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INFLUENCE OF BOUNDARY CONDITIONS ON THE AIR FLOW INSIDE THE SUBWAY STATION OF MUZEUM C-A ARE AND COMPARISON OF NUMERICAL AND PHYSICAL RESULTS OF WARFARE COMPOUND SUBSTTUENT DIFFUSION

VLIV OKRAJOVÝCH PODMÍNEK NA PROUDĚNÍ VZDUCHU V PROSTORÁCH STANICE METRA MUZEUM C-A A POROVNÁNÍ VÝSLEDKŮ NUMERICKÉHO A FYZIKÁLNÍHO EXPERIMENTU ŠÍŘENÍ SUBSTITUENTU OTRAVNÉ LÁTKY

Abstract

Article deals with numerical modeling of air flow in area of subway station Museum C-A with consideration of ventilation and eventually diffusion of warfare compound substituent. Influence of boundary conditions defining by ventilation was tested on the process of air flow. Comparing of physical and numerical experiment of warfare compound substituent diffusion was considered which it was loosen on the platform of subway station Museum C. Results are evaluated by velocity vectors and concentrations of warfare compound. Agreement both experiments are showed by concentration dependence on the time in the middle of platform. Program Fluent 6.3.26 was used for solution the defining mathematical model.

1 INTRODUCTION

Prague subway is important traffic unit with big concentration of people which can be potentially dangerous of place for imposition military toxicant in result of criminal or terrorist attacks. Sarin and next nerve substance are esters, if central atom is phosphorus. It was necessary to find substance (substituent) for testing of warfare compound substituent diffusion in real area (in-situ) which it was similar to sarin to the relation of basic physical properties (boiling point, vapor pressure). Therefore pentylacetate was selected, which is not optimal equivalence to dependence of kinematics, dynamic viscosity and coefficient of diffusion on the temperature and therefore it was necessary to make specific correlation. Pentyl and isopentylacetate is named banana oil, this aroma is sufficiently intensive, as for ester it is usually, and then subjective detection is provided (using gas-liquid chromatography). Ventilation during experiment was defined as so-called winter operation, i.e. inlet of air in station area (Main station-Museum C ($52 m^3/s$); Museum C – I. P. Pavlova ($37 m^3/s$)) and outlet of air from station Museum C ($75 m^3/s$). Scheme of ventilation is demonstrated on the Fig. 1.1.

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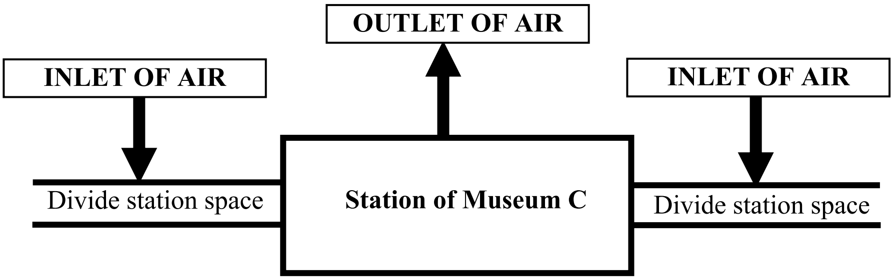


Fig. 0.1 – Scheme of winter ventilation inside the station of Museum C

Similar system of ventilation was applicable for station Museum A too. Horizontal projection of station C-A is presented in *Fig. 1.1*.From schema are evidently all places as platforms, railroad tracks, escalators, stairs, exits, changes. The Incoming and out coming subway train sets influence direction of air flow significantly. Move of trains was not considered from reason of influence on the boundary conditions.

