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Parameters calculation of turbulent fluid flow in a pipe of a circular cross section

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ABSTRACT

The dependencies of total pressure, velocity, vorticity, turbulent length, turbulent dissipation, turbulent viscosity, turbulent energy and turbulent time of moving fluid from a straight pipe length of a circular cross section are presented in graphical and mathematical forms. Changing analysis of considered parameters was performed at mass flow rates of 0.45, 1.0 and 1.5 kg/s. A transition boundary of laminar flow of fluid to turbulent flow is at the distance of $^2/_5$ of length from the inlet of the pipe (at accepted total length of the pipe of 1000 mm).

Keywords *– fluid, turbulent flow, a pipe, a model, a section.*

I. INTRODUCTION

At present, a question of sustainability of laminar/transient flow regimes of fluid in pipelines has not been fully studied. According to numerous experimental data, it is determined that even in small straight sections of the pipeline, fluid flow changes from laminar to turbulent [1 – 7].

Flow pattern of fluid is determined by viscosity, flow velocity, a cross-sectional area of the pipe, composition of fluid mixture and other parameters. Also, flow pattern of fluid depends on the ratio of accelerating force and viscous friction force.

Conducting of experiments on a research of fluid flow regimes in the production, and even in the laboratory conditions, is difficult. A computer simulation of hydrodynamic processes of fluid flow in the pipelines allows not only to present a visual model of fluid flow, but also to obtain accurate or approximate mathematical equations describing pattern of each flow regime.

II. MATERIAL AND METHOD

Intensity changing of the parameters of turbulent fluid flow in the pipe of the circular cross section was determined by calculations in the *Flow Simulation* special computer program. Three solid-state pipe models with the same overall dimensions (internal diameter is 30 mm and total length is 1000 mm) were built for the computer simulation.

Different mass of the incompressible fluid model (water) at temperature of 293.2 K was supplied per unit of time (second) in the inlet of the pipe models. Specified mass flow rates for three pipe models are presented in the table I.

TABLE I. MASS FLOW RATES OF FLUID.

The pipe model	The first	The second	The third
Mass flow rate of fluid Q_M, kg/s	0.45	1.0	1.5

Fluid flow direction was taken normal to a face of the inlet of the pipe model. Turbulence intensity I_t (2%) and turbulence length L_t (0.0008 m) were taken as the basic parameters of developed turbulent fluid motion in the pipe model. Turbulence intensity of fluid flows depends on characteristics of the pipe and the Reynolds number *Re*. Fluid pressure at the outlet of the pipe model was taken of 101325 Pa. Laminar and turbulent fluid flows were taken into account in the calculation. The cavitation process in the calculation was not accepted.

An inner wall of the pipe model had the properties of the adiabatic wall with the perfectly smooth surface (the surface roughness is 0 μm). Initial temperature of the inner surface of the pipe model was taken of 293.2 K.

Accuracy of the calculation results was average when a number of finite elements of the fluid model equal to 3264 and the pipe model equal to 528.

III. Result and discussion

Flow pattern of fluid in the pipe model of the circular cross section is presented in the form of vectors (the Fig. 1).

