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IMPACT OF VEHICLE INTERIOR GEOMETRY ON CHOSEN VOLATILE CARCINOGENS CONCENTRATION DISTRIBUTION IN VEHICLE CABIN

WPŁYW GEOMETRII WEWNĘTRZNEJ POJAZDU NA ROZKŁAD STĘŻEŃ SUBSTANCJI KANCEROGENNYCH W ATMOSFERZE WNĘTRZA KABINY

Abstract: The phenomena of volatile carcinogens pollution of interior atmosphere is an important issue on public health field. A car vehicle is a specific environment of human life where levels of volatile compounds concentration are much higher than *ie* in buildings (houses or offices). The VOCs sources can be divided on external (polluted air inlet through vehicle ventilation system) an internal (emission from cabin equipment materials). The volatile organic compounds are absorbed by human body mostly by respiratory system. The significant impact on toxicological characteristic of in-vehicle VOCs, in parallel with physical-chemical properties of the substance and exposition time, has also concentration distribution in vehicle cabin, especially the concentration on user head level. In the paper the results of CFD simulation of cabin geometry impact on chosen VOCs (benzene and toluene) distribution is presented. The geometrical model of vehicle cabin has been made and its insignificant modification was conducted to proof cabin geometry impact on driver exposure on the carcinogens carried out by ventilation system.

Keywords: CFD modeling, vehicle interior, volatile organic compounds

Introduction

Many organic compounds are known to cause cancer in animals; some are suspected of causing, or are known to cause, cancer in humans [1]. From *volatile organic compounds* (VOC) group especially *BTX* (benzene-toluene-xylene and their isomers) have been classified as a human carcinogens by IARC (1982) and was listed by both the European Commission and the World Health Organization as one of the top-priority compounds for the development of guidelines for indoor air quality (EC JRC, 2005; WHO, 2006). As with other pollutants, the extent and nature of the health effect will depend on many factors including the level of exposure and length of time exposed.

Benzene concentrations measured in vehicles are generally higher than those outdoors. Levels of benzene measured in vehicles in Europe ranged from 13 to 42 μg/m^3, while lower levels of 1.3-3.8 μg/m^3 were measured in a recent United Kingdom study [2]. Benzene levels measured in Mexico and the United States ranged from 1.7 to 42 μg/m^3 and a similar range (0.5-47 μg/m^3) was found in several Asian cities [3]. The highest in-vehicle benzene levels were measured in Italy in the early 2000s, with geometric means ranging from 17 to 101 μg/m^3 [3].

The aim of this study was Computational Fluid Dynamics simulation of cabin geometry impact on chosen VOCs (benzene, toluene and xylene) distribution is presented. The geometrical model of vehicle cabin has been made and its insignificant modification

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was conducted to proof cabin geometry impact on driver exposure on the carcinogens carried out by ventilation system.

Methodology

As an object for modeling chosen aromatic compounds particle distribution geometry passenger-vehicle (Fiat Grande Punto) was chosen as an examples of basic geometry of popular car vehicle. Three-dimensional computational model of sampler was design in Gambit software (Fig. 1).

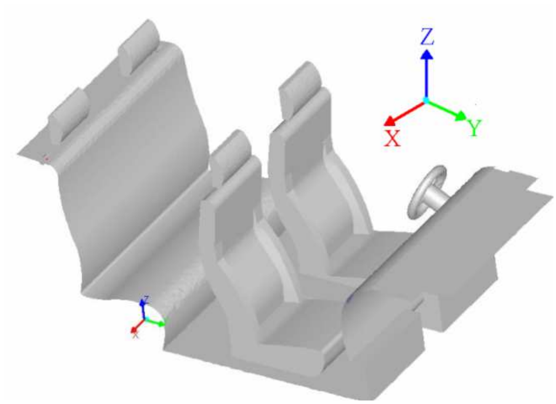


Fig. 1. Grande Punto geometry model (Gambit software)

For flow modeling application FLUENT-ANSYS software was applied. Numerical mesh on tetra elements was made. Two-equational k-ε turbulence model was applied. For particle of chosen VOCs modeling DPM model was used.