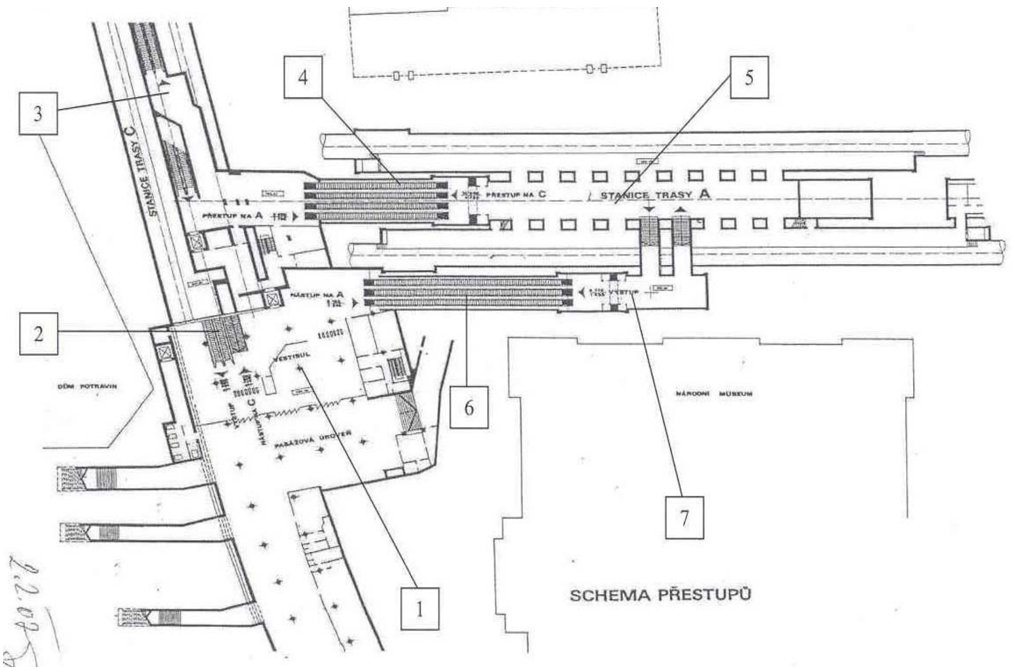


Fig. 0.2 - Horizontal projection of station Museum C – A with schema of entrances, exits, changes and measuring position

Petylacetate was evolved by pressure as aerosol with carrier air gas on the station trace C in the two-thirds of distance from exit of station (Fig. 0.3). The substituent detection time and concentration was recorded in seven measuring points (see *Fig. 1.1*) from time evolving on the platform. Time dependence of substituent concentration is showed in this paper in the point of 3. Then three-dimensional turbulent mathematical model of mixture air and species (pentylacetate) was defined in general geometry as time independence isothermal flow of incompressible mediums. The balance equations are consisted with continuity equation, Navies-Stokes equations, species transport equation and equations for turbulent quantity (k,ε). Those equations were solved by method of finite volume. In first phase influence of ventilation boundary conditions was probed on the above defined mathematical model without substituent (pentylacetate). Then physical experiment of pentylacetate diffusion was made in station Museum C. Time behavior of substituent concentration was evaluated in point 3 (Fig. 1.2). Numerical simulation of the defined mathematical model with species (pentylacetate) flow was made by same conditions. Dependence of substituent concentration for numerical and physical experiment was compared in same point.

