caused by various substances emitted from interior materials inside a vehicle. The volatile organic compounds (VOCs) are an example of emitted substances from the interior materials which is harmful to the human body. As stated by previous researches, there is a strong correlation between the total VOCs emission and interior temperature. This occurs due to the solar radiation through the back window glasses, windscreen and side window glasses. This trapped heat can accelerate the melting process of trim materials such as hard plastic and rubber, thus causing the emission of total VOCs (TVOCs). Therefore, reducing the percentage of visible light transmittance (VLT) will help to reduce radiation process. The aim of this study is to investigate the effect of VLT level on TVOCs emission in the vehicle cabin under static condition (parked and unventilated) and operating condition (driving and air-conditioned). For static condition the result shows that the TVOCs concentration linearly decreases whenever the percentage of VLT level decreases. However, for operating condition the percentage of VLT have less significance after 50 minutes driving time. In conclusion, the VLT levels have a strong relationship to the TVOCs concentration despite after a long driving time.

Keywords: VIAQ, TVOC, VLT, static condition and driving condition.

INTRODUCTION

Indoor air quality at micro-environment such as in-vehicle plays an important role because it can cause severe health effects such as headaches, eye irritation, sneeze, lethargy and asthma to the drivers and also passengers [1-4]. Such illness may not only affect the driver's health but also safe driving. Vehicle Indoor Air Quality (VIAQ) is often associated with the concentrations of Volatile Organic Compounds (VOCs) and concentration of fine particulate matter (PM) that are harmful to the human body. Exposure to the VOCs or PM in-vehicle is higher in comparison to other indoor micro-environment or outdoor micro-environment[5]. Praml and Schierl [6] conducted a survey from 1993 to 1996 on PM_{10} concentration inside buses and tramways around Munich. The results obtained show that PM_{10} concentration inside the public transport is 1.7 to 4 times higher than the outdoor environment, measured at the station close to the roadside.

In 2012 the International Organization of Standardization (ISO) enacted measurement standard ISO 12219-1:2012 which is a method of measuring the types and levels of VOCs in vehicle cabin air. VOCs are carbon-based chemical and can exist in indoor or outdoor air and are normally higher in indoor air. Each terms of volatile organic compound has its own purpose, which 'volatile' means that chemicals will be evaporated or can easily mixed with air at room temperature and 'organic' means these chemicals are carbon based. Long term exposure to the volatile organic compound will increases risk to us such as cancer, liver damage, kidney damage and central nervous system damage.

Various kind of chemical substance may be emitted from materials inside the vehicle cabin. Several investigators have measured in-vehicle VOCs concentrations associated with in-vehicle trim materials emission such as hard plastic, rubber, elastomers, synthetic or natural lather, fabrics and fibres [4, 7-9]. Faber *et al*.[8] identified 200 different organic compounds inside the cabin of nine new vehicles with different interior equipment's and materials. In addition, Zhang *et al*.[9] tested the air quality inside 830 new vehicle cabin in static condition at well-ventilated parking and compared the air quality of 20 old car in the same condition. The results show that all compounds were higher inside the new vehicle in comparison to the old ones.

Many studies have measured VOCs during static condition (parking). Investigation of VOCs and total VOCs became more comprehensive when the driving conditions with various operating situations (air-conditioning, naturally ventilated or half window open) are considered. In example, Fedoruk and Kerger [10] used five different sedan vehicles of three different manufactures to evaluate the concentration of individual VOCs and total VOCs (TVOCs). They performed an experiment under static conditions (parked, unventilated) and driving condition (air-conditioned and naturally ventilated) and revealed that under static condition the TVOC level is 4 to 8 times higher than driving conditions.

The TVOCs concentration inside the vehicle cabin was influenced by interior temperature [7, 9-11]. Faber *et al*.[11] reported that the total VOCs increased, from 20 °C to 30 °C by 63.3%, from 30 °C to 40 °C by

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42.7% and from 40 °C to 50 °C by 58.5%. During static condition, the maximum temperature inside the vehicle cabin can range from 46 °C - 76°. When compared to ambient temperature the difference is more than 20 °C[12]. The increase in interior temperature will increase the concentration of airborne chemicals diffusing from interior materials [13] Therefore, it will growth the level of TVOCs, which can cause diverse health effect to the driver and passengers.