For simulations boundary conditions of benzene and toluene was based on chromatographic analysis on real object (Emission Research Laboratory, Varian 450GC-FID chromatograph) in a brand new passenger. The VOCs samples were up-taking in points set according to according to ISO/DIS 12219-1draft [4]. The temperature and pressure was kept in standard conditions of human existence (293 K, 101300 Pa).

The vehicle geometry was modified as in Table 1.

Table 1

Geometry modifications variants

Symbol	Geometry variant	Dimension		
		Width	Length	Height
B	Basic geometry	X	Y	Z
E1	Resized geometry (expanded): variant 1	X + 10%	Y	Z
E2	Resized geometry (expanded): variant 2	X	Y + 10%	Z
E3	Resized geometry (expanded): variant 3	X	Y	Z + 10%

Boundary conditions

In Table 2 boundary conditions for simulation are presented:

Table 2

Boundary conditions for modeling

Compounds concentration [kg/m³]	
Benzene (and isomers)	$1.58 \cdot 10^{-6}$
Toluene (and isomers)	$3.14 \cdot 10^{-6}$
Flow set	
Flow intensity [m³/s]	$4.2 \cdot 10^{-4}$ m³/s
Ventilation system mode	Central ventilation nozzles

Results

The results were presented in tables and figures below.

In Figure 2 the air stream lines are presented according to applied ventilation system set (Table 2).

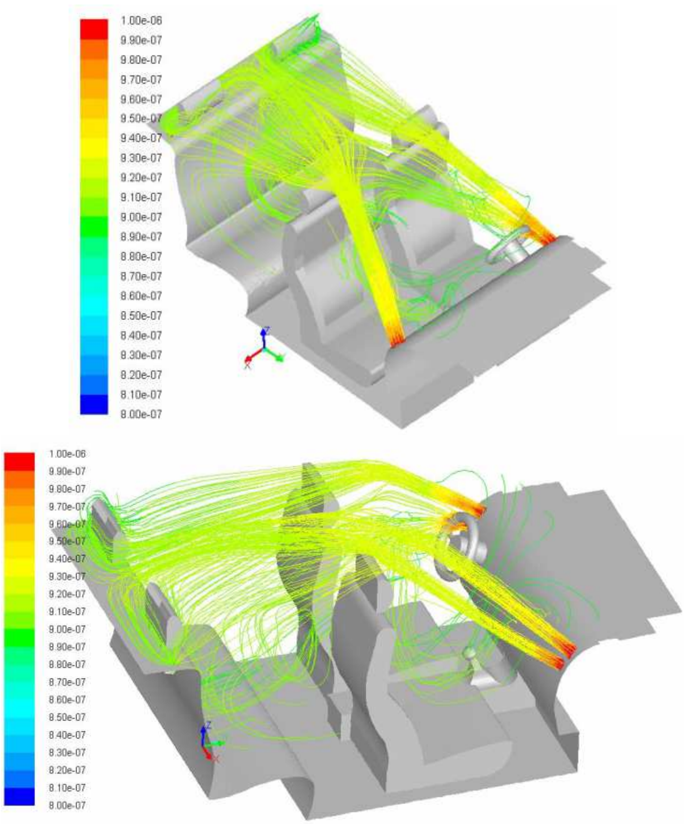
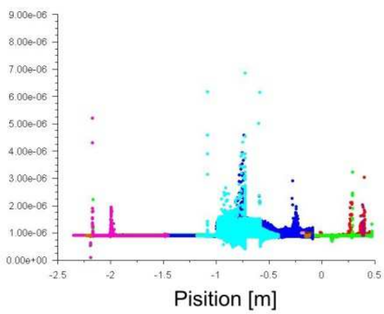
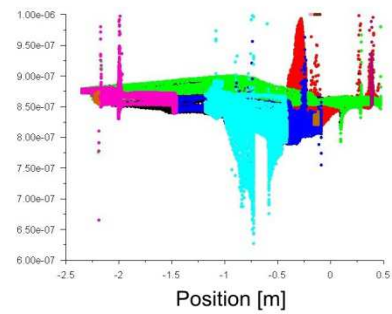
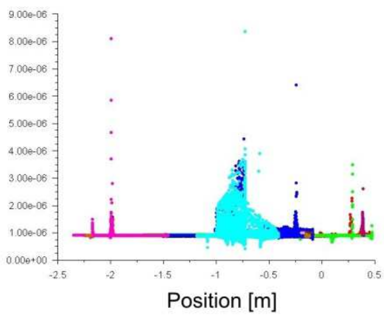
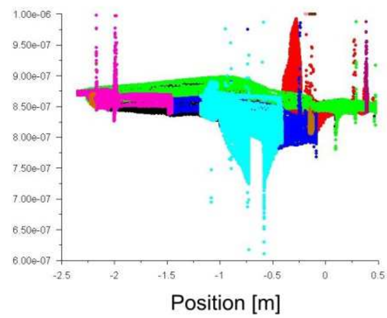
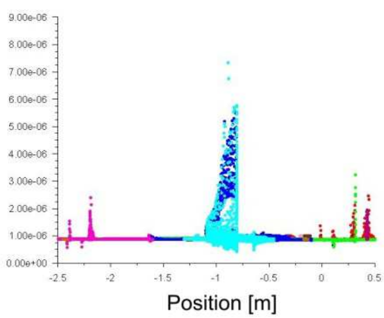
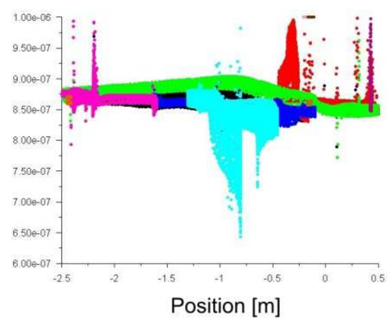