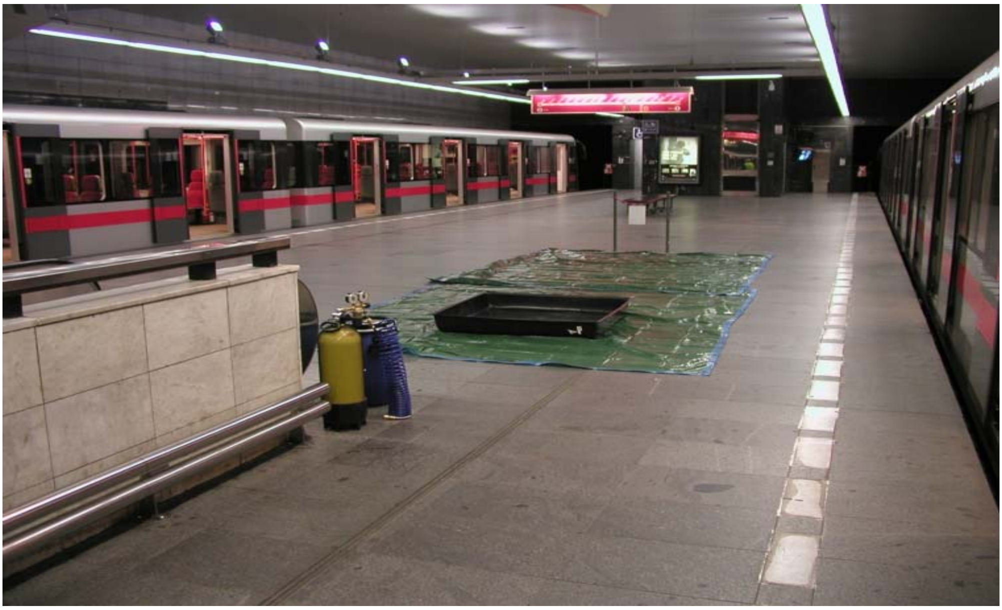


Fig. 0.3 – Preparation the experiment of substituent diffusion to area

2 DEFINITION OF MATHEMATICAL MODEL OF AIR FLOW AND DIFFUSION OF WARFARE COMPOUND

Programmatic system Fluent 6.3.26 was used for mathematical modeling of air flow and warfare compound substituent diffusion inside the area of transfer station Museum C-A. Gambit 2.4 was used too. Program Gambit is used for creating of computational grid by finite volumes different shape. Three-dimensional turbulent $k-\varepsilon$ mathematical model flow of mixture air and species (pentylacetate) was defined as time independence isothermal flow of incomprisseble mediums. The balance equations are consisted with continuity equation, Nervier-Stokes equations, species trnasport equation and equations for turbulent quantity (k,ε).

2.1 DEFINITION OF GEOMETRY AND BOUNDARY CONDITIONS

Procedure of creating the computational are can be separated to three basic steps. In the first step we can create all geometry area by different CAD systems. Charasteristic the geometry of station Museum C-A is showed on the Fig. 2.1. It is necessary to make specific simplified before creation computational area because all area is very complicated. Main reason of simplified is next connection with all number of cells computational area because next numerical simulation would be involve long time solution. Determine is keeping main distance of station (height, lenght). So conditions are completing from stand of reach corresponding accuracy of numerical simulation. All number of cells is 170 000.

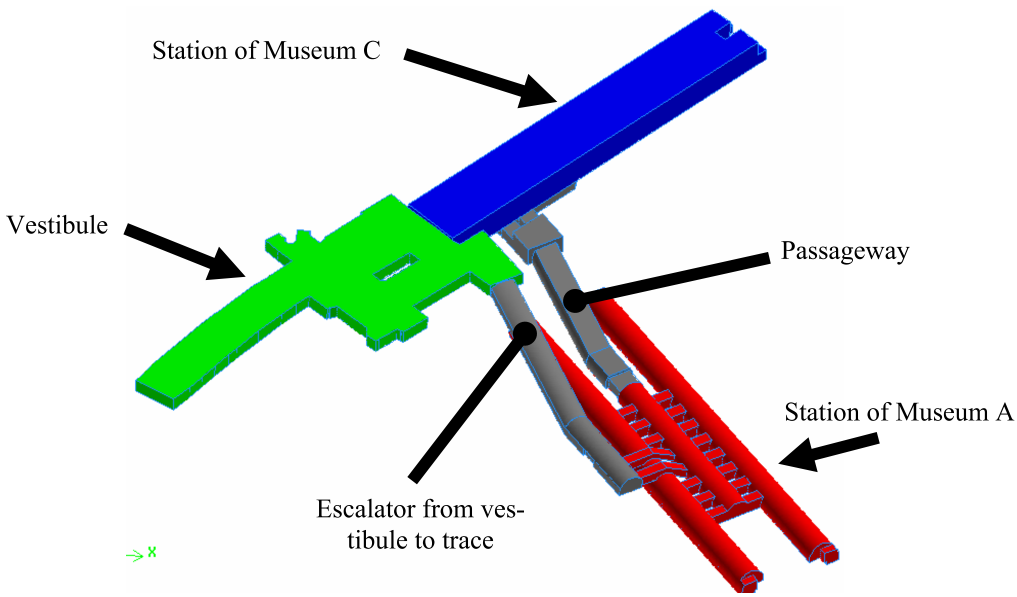


Fig. 0.4 - Characterization of geometry (transfer station Museum C - A)