The solar radiation enter the vehicle through the glass or wind shield considered to be the most influencing factor of interior temperature to be increase [14]. This will experience the drastic increase interior temperature such as steering wheel, dashboards and seats. Therefore the TVOCs concentration produced by materials emission will increase proportionally. The study carried out in Malaysia by Jasni and Nasir[15], indicate that the maximum interior temperature occurs at dashboard with a maximum temperature can reach 87.5 °C. They proposed three passive methods to reduce the interior temperature i.e. sunshades, ventilators and window tinted and concluded that the window tinted is the most efficient method to reduce the interior temperature. These indicate that the lower the visible light transmittance (VLT) levels the lower solar radiation effect to the in-vehicle cabin.

Thus, the main objective of this study is to investigate the effect of VLT level of tinted film on TVOCs concentrations under the static condition (parking and unventilated) and operating condition (driving and air-conditioned). In Section 2, we describe the details of experimental setup, including the percentage of VLT for each windscreen and glass windows. Subsequently, the experimental procedures are presented in Section 3. Finally, in Section 4, we systematically discuss the dependency of TVOCs concentrations on percentage of VLT

EXPERIMENTAL METHOD

Experimental setup

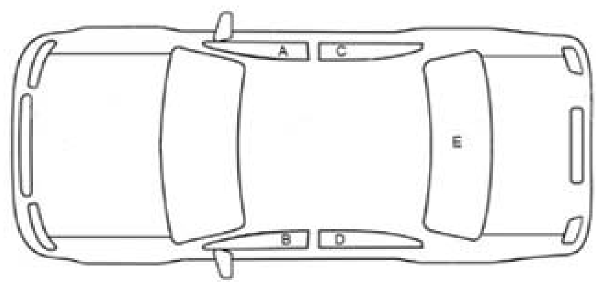
The vehicle used in the present study is a nationally made sedan car as shown in Figure-1a. Figure 1b shows the schematic diagram of the location where the tinted layer is applied. Due to the safety factor during operating condition the windscreen was not tinted. The details of experimental condition were shown in Table-1.

Figure 2 shows the view of instrumentation used in this experiment. It consists of a thermal recorder used to measure the temperature, TVOC instrument to measure the TVOC level and Telaire 7001 to measure the CO_2 concentration, relative humidity and temperature. The thermal recorder was placed at the front and rear passenger cabin by hanging it 20cm from the roof as shown in Figure-3(a) and (b). Whereas the TVOC instrument was placed between the driver seat and the front passenger seat as shown in Figure-4.

Experimental procedure

In this experiment, for both conditions the duration of the data sampling was about 50 minutes with 5 minute intervals and was repeated three times in one day. This experiment was conducted within the Universiti Teknologi MARA (UiTM), Shah Alam area. An experiment was carried out during the equatorial season from the end of February 2015 to mid-May 2015. The experiment was conducted between 9am until 5pm. For static condition (parking condition), the car was parked at the open space car park of Faculty Mechanical Engineering UiTM Shah Alam. For operating condition, all windows were closed and air conditioning was on with constant fan speed. During operating condition the vehicle was driven for 4 to 5 km inside the UiTM campus.

(a)



(b)

Figure-1. An overview of vehicle used in experiment: (a) photographic image of sedan car and (b) schematic diagram of tinted location from top view.

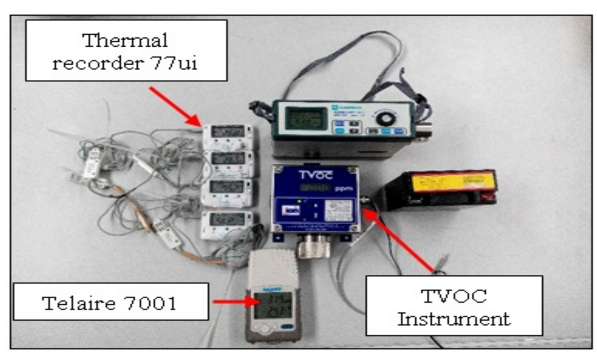


Figure-2. Experimental instrument.

