A study of the source-sink system with uneven suction

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Abstract. Suction hoods are used on a wide-spread basis in ventilation equipment in order to capture harmful substances released by process equipment. The efficiency of such devices is dependent not only on the relative position of the source of contamination and that of the suction hood but also on suction uniformity. Where the location of the source and that of the suction hood is misaligned, the need arises to put in place an uneven velocity field in the suction hood.

This paper explores the flow of hazardous substances from the "source" to the "sink" located at an angle of 180 degrees relative to each other. Collection efficiency was determined numerically by means of the Fluent software as well as experimentally. A screen was mounted inside to ensure uneven suction. The study yielded flow current lines and constant temperature lines. It also helped to define maximum suction intensity.

The findings may be used for designing ventilation systems intended for industrial buildings.

Key words: local suction, uneven suction, numerical method, Fluent, maximum intensity.

1 Introduction

An industrial enterprise ramping up efficiency is related to the need to boost output, which is oftentimes accompanied by growing emissions of harmful substances into the working area. Various suction panels and suction hood devices are installed at the workplace in order to remove emissions [1-3].

A number of works focus on determining the design features and collection efficiency of suction hood systems [4, 5]. In some instances, the technological process and insufficient space heightwise preclude the use of such devices. In such environments, side suction systems with various angles of installation in relation to the source of harmful emissions are rolled out. Uneven suction, once in place, helps reduce the volume of air removed as opposed to the same side uniform suction which results in substantial cost reductions associated with ventilation systems[6]. At the present moment, there are no methods available for calculating local suction with uneven intake of air removed.[7] Once such a technique is designed, it will significantly reduce the energy costs of the local ventilation system while boosting collection efficiency [8, 9].

The geometric and kinematic properties of the suction port must be determined in order to define the efficiency of capture of harmful substances [10, 11].

It is believed that high suction uniformity ensures high efficiency of local suction. However, this is true exclusively for the source of harmful substances and that of suction being located coaxially. Their misalignment leads to the necessity of putting in place an uneven velocity field in the suction port [12].

This paper explores the action of a slotted hood which serves the function of capturing the convective jet [13] rising above the source of heat. This study is carried out numerically by means of the Fluent software package [14, 15]. A full-scale experiment is carried out to verify the numerical model.
2 Material and methods

This paper investigates the action of a slotted hood located at an angle of $\phi=180^0$ relative to the source of heat (figure 1).

![Figure 1. The geometry of the source-sink system under examination: 1 – working area; 2 – jet; 3 – source of heat; 4 – hood.](image)

The study [16] is carried out numerically [17, 18] by means of the Fluent software which helps solve a set of differential equations of fluid motion by the method of finite volumes. The set of equations of plane turbulent motion [19] complemented by the equation of gas state and boundary conditions was closed by means of the "standard" K – epsilon model ($k$ – kinetic energy of turbulent pulsations, $\varepsilon$ – specific dissipation of turbulent energy) with extended wall functions used to calculate the flow properties near impermeable walls.

The hood is divided by a partition into two slots with a width of $l_{b1}$ and $l_{b2}$ in order to generate an uneven velocity profile. Two types of the area geometry are studied: $l_{b1}>l_{b2}$ and $l_{b1}<l_{b2}$. The suction rate in the right slot is $V_{02}$ with $V_{01}$ in the left.

The initial data used in the calculations are as follows: heat source width: $l_b = 0.2$ m, specific heat output: $Q_0=1000$ W/m.

It follows from the obvious equalities $B_1+B_2=2B$, $L_{01}+L_{02}=V_{01}B_1+V_{02}B_2=V_{01}2B=L_0$, that:

\[
B_2 = 2 - \bar{B}_1, \quad L_{01}+L_{02} = 1, \quad V_{01}B_1 + V_{02}B_2 = 2, \quad (1) \quad (2) \quad (3)
\]

where $\bar{B} = B_1/B_2$, $B_2 = B_2/B_1$, $V_{01} = V_{01}/V_0$, $V_{02} = V_{02}/V_0$, $L_{01} = L_{01}/L_0$, $L_{02} = L_{02}/L_0$.

$V_0$ is the uniform suction velocity at a specific air flow rate of $L_0$, $m^2/s$.