On the individual boundary of area we have to define corresponding boundary conditions before numerical simulation. Program system Fluent offers many different variants with respect on the characterization of problems. Inlet velocities define on the surfaces end of tunnel track which corresponding to flow of ventilators by chapter 1. Same boundary conditions are defined for pair stations (Museum A, Museum C). Four inlet velocity conditions assign on the one station. By velocity condition is defined ventilation of station which it is setting on the surface of ceiling station Museum A and Museum C with opposite flow of direction. On the inlets of vestibule are defined pressure boundary corresponding to atmospheric pressure (OUTLET). Seven inlet conditions are defined to vestibule from surroundings. Different values of velocity were defined with influence on the detection of flow direction in area of station. Next surfaces are defined as non-conduction walls, because isothermal flow is considered.

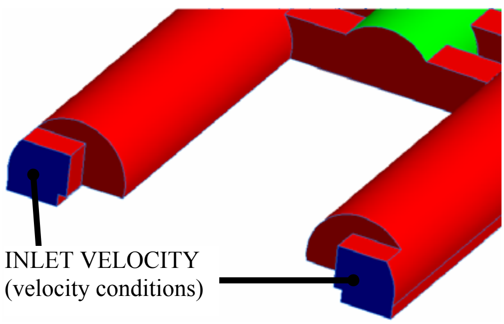


Fig. 0.5 – Inlet velocity conditions defined on the parameters of divide station ventilation (INLET), station of Museum A

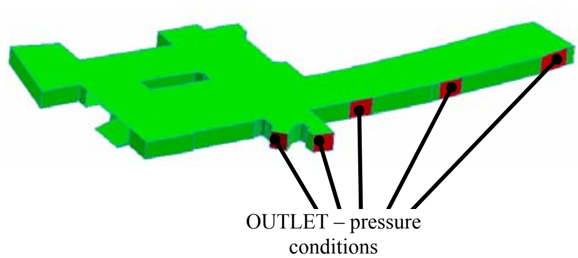


Fig. 0.6 – Inlets to vestibule – pressure boundary conditions (OUTLET)

Velocity conditions on the ends of tunnel track are defined by flow of ventilators, chapter 1. Ventilation of station is defined by velocity condition on the surfaces of ceiling station Museum A and Museum C for two variants, see Tab. 2.1.

Tab. 0.1 – Boundary conditions of station ventilation

Boundary conditions of station ventilation	Variant 1	Variant 2
	velocity v (m/s)	
Station **Museum A**	0.01	0.035
Station **Museum C**	0.01	0.035

2.2 DEFINITION OF MATHEMATICAL MODEL

Defining mathematical model solves the set of following partial differential equations:

- Mass conservation equation

$$\frac{\partial \rho}{\partial t} + \frac{\partial (\rho u_j)}{\partial x_j} = 0 \qquad (0.1)$$

Mass conservation equation is valid for incompressible and compressible flows.

- Momentum conservation equation

$$\frac{\partial (\rho u_i)}{\partial t} + \frac{\partial (\rho u_i u_j)}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\mu \frac{\partial u_i}{\partial x_j} \right) + \rho \delta_{i3} g \qquad (0.2)$$

Third term on the right hand side introducing influence gravitational body force.

- Species transport equation

$$\frac{\partial (\rho Y_{i'})}{\partial t} + \frac{\partial (\rho u_j Y_{i'})}{\partial x_j} = -\frac{\partial}{\partial x_i} J_{i'} \qquad (0.3)$$

Variable $Y_{i'}$ define local mass fraction of species and $J_{i'}$ define mass diffusion of species i'. This set of differential equations is extended by transport equations of turbulent quantities (turbulent kinetic energy k and rate of dissipation ε) more.

