FRI-9.3-1-THPE-04

NUMERICAL MODELING THE INTERACTION OF TURBULENT JET WITH SUCTION OPENING WITH ECCENTRICITY BETWEEN SECTIONS[1]

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Abstract: *This paper is about the use of the computational fluid dynamics for obtaining a solution concerning interaction of a turbulent jet with suction opening with eccentricity between the sections. The accuracy of modern calculation methods give a reason to be used in the design of a local exhaust ventilation. This option with the presence of eccentricity is interesting for modeling because most of the technological processes in different industries are related to the separation of heated vapor and fine particles whose capture requires the use of eccentricity between the injection jet and the suction opening.*

Keywords: *turbulent jet, CFD modeling, suction opening, pollutants*

INTRODUCTION

Much of the industrial processes are related to the release of highly harmful substances, heavy metals and vapors. The main purpose of the ventilation systems is to evacuate these pollutants from the workspace and to keep the air clean in the relevant regulatory requirements. Researches (*Hayashi T., Howell R., Shibata M., Tsuji K. (1985); Industrial ventilation and air conditioning*; *Penev S. (2001). Promishlena ventilatsiya I obezprashavane, Sofiya*) show that, in the event of releases of substances with a relatively greater or less specific weight than that of the air it is most advantageous to use suction openings situated at an incline relative to the inflow (contaminated) jet or in the presence of eccentricity between the two sections.

Opportunities for rapid and efficient investigation of the interaction of turbulent jets carrying pollutants with suction opening through the use of modern software products, allows relatively easily with sufficient precision to be dimensioned local exhaust ventilation systems, knowing the initial and boundary conditions of a particular engineering task.

The purpose of this work is to show the interaction of a turbulent jet with a suction opening in the presence of eccentricity between the sections. The influence of the basic output parameters are investigated (inlet and suction velocity, distance between the suction noozle and inflow) on the distribution of velocity fields and the type of capture on the suction opening.

EXPOSITION

Build a geometric model

It is considered relatively simple construction, shown on figure 1. Position 1 is inlet duct submitting a turbulent jet to suction nozzle, marked with 2. Suction duct is shown on position 3. The presence of eccentricity between sections is indicated with "*e*", and the distance between sections with "*L*". The geometry of the model was built using the software product SolidWorks.

[1] Presented a report of October 27, 2016 with the original title: ЧИСЛЕНО МОДЕЛИРАНЕ НА ВЗАИМОДЕЙСТВИЕТО НА ТУРБУЛЕНТНА СТРУЯ СЪС СМУКАТЕЛЕН ОТВОР ПРИ НАЛИЧИЕ НА ЕКСЦЕНТРИЦИТЕТ МЕЖДУ СЕКЦИИТЕ.

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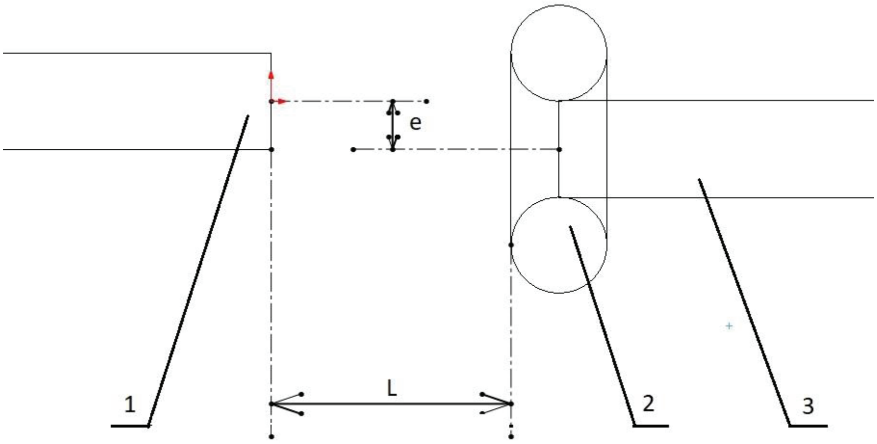

Figure 1. Geometric model for the study of turbulent jet interaction with suction opening in the presence of eccentricity between sections