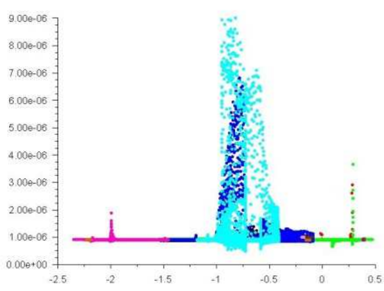
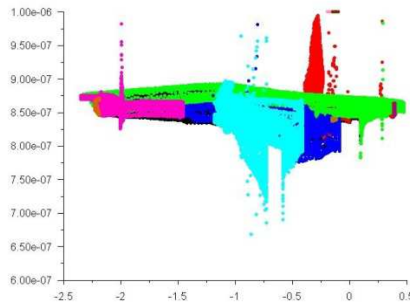
Fig. 2. Flow intensity stream lines [m³/s] (central nozzles mode)

In Table 3 the results of modeling - benzene and toluene concentration distributions in analyzed variants of geometry models are presented for all Y-Z cross-sections.

Table 3

Benzene and toluene volume fraction distribution on all Y-Z cross-sections

<table>
<tr><th colspan="2">Volume Fraction</th></tr>
<tr><th>Benzene</th><th>Toluene</th></tr>
<tr><td colspan="2">B</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">E1</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">E2</td></tr>
<tr><td>
</td><td>
</td></tr>
</table>

<table>
<tr><th colspan="2">Volume Fraction</th></tr>
<tr><th>Benzene</th><th>Toluene</th></tr>
<tr><th colspan="2">E3</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">sidewall
cocpit
topwall
floorwall
frontseat
backseat
inlet: driver -bottom
inlet: driver-top
inlet: passenger-bottom
intel:passenger-top
inlet: central
inlet:front window
outlets</td></tr>
</table>

According to the modeling results it is visible that even insignificant (10% in one dimension) changes in vehicle geometry cause change in carcinogens distribution, especially for particular health-hazardous benzene.