3 EVALUATION OF NUMERICAL AND PHYSICAL EXPERIMENT

Numerical simulation of influence boundary conditions on the flow in area of station Museum C-A is evaluated in first variant in context to flow direction in vestibule. Two variants of mass flow magnitude were tested for station ventilation of station Museum C-A. Then physical experiment of substituent (pentylacetate) diffusion was made, which it was compared with numerical experiment by same conditions.

3.1 EVALUATION OF INFLUENCE BOUNDARY CONDITIONS ON THE AIR FLOW IN TRANSFER STATION MUSEUM C-A

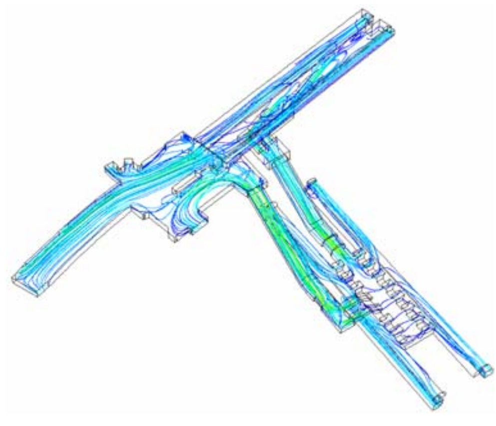


Fig. 0.7 – Trajectory of air flow in area of station – Variant 1

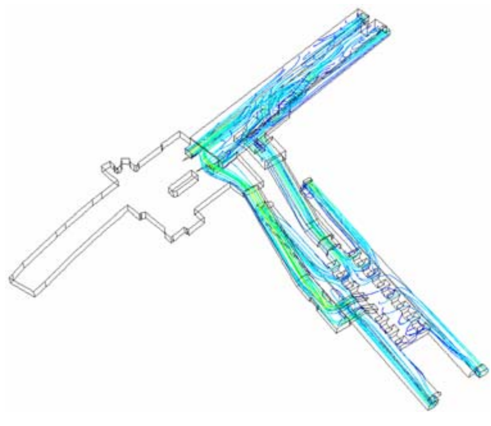
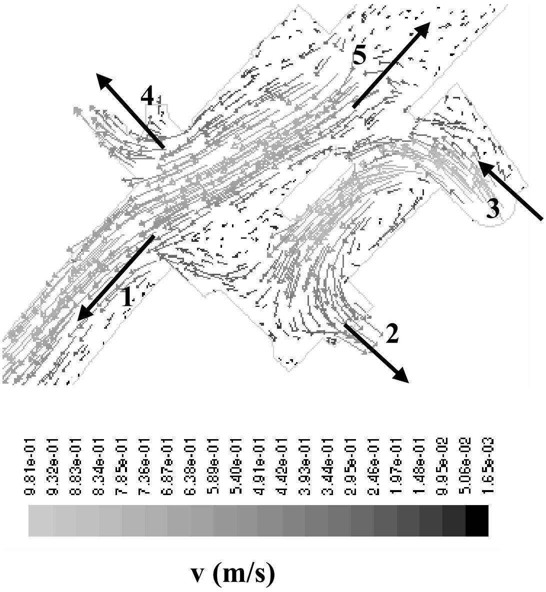
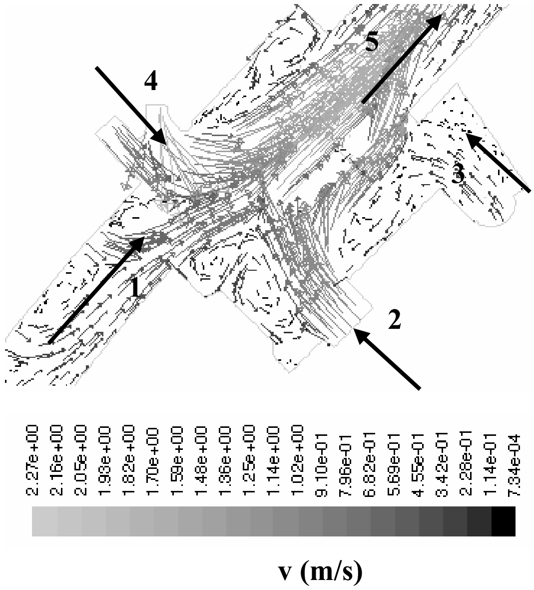