Combining expressions (1), (2) it is found that:

\[
V_{02} = (2 - V_{01} \bar{B}_1)/(2 - \bar{B}_1). \quad (4)
\]

It is clear that $V_{02}>0$ means that the condition $V_{01} \bar{B}_1<2$ must be met when setting suction unevenness.

For capture efficiency to be determined, the rate of $V_{01}$ is assumed to be a constant equaling 0.1; 0.25 and 0.5; the rate of $V_{01}$ varying until maximum capture is obtained. In this case, the incomplete
capture mode sees part of the jet going beyond the hood; the excessive capture mode involves not only the upstream flow going to the hood but also the surrounding unheated air.

The purpose of the experiment is to establish the limit mode of capture and the corresponding value when the upstream jet is captured completely, but not excessively [20]. Below are the results of the numerical solution.

3 Results and discussions

The numerical solution yielded flow current lines and constant temperature lines.

Different bypass ratios lead to the following options: harmful emissions fully captured; a flow breakout is observed when some of the emissions enter the working area which reduces the efficiency of local suction. Figure 2 shows the current lines corresponding to the flow breakout. It can be seen that some of the air is left uncaptured with harmful emissions going to the inside air thus taking a toll on how the sanitary and hygienic standards are kept.

Figure 2. Current flow lines in the case of a flow breakout.

Changing the position of the separating partition of the hood and changing the ratio of air intake rates helped obtain flow patterns which corresponded to maximum suction intensity.

Figure 3 illustrates the flow current lines with a ratio of suction slots as \( l_{B2}/l_{B1} = 3/1 \).

Figure 3. Flow current lines with optimal capture; the ratio of suction slots is 3 to 1, the location of the source and the sink is 180°: 1 – working area; 2 – jet; 3 – source of heat; 4 – the hood.
For this installation geometry, optimal capture is observed at dimensionless rates of \( \bar{V}_{01} = 28.80 \) and \( \bar{V}_{02} = 0.5 \).

Figure 4 illustrates the flow current lines with a ratio of suction slots as \( \frac{l_{B2}}{l_{B1}} = 1/3 \).

\[ \begin{align*} \bar{V}_{01} &= 28.80, \\ \bar{V}_{02} &= 0.5. \end{align*} \]

In this case, optimal capture is observed at dimensionless rates of \( V_{01} = 42.666 \) and \( V_{02} = 0.5 \).

In order to verify the obtained dependencies, experimental studies were conducted using the Schlieren instrument (figure 5). The experimental installation shown in figure 5 is an air duct 1. A heater 2 was placed at the beginning of the air duct. An asbestos cord 3 is used to insulate the air duct. A laboratory autotransformer 4 is used to adjust voltage on the heater. A vacuum cleaner 10 whose performance was

\[ \begin{align*} \bar{V}_{01} &= 28.80, \\ \bar{V}_{02} &= 0.5. \end{align*} \]

The convective flow exited through a hole 5 sized 0.04 x 0.01 m. with optical glasses installed along the larger edge in order to make the flow near-flat, and through a hole sized 0.04 x 0.04 m. The convective flow was captured through equally sized holes 6. Uneven suction in the holes heightwise was ensured through screen installed inside 7. The air velocity in the convective flow was measured by a thermoanemometer. The air was removed by a vacuum cleaner 10 whose performance was
controlled by a laboratory transformer. The air flow rate in the intake air duct was determined by the dynamic pressure in it which was measured by a pneumatic tube and a MMH-250-9 micromanometer. The experiment is run with the hood placed at an angle of $\phi=180^\circ$ relative to the source of harmful emissions. The coefficient was assumed to be 0.23 during calculations $m$.

Similarly to the numerical experiment, an instance of optimal capture (figure 6) along with an instance of a flow breakout (figure 7) can be observed.

**Figure 6.** The current flow lines where the source of harmful emissions and the exhaust hood are located at an angle of 180°; optimal capture mode.

**Figure 7.** The current flow lines where the source of harmful emissions and the exhaust hood are located at an angle of 180°; insufficient capture mode; a flow breakout occurs.

### 4 Conclusion

The effect of a slotted hood located at an angle of 180° to the source of heat has been studied numerically by means of the Fluent software.

The separating screen located inside the hood is used to create an uneven flow which produces a significant impact on the efficiency of capturing harmful emissions. The decline in the volume of removed air for the given uneven suction examples amounts to about 46% against 78% for uniform suction.