The model equations representing the flow mathematicaly are known and used in Ansys Fluent and according to (Antonov I., 2016) are:

$$\rho\frac{\partial u}{\partial t}+\rho u\frac{\partial u}{\partial x}+\rho v\frac{\partial u}{\partial y}+\rho w\frac{\partial u}{\partial z}=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)+\frac{1}{3}\mu\frac{\partial}{\partial x}\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)+ \mu_t\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)+\frac{1}{3}\mu_t\frac{\partial}{\partial x}\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right) \quad (1)$$

$$\rho\frac{\partial v}{\partial t}+\rho u\frac{\partial v}{\partial x}+\rho v\frac{\partial v}{\partial y}+\rho w\frac{\partial v}{\partial z}=-\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)+\frac{1}{3}\mu\frac{\partial}{\partial y}\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)+ \mu_t\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)+\frac{1}{3}\mu_t\frac{\partial}{\partial y}\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right) \quad (2)$$

$$\rho\frac{\partial w}{\partial t}+\rho u\frac{\partial w}{\partial x}+\rho v\frac{\partial w}{\partial y}+\rho w\frac{\partial w}{\partial z}=-\frac{\partial p}{\partial z}+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)+\frac{1}{3}\mu\frac{\partial}{\partial z}\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)+ \mu_t\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)+\frac{1}{3}\mu_t\frac{\partial}{\partial z}\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right) \quad (3)$$

The continuity equation is added:

$$\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0 \quad (4)$$

The system of equations (1÷4) is limited to the following characteristic equation:

$$\frac{\partial}{\partial t}(\rho\Phi)+div(\rho V\Phi)=div(\Gamma grad\Phi)+S\,, \quad (5)$$

where Φ is dependent variable; Γ – diffusion coefficient of Φ; S – source part of of the respective Φ. Their values are given at table 1.

Table 1 Values of Γ and S for each Φ

Φ	Γ	S
1	0	0
u	$\mu+\mu_t$	$\Gamma\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)-\frac{\partial p}{\partial x}+\frac{1}{3}\frac{\partial}{\partial x}\Gamma\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)$
v	$\mu+\mu_t$	$\Gamma\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)-\frac{\partial p}{\partial y}+\frac{1}{3}\frac{\partial}{\partial y}\Gamma\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)$
w	$\mu+\mu_t$	$\Gamma\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)-\frac{\partial p}{\partial z}+\frac{1}{3}\frac{\partial}{\partial z}\Gamma\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)$

Standard k-ε turbulence model is chosen, which is based on the transport equations for turbulent kinetic energy “k” and turbulent dissipation „ε“, respectively equations (6) and (7):

$$\rho \frac{Dk}{Dt} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G_k - \rho\varepsilon \qquad (6)$$

$$\rho \frac{D\varepsilon}{Dt} = \frac{\partial}{\partial x_j}\left(\frac{\mu_t}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial x_j}\right) + (C_{1\varepsilon}G_k - C_{2\varepsilon}\varepsilon)\frac{\varepsilon}{k} \qquad (7)$$

where: Gk – generation of turbulence kinetic energy due to the mean velocity gradients, $\mu t = C\mu\rho k^2/\varepsilon$ – turbulent viscosity. The standard values of the constants in the equations are:

$C\mu=0.09$ $C_{\varepsilon 1}=1.44$ $C_{\varepsilon 2}=1.92$ $\sigma_k=1$ $\sigma_\varepsilon=1.3$

Simulation of processes is made in Fluent module of software product Ansys (Ansys Fluent 12.0 User’s guide, 2009). The solution is reached after approximately 380 iteractions, according to the predefined criteria.

Results of the numerical solution

In the present work are considered three options of interaction of turbulent jet with suction opening with the presence of eccentricity “e” 50 mm between the sections. Variable parameter is the distance “L” between suction nozzle and inlet duct, and varies between 250 and 750 mm. The output data for the three options considered are shown in a tabular form:

Table 1: Output data for the three options of interaction of turbulent jet with suction opening

Option 1 L=250mm, e=50mm			**Option 2 L=500mm, e=50mm**		
Name	Value	Dimensionality	Name	Value	Dimensionality
Inlet duct			Inlet duct		
Diameter Dн	100	mm	Diameter Dн	100	mm
Lenght	300	mm	Lenght	300	mm
Suction duct			Suction duct		
Diameter Dc	100	mm	Diameter Dc	100	mm
Lenght	1900	mm	Lenght	1650	mm
Distance between sections, L	250	mm	Distance between sections, L	500	mm
Параметри на струите			Параметри на струите		
Inlet flow rate, Qн	0,039132	kg/s	Inlet flow rate, Qн	0,0402	kg/s
Suction flow rate, Qc	0,13656	kg/s	Suction flow rate, Qc	0,13688	kg/s
Flow rate relationship: Qc/Qн	3,49		Flow rate relationship: Qc/Qн	3,40	
Eccentricity	50	mm	Eccentricity	50	mm