For driver exposure investigation, as a most exposed vehicle user because of in-vehicle time residence, the cross-section on driver position (Fig. 3) was separately analyzed.

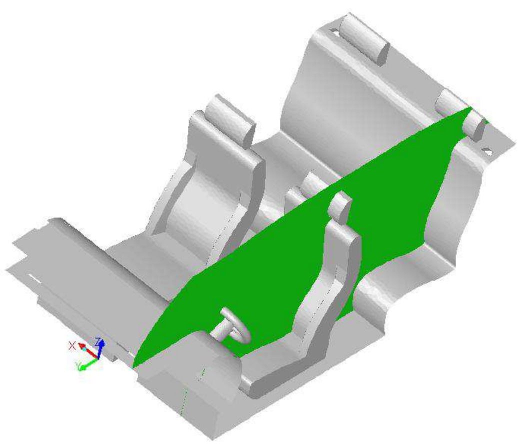
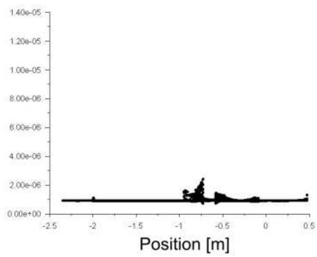
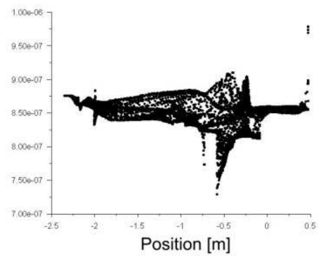
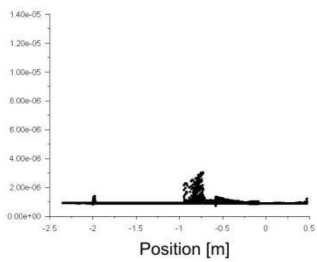
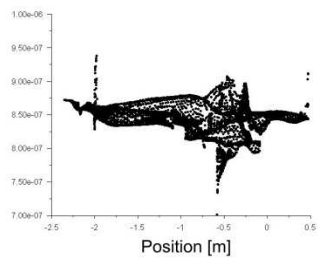
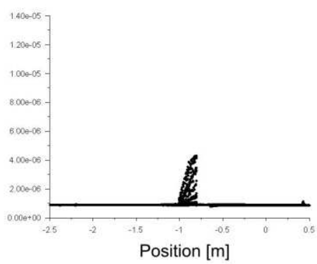
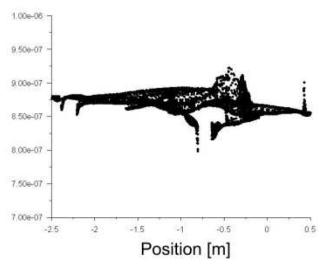
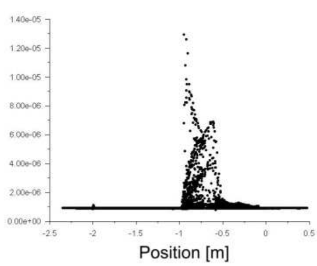
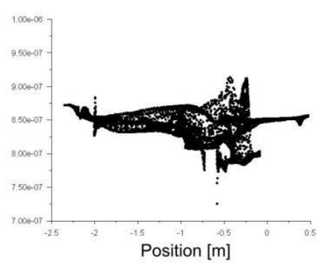


Fig. 3. Cross-section on driver position

Table 4

Benzene and toluene volume fraction distribution on driver position (according Fig. 3)

Volume Fraction	
Benzene	**Toluene**
B	
	
E1	
	
E2	
	
E3	
	

The results of the simulation on a cross-section on driver position are presented in Table 4.