Fig. 0.8 – Trajectory o fair flow in area of station – Variant 2

Trajectory of air flow is showed on the Fig. 3.1, Fig. 3.2 in area of station Museum. Two variants of station ventilation are compared by Tab. 2.1. When we define variant 2, then we consider more then three times mass flow from ventilators. From results (Fig. 3.2) is visible effect direction of air flow to station from surroundings. This effect is in agreement with projection of defining ventilation. Then If we consider more than three times mass flow then air does not come to direction from out vestibule to surroundings, Fig. 3.2.





1, 2, 4 – direction of flow from vestibule to individual inlets of station from surroundings

3 – direction of flow from vestibule to station Museum A

5 – direction of flow from vestibule to station of Museum C

Fig. 0.9 – Velocity field in vestibule area – Variant 1

Fig. 0.10 – Velocity field in vestibule area – Variant 2

Velocity field is evaluated in surface through the vestibule (Fig. 3.3, Fig. 3.4). We can see detailed character of flow in area of vestibule with influence on the boundary condition of ventilation. Evaluating is supplemented by direction of flow individual area for transparency. From results is evident analogy with evaluating of trajectory of air flow (Fig. 3.1, Fig. 3.2).

3.2 COMPARING OF NUMERICAL AND PHYSICAL EXPERIMENT OF WARFARE COMPOUNT SUBSTITUENT DIFFUSION IN AREA OF SUBWAY

Vacation of pentylacetate was occurred in two třetiny platform Museum C. From comparing of results of those varints (physical and numerical experiment) is the best to evaluate concentration of pentylacetat in arbitrary place of field flow.

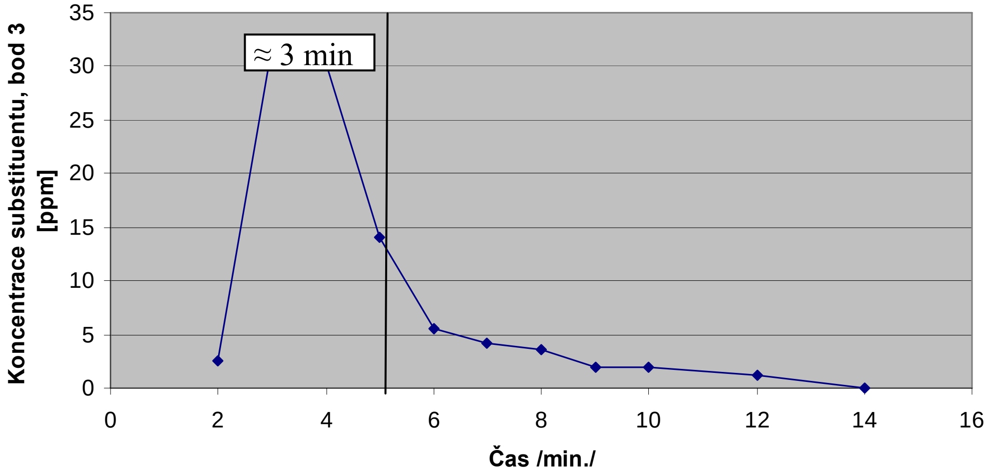
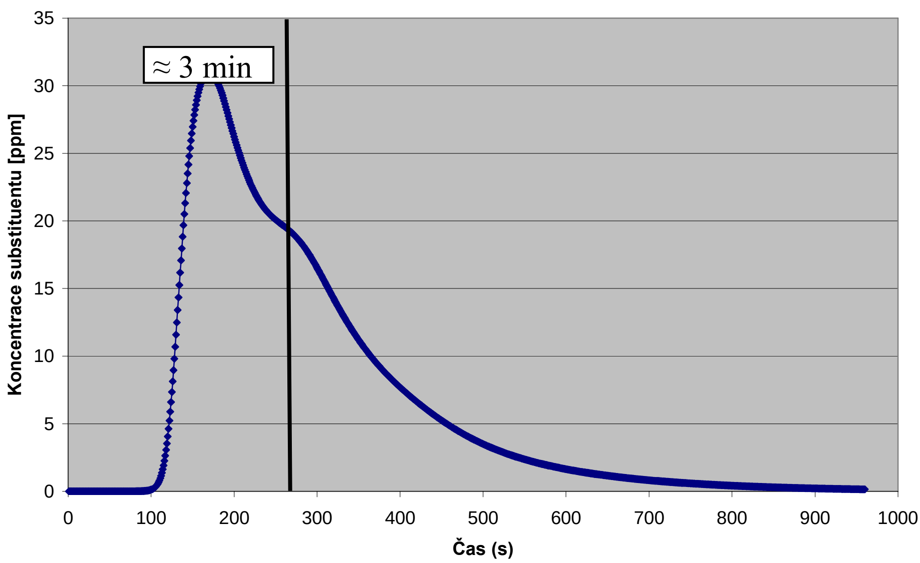