Option 3 L=750mm, e=50mm		
Name	Value	Dimensionality
Inlet duct		
Diameter Dн	100	mm
Lenght	300	mm
Suction duct		
Diameter Dc	100	mm
Lenght	1400	mm
Distance between sections, L	750	mm
Параметри на струите		
Inlet flow rate, Qн	0,043368	kg/s

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Suction flow rate, Qc	0,15024	kg/s
Flow rate relationship: Qc/QH	3,46	
Eccentricity	50	mm

Visualisation of the velocity fields from simulated options, described above are shown on figures 2-4 with sections on the leakage axis. The turbulent character is clearly visible also the jet curvature approaching to the suction nozzle, because of the eccentricity.

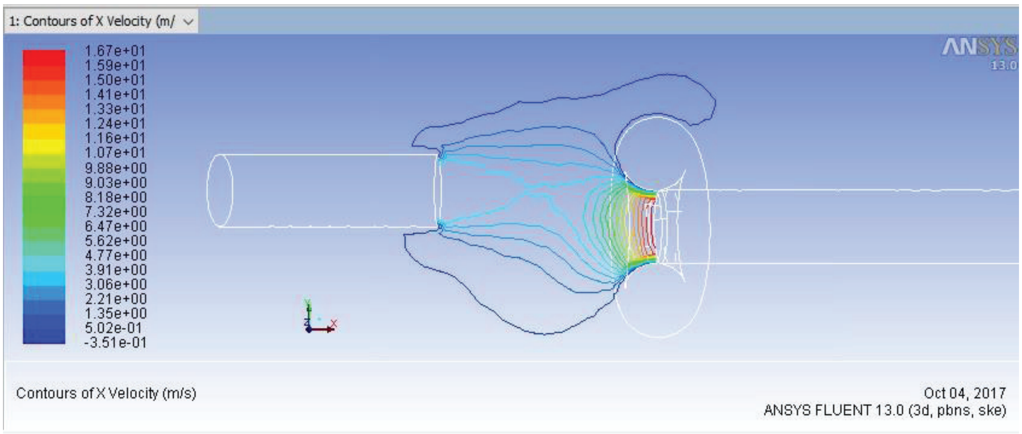

Figure. 2. Current lines of the jet at a distance L=250 mm

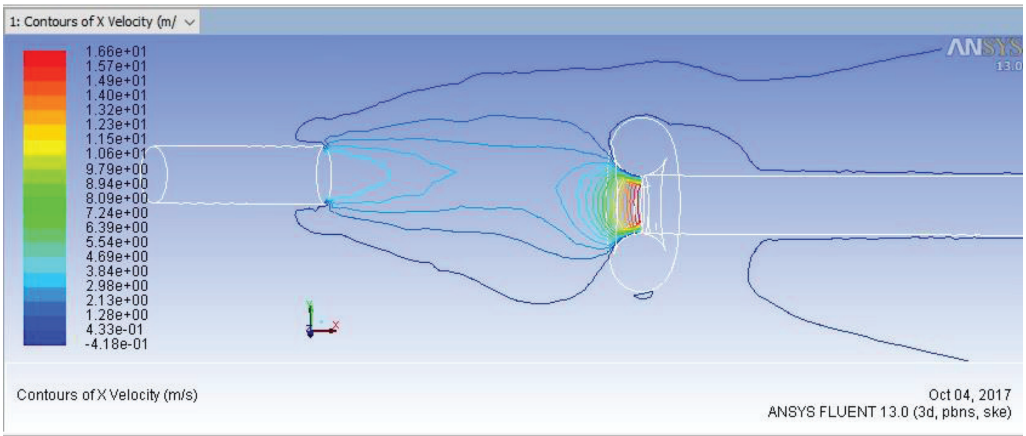

Figure 3. Current lines of the jet at a distance L=500 mm

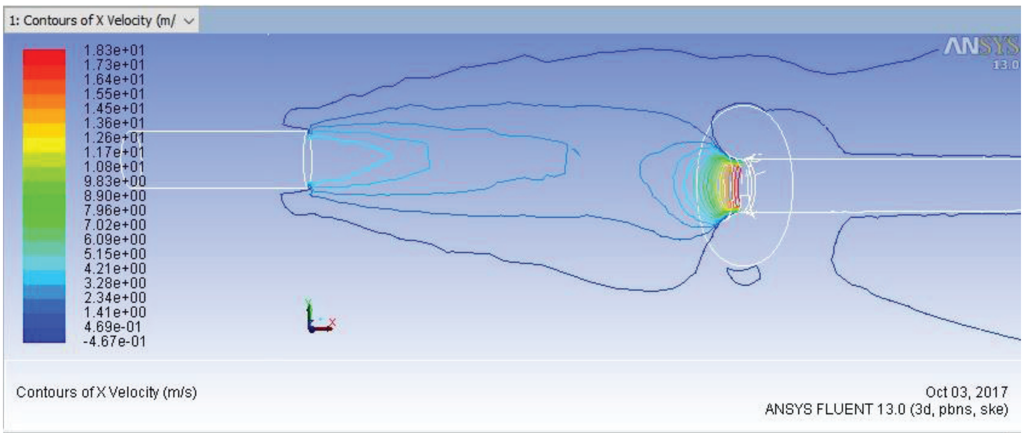

Figure 4. Current lines of the jet at a distance L=750 mm

Speed profiles in characteristic sections are considered and shown on figures 5-7. Now it is clear that at different distances between the two sections maintaining the ratio of the sucked to the main flow, even in the presence of eccentricity, the velocity profiles in the characteristic sections (near the suction nozzle and after the inlet section) are kept constant.