The optimal mode for capturing harmful substances was determined when the ratio of the suction rate was changed backed up by a full-scale experiment.

The findings may be used for designing ventilation systems intended for industrial buildings.
References

[1] A M S, Jain T, Yamé J J 2020 Bilinear model-based diagnosis of lock-in-place failures of variable-air-volume HVAC systems of multizone buildings Journal of Building Engineering doi: 10.1016/j.jobe.2019.10102

[2] Wiriyasart S, Naphon P 2019 Numerical study on air ventilation in the workshop room with multiple heat sources Case Studies in Thermal Engineering doi: 10.1016/j.csite.2019.100405

[3] Ahmed A Q, Gao S, Kareem A K 2016 A numerical study on the effects of exhaust locations on energy consumption and thermal environment in an office room served by displacement ventilation Energy Conversion and Management doi: 10.1016/j.enconman.2016.03.004

[4] Awbi H B 2017 Ventilation for Good Indoor Air Quality and Energy Efficiency. doi: 10.1016/j.egypro.2017.03.1098

[5] Seng N C, Leman A M & Sadikin A 2013 Experimental and Simulation Validation Methods of Local Exhaust Ventilation (LEV) in Training Facilities Building Applied Mechanics and Materials, 315, pp 997-1001. https://doi.org/10.4028/www.scientific.net/amm.315.997

[6] Zheng X 2018 Natural ventilation. doi: 10.1007/978-3-662-49120-1_8

[7] Song M 2018 An experimental study on time-based start defrosting control strategy optimization for an air source heat pump unit with frost evenly distributed and melted frost locally drained Energy and Buildings doi: 10.1016/j.enbuild.2018.08.027

[8] Frederi A, Salmon M 2019 Design of experiment.

[9] Pagukuman D, Norerama B Leman Abdul & Md Yusof, Mohammad Zainal 2013 The Efficacy of Local Exhaust Ventilation (LEV) System Controls on Aerosols Exposures during Aluminium Cans Production Applied Mechanics and Materials 465-466 pp 438-442. doi: 10.4028/www.scientific.net/AMM.465-466.438

[10] Bremer B 2015 Heating, Ventilation, and Air-Conditioning Systems. doi: 10.1002/9781119033226.ch24

[11] Chitaru George-Madalin, Sandu Miheea, Croitoru Cristina & Bode Florin 2019 Local exhaust ventilation solutions for an industrial hall – Part 1 CFD analysis of the local exhaust systems E3S Web of Conferences 85 p 02012. doi: 10.1051/e3sconf/20198502012

[12] Davidov A P, Valiullin M A, Gabdrafikov R R 2013 To the question of the influence of suction irregularity on the exhaust air volume News of the KSUA

[13] Rostami M N, Dinavand S, Pop I 2018 Dual solutions for mixed convective stagnation-point flow of an aqueous silica-alumina hybrid nanofluid Chinese Journal of Physics doi: 10.1016/j.cjph.2018.06.013

[14] 2016 Fluent Inc Discrete Phase Modelling ANSYS FLUENT User’s Guide.

[15] Özakin A N, Kaya F 2019 Effect on the exergy of the PVT system of fins added to an air-cooled channel: A study on temperature and air velocity with ANSYS Fluent Solar Energy doi: 10.1016/j.solener.2019.03.100

[16] Chenari B, Dias Carrilho J, Gameiro Da Silva M 2016 Towards sustainable, energy-efficient and healthy ventilation strategies in buildings: A review Renewable and Sustainable Energy Reviews doi: 10.1016/j.rser.2016.01.074

[17] Patel R 2020 Mathematical Modelling.

[18] Subbiah R, Littleton J E 2018 Mathematical model.

[19] Bratanov V, Jenko F, Frey E 2015 New class of turbulence in active fluids Proceedings of the National Academy of Sciences of the United States of America

[20] Zare Sajad, Sahranavard Yaser, Hakimi Hossein, Bateni Mokhles, Karami Masoumeh & Hemmatjo Rasoul 2017 Designing, Constructing and Installing a Local Exhaust Ventilation System to Minimize Welders’ Exposure to Welding Fumes Archives of Hygiene Sciences 6 pp 356-362 doi: 10.29252/ArchHygSci.6.4.356