Fig. 0.11 – Time dependence of concentration substituent diffusion (pentylacetat) – physical experiment

In this paper is compared time dependence of concentration substituent diffusion (pentylacetate) in the middle of platform Museum C. Physical and numerical experiment was done by same boundary conditions. Total time of experiment was 16 minutes from time of arbitrary substance to area. From results (Fig. 3.5, Fig. 3.6) is visible very good agreement in maximal concentration $(\approx 32\,ppm)$. Then we can evaluate time when the maximal concentration is reached from arbitrary substance. This time is about three minutes. Then time when concentration of warfare compound substituent is zero in the middle of platform station Museum C is about 14 minutes for numerical and physical experiment Fig. 3.5, Fig. 3.6. Results are in good agreement.



Obr. 0.12 - Time dependence of concentration substituent diffusion (pentylacetat) – physical experiment

4 CONCLUSION

In this paper comparing of results influence of boundary conditions is presented on the air flow in area of transfer station Museum C-A by numerical simulation of software Fluent 6.3.26 in the first part. Effect of air flow is evident from publishing results by trajectory of air flow and velocity field in direction from vestibule to individual inlets of station in consequence changing of ventilation. In the connection corresponding turbulent mathematical model of air and species flow was defined with detailed description of boundary condition. Comparing results of experimental measuring of warfare compound substituent diffusion (pentylacetate) is published in area of stansfer station Museum C-A with mathematical model of flow without move of train set in the next part of article. For numerical and physical experiment is evaluated time dependence of substituent concentration in the middle of station Museum C. From presenting results is visible very good agreement with time when maximal concentration is extended. Then good agreement is in time when area is cleanup from contamination of warfare compound. Next work should be tend to extension current mathematical model by move of train set on the individual tracks.

LITERATURA

[1] Bingelli, P.: *4th. Int. Symp. Protection Against Chemical Warfare Agents.* Stockholm, 8-12 June, 1992.

[2] Kotinský, P., Hejlová, J.: *Dekontaminace v požární ochraně*, Edice SPBI Spektrum, 34, Ostrava 2003, ISBN 80-86634-31-0.

[3] Středa, L., Halámek, E., Kobliha, Z.: *Bojové chemické látky*, AZIN CZ Praha 2004, ISBN 80-239-3102-4.

[4] Kozubková, M., Drábková, S., Šťáva, P.: *Matematické modely nestlačitelného a stlačitelného proudění. Metoda konečných objemů*. [Skripta]. Ostrava: VŠB-TU, 1999, 106 s.

[5] FLUENT: Fluent 6.3.26 - *User's guide* Fluent Inc. 2003. VŠB-TU Ostrava <URL:http://sp1.vsb.cz/DOC/Fluent_6.3.26/html/ug/main_pre.htm>

[6] Klouda, K., Dudáček, A., Bezpalcová, K.: *Úvahy nad zneužitím „podomácku" připraveného sarinu*. Sborník 15. mezinárodní konference Požární bezpečnost 2006, str. 169, Ostrava 2006, ISBN 80-86634-88-4.

[7] Tomášek, T.: Metroprojekt Praha, a.s., projekt – půdorys, 2007.

[8] www.metroweb.cz

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