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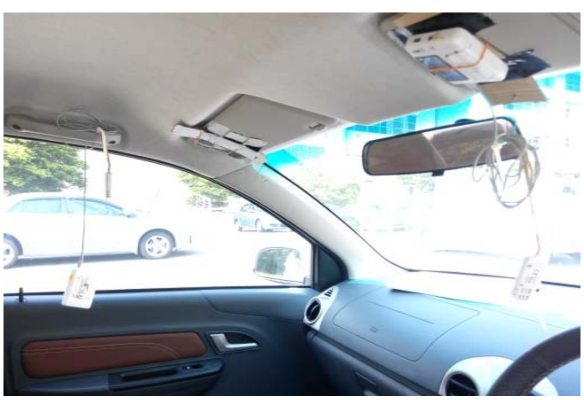
Table-1. Experimental condition.

Case	Operating condition	Measuring Time	Percentage of Visible Light Transmittance (VLT)
SC1	Static condition (Parking and unventilated)	50 min	All window glasses have 70% VLT except windscreen.
SC2			Standard tinted that allowable by Malaysia government. Wind screen 0%, front windows (A & B) 50% VLT, rear windows (C & D) 30% VLT and back window 30% VLT. Location A, B, C, D and E reference to Figure 1b.
SC3			All window glasses have 20% VLT except windscreen
OP1	Operating condition (Driving with fully closed windows and air-conditioning)	50 min	All window glasses have 70% VLT except windscreen.
OP2			Standard tinted that allowable by Malaysia government. Wind screen 0%, front windows (A & B) 50% VLT, rear windows (C & D) 30% VLT and back window 30% VLT. Location A, B, C, D and E reference to Figure 1b.
OP3			All window glasses have 20% VLT except windscreen

(a)



(b)

Figure-3. Setup of thermal recorder: (a) rear compartment and (b) front compartment.

Figure-4. Setup of TVOC instrument and Tolaire 7001.

RESULT AND DISCUSSION

Figure-5 shows the temperature difference during static condition and operating condition. For static condition (*see* Figure-5a) the temperature difference increases linearly as time increased. A lower temperature difference occurred at case SC3 where the percentage of VLT is 20%. However, for case SC1 and SC2 the temperature differences are close to each other. This result was similar to the experimental data obtained by Jasni and Nasir [15]. This indicated that the lower the VLT level, the further the in-vehicle temperature can be reduced.

Figure-5b shows the temperature difference measured during operating condition. The trend of temperature differences against the measurement time shows inconstancies for all three cases. Comparison between static and operating condition shows that a higher temperature difference occurs during parking condition. This may be due to the effect of cooling by air-

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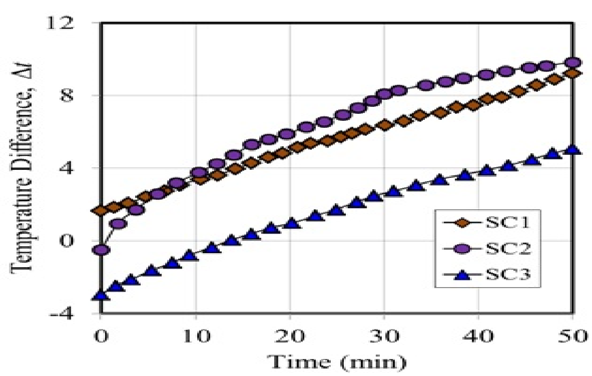
conditioning during operating condition. However, for static condition the hot air is totally trapped inside the vehicle cabin due to unventilated situation.