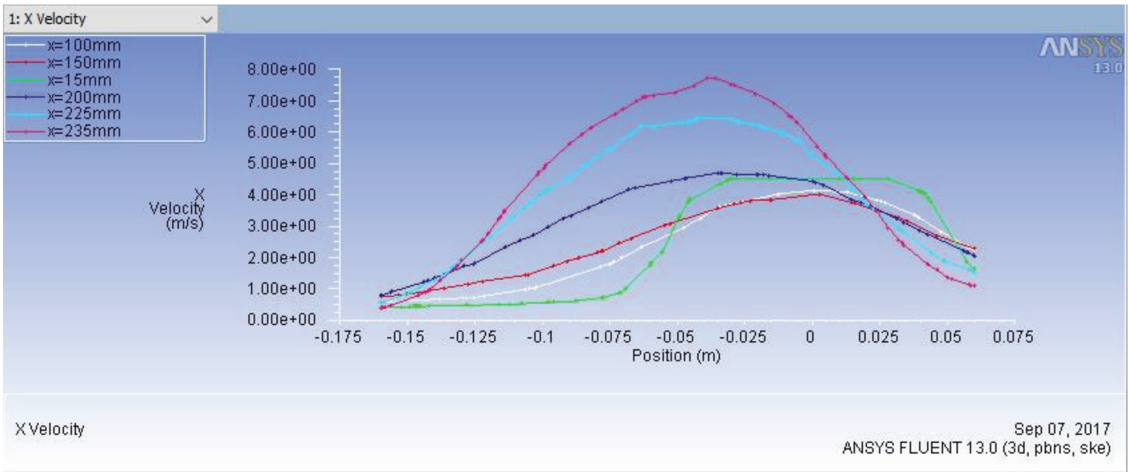

Figure 5. Velocity profiles of the jet at a distance L = 250 mm

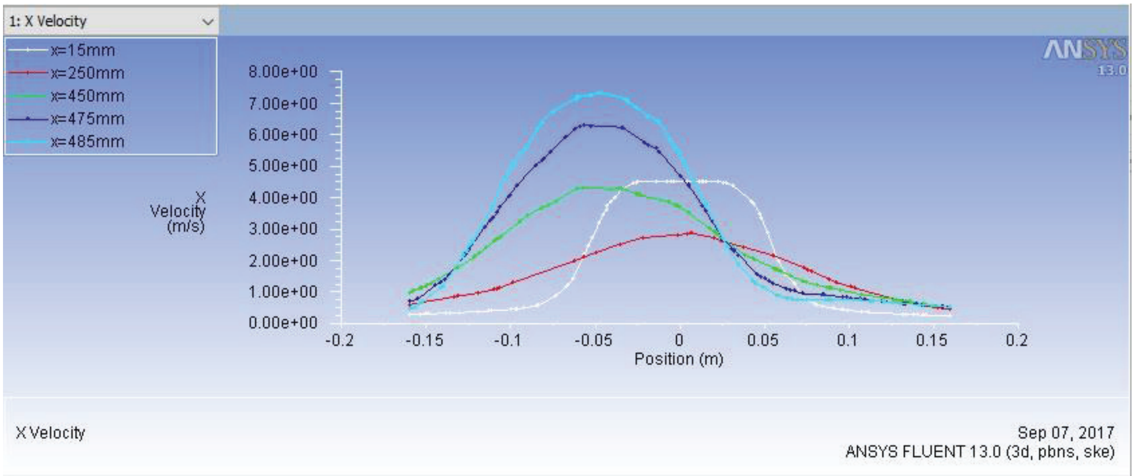

Figure 6. Velocity profiles of the jet at a distance L = 500 mm

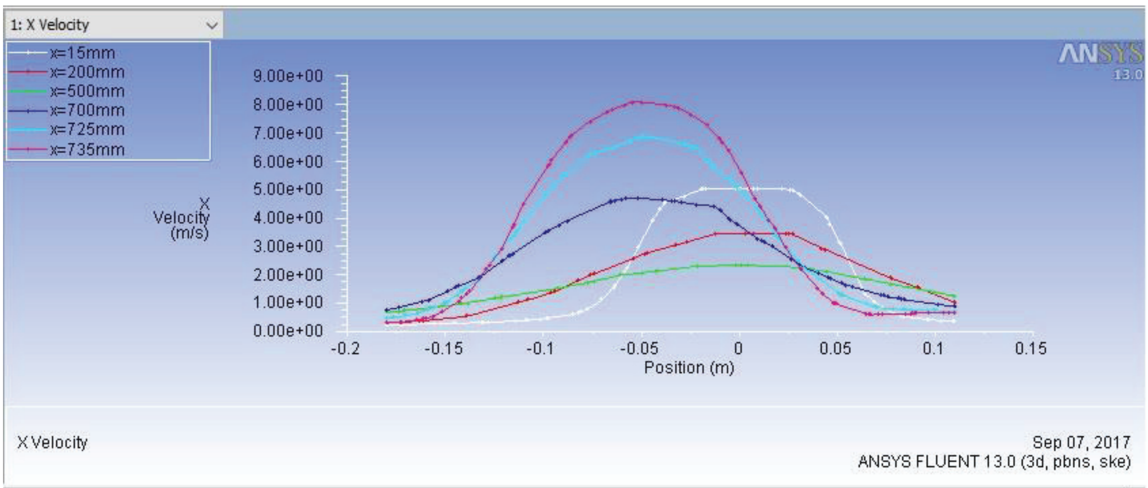

Figure 7. Velocity profiles of the jet at a distance L = 750 mm

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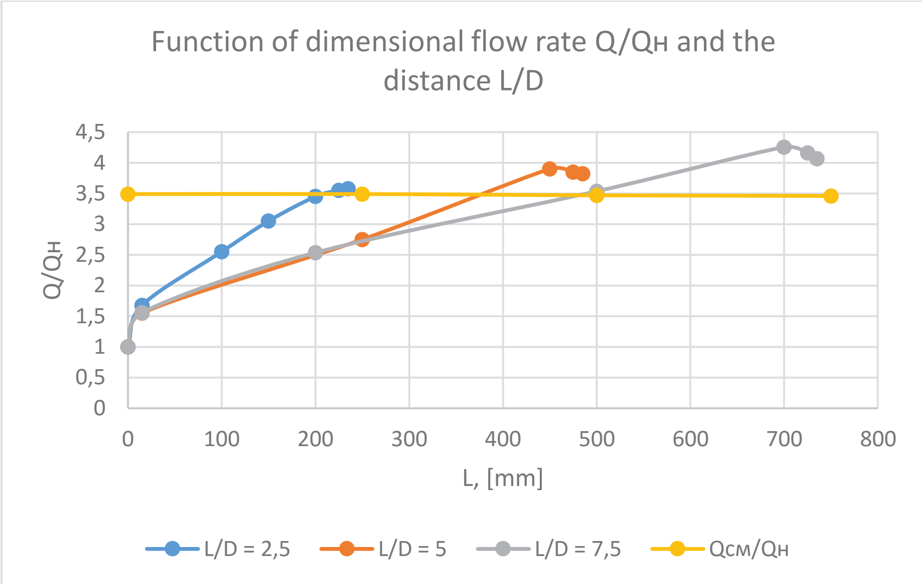
CONCLUSION

The numerical simulations of interaction of a turbulent jet with suction opening, using CFD modelling can be used for building a dimensionless graphic dependence (figure 8) of the flow ratio in a given section related to inlet flow „Q/Qн“ at different dimensional distances of inlet and suction ducts „L/D“. This graph can be used to design local exhaust ventilation and to determine the optimal distance between the suction and the inlet ducts at a given flow rate Qсм/Qн to achieve complete trapping of the suction nozzle.



Фиг. 8. Function of dimensional flow rate Q/Qн and the distance L/D

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