The highest benzene concentration on driver position (frontseat) was observed in case E3 geometry variant (10% interior height expand). The basic variant seems to be most advantageous for benzene distribution. Analyzing toluene dispersal the most advantageous is E2 variant (10% extend of vehicle length). For both volatile compounds the impact of geometry change on carcinogens distribution is visible.

Summary

To discuss the toxicological characteristic of in-vehicle VOCs, in parallel with physical-chemical properties of the substance and exposition time, also carcinogens concentration distribution in vehicle cabin, especially the concentration on user head level need to be consider. CFD modeling enable in a relative short time analyze different geometry variants of vehicle interior and evaluate their impact on volatile individuals distributions.

The paper presents results of the modeling of benzene and toluene distribution inside popular passenger car and the impact of insignificant interior geometry modifications on those compounds concentration. According to the simulations some conclusions should be emphasized:

- The analyzed geometry variations impact on benzene and toluene concentrations.
- The most advantageous variant in aspect of driver exposure seems to be basic variant (B) for benzene and 10% length expand variant (E2) for toluene.
- The results of the modeling indicate on its applicability to evaluate the vehicle user exposure on particular volatile carcinogens. The researches need to be expanded on more geometry modifications (also geometry reduction and mixed variants) for finding optimal variant of particular vehicle interior in aspect of human health exposure on VOCs carcinogens.

References

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[3] WHO Guidelines for indoor air quality, Copenhagen Ø, Denmark, WHO Publications; 2010.

[4] ISO/DIS 12219 (2011): Indoor air of road vehicles: Whole vehicle test chamber - Specification and method for the determination of volatile organic compounds in cabin interiors.

WPŁYW GEOMETRII WEWNĘTRZNEJ POJAZDU NA ROZKŁAD STĘŻEŃ SUBSTANCJI KANCEROGENNYCH W ATMOSFERZE WNĘTRZA KABINY

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Abstrakt: Obecność kancerogenów z grupy lotnych połączeń organicznych, w szczególności w pomieszczeniach zamkniętych, jest istotnym problemem z zakresu zagadnień w obszarze zdrowia publicznego. Pojazd samochodowy jest środowiskiem życia człowieka, w którym poziomy stężeń substancji z grupy lotnych połączeń organicznych znacznie przekraczają stężenia w budynkach mieszkalnych czy biurowcach. Źródła LZO (benzenu i toluenu) w kabinie pojazdu można podzielić na dwa rodzaje: zewnętrzne (zanieczyszczone powietrze wprowadzane do wnętrza kabiny za pomocą systemu wentylacyjnego pojazdu) oraz wewnętrzne (emisja z materiałów stosowanych we wnętrzu kabiny pojazdu). Lotne związki organiczne przedostają się do organizmu ludzkiego głównie za pomocą dróg oddechowych, a na ocenę ich wpływu toksycznego na zdrowie użytkowników oprócz właściwości fizykochemicznych substancji oraz czasu ekspozycji ma również znaczący wpływ dystrybucja tych substancji we wnętrzu pojazdu, w szczególności ich koncentracja na wysokości głowy użytkownika. W niniejszym artykule zaprezentowano wyniki symulacji komputerowej (metoda CFD) cyrkulacji powietrza wewnątrz kabiny pojazdu w aspekcie rozkładu wybranych kancerogenów z grupy LZO. Wykonano model geometryczny kabiny pojazdu, a następnie poprzez nieznaczne modyfikacje geometrii wnętrza udowodniono wpływ geometrii na narażenie kierowcy na kontakt z lotnymi substancjami o charakterze kancerogennym wprowadzanymi poprzez system wentylacyjny pojazdu.

Słowa kluczowe: modelowanie przepływów, wnętrze pojazdu, lotne związki organiczne