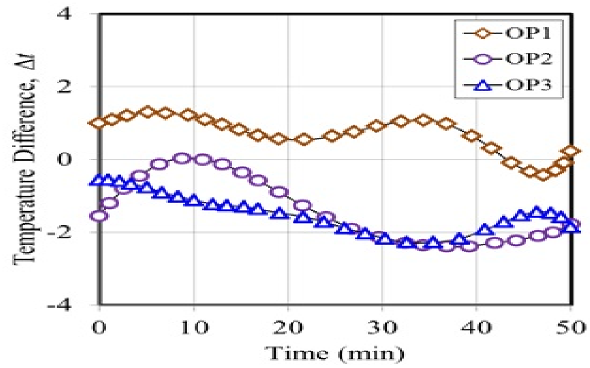
Total VOCs concentration from in-vehicle cabin at static condition increased linearly with the increase in indoor temperature as presented in Figure-6a. The TVOCs concentrations for SC1 and SC2 collapse with each other despite difference in VLT level. However for case SC3, the TVOCs concentration is lower in comparison to SC2 and SC3. This result was consistent with the temperature difference data depicted in Figure-5a. This indicates that the increase in temperature of the in-vehicle will increase the TVOCs concentration. This finding was similar to those presented by Faber *et al.*[11] and Fedoruk and Kerger[10].

Figure-6b depicted the TVOCs concentration during operating condition. Measurement of in-vehicle TVOCs concentration did not show any correlation with the temperature difference shown in Figure-5b. During operating condition with air-conditioning mode shows that the TVOCs concentrations decreased dramatically despite the difference in VLT level and indoor temperature trend. This result is in consistence with Fedoruk and Kerger[10] where, they discovered that the TVOCs concentrations during operating condition is caused by air circulation rather than indoor temperature. It shows that TVOCs concentration is not much affected by the VLT level for more than 30 minutes of driving time. As revealed by Figure-6b, TVOCs level fall to almost the same concentration value from the 30th to the 50th minute.

Figure-7 shows the comparison of TVOCs concentration between static condition and operating condition for a measurement time of 50 minute. The standard VLT (Case SC2 & OP2) level is the combination of 50% VLT at front windows and 30% VLT at rear windows and 30% VLT level at back window. Whereas for 20% VLT (Case SC3 & OP3) condition all windows have 20% VLT level. For both VLT level (Figure-7a and b) the TVOCs concentration trends in the opposite direction. As previously discussed, the TVOCs level linearly increased at static condition and gradually decreased at operating condition. This condition explains that on increase in the percentage of VLT level is important for vehicles parked in open parking spaces.

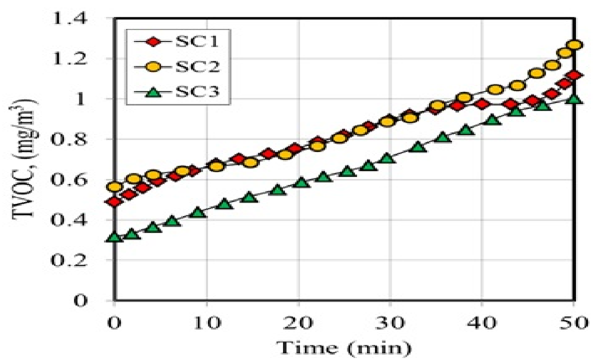


(a)

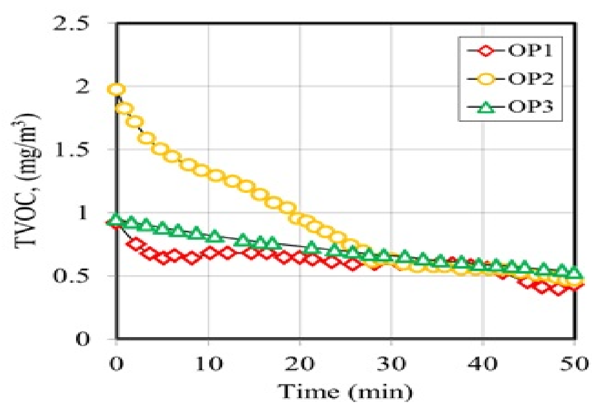


(b)

Figure-5. Temperature difference ($\Delta T = T_{in} - T_{out}$) for 50-min: (a) Static condition and (b) Operating condition.



(a)



(b)

Figure-6. TVOCs concentration in-vehicle cabin for 50 minute: (a) Static condition and (b) Operating condition.

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The TVOCs level at static condition can increase up to 1.207 mg/m^3 during static condition with standard VLT level as shown in Figure-8. The lowest TVOCs level was recorded at 0.431 mg/m^3 during operating condition with 70% VLT. During operating condition the TVOCs level showed an increase in concentration with the decrease of VLT percentage. However, the VLT level did not show any significant relationship to the TVOCs concentration for static condition. This can be seen as in

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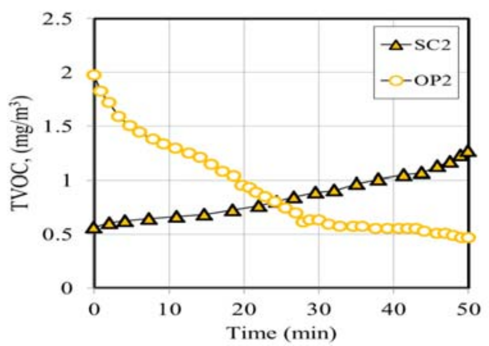
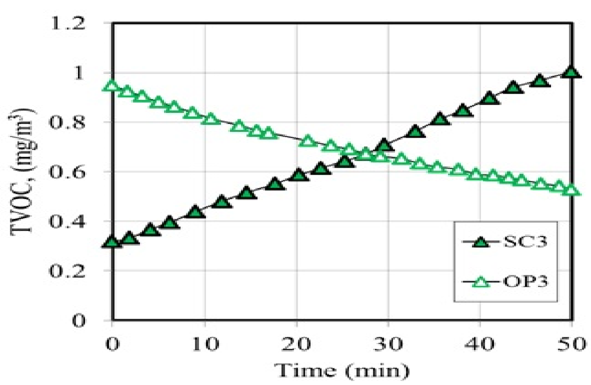
Figure-8, where the TVOCs concentrations are higher at standard VLT in comparison to 70% VLT. As indicated in Table 1, VLT level for case SC2 is much lower than case SC1 for all windows. Based on results obtained by Jasni and Nasir[15], the higher VLT level, the lower the TVOCs concentrations. This condition may only be applicable to uniform VLT level for all windows. Further investigation on non-uniform VLT level needs to be carried out in more detail.



(a)



(b)

Figure-7. Comparison of TVOCs concentration for static and operating condition for 50 min: (a) Standard VLT and (b) 20% VLT.

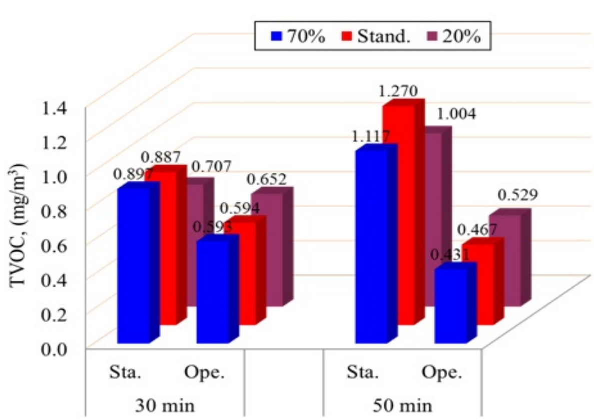


Figure-8. Effect of VLT level on TVOCs concentration after 30 min and 50 min measurement.

CONCLUSIONS

Temperature in-vehicle cabin during operating condition strongly influence by air-circulation by Heating, Ventilation and Air-Conditioning (HVAC) system of vehicle. Therefore effect of VLT level is less dominant in this situation. However, the VLT levels show very dominant compare to other factor in static condition. Increase in temperature shows strong implication to the increase the TVOCs concentration. By reducing VLT level in-vehicle temperature also decrease especially during static condition. For static condition, this relationship is clearly represented in the present study. However, the VLT level is less dominant for operating condition.

For operating condition, the in-vehicle temperature is strongly influence by air-circulation. Apart from that, the air-circulation also mainly influenced the TVOCs level after certain period of time for operating condition. Even though the TVOCs gradually reduced the initial condition still showed higher TVOCs concentrations because of the effect coming from static condition (parking and unventilated). The initial high TVOCs level condition can affect the driver and put them in a dangerous situation during driving time. The air circulation with high TVOCs level not only affects the driver but the passenger as well.

Uniformity of VLT level applied to all windows showed a significant relationship. Therefore additional investigation on various configurations of VLT level applied to the windows need be carried out.

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