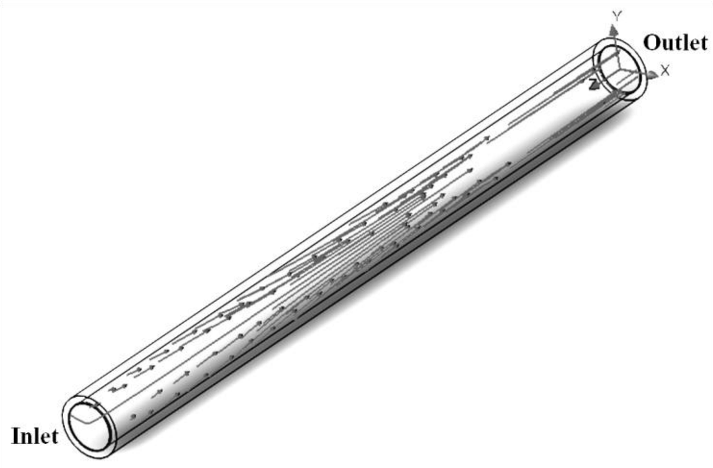
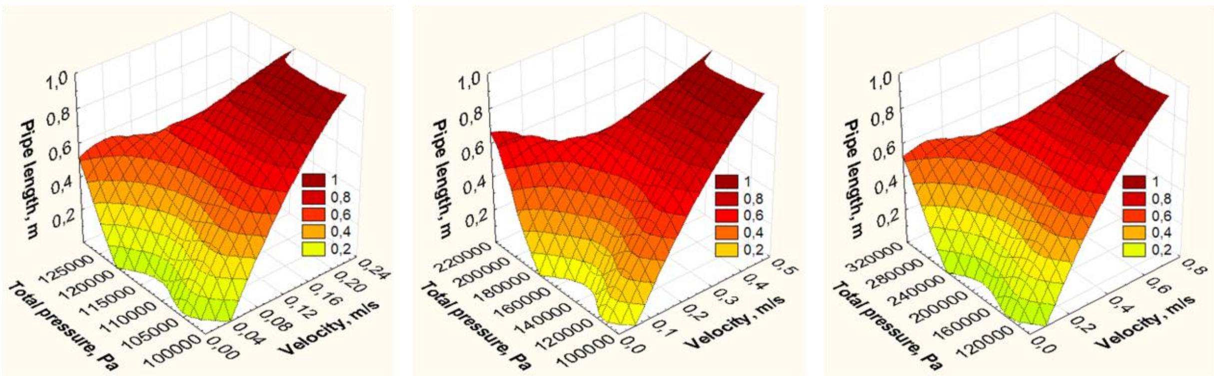


Fig. 1. Water flow at the straight section of the three-dimensional pipe model of the circular cross section.

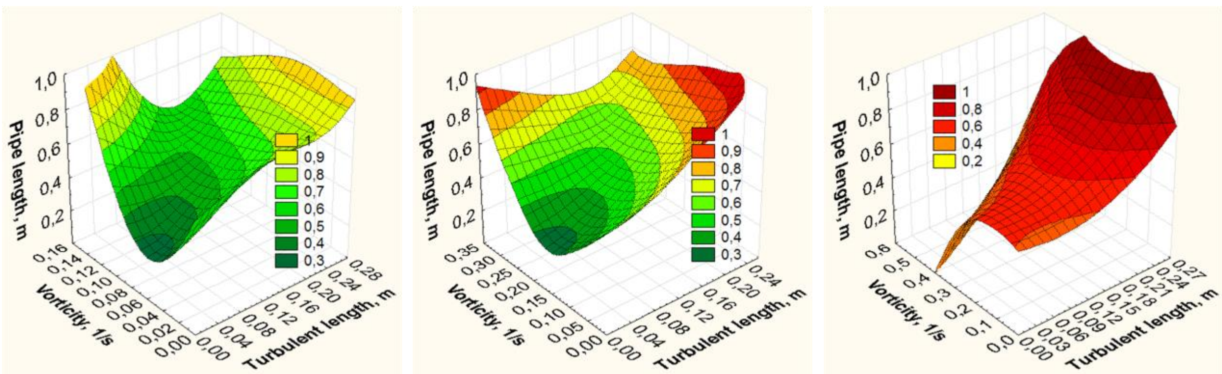
Vortex formation of fluid flows is observed in a center part of a calculated field of the pipe model, laminar regime prevails at the inlet and the outlet.

The dependencies of the changing values of the turbulent fluid flow parameters from length of the model pipe of the circular cross section are presented in the Fig. 2 – 5. The data were obtained from the axial line of fluid motion in the pipe model.



a) b) c)

Fig. 2. The dependencies of flow velocity and total pressure of fluid from the pipe length: a) at Q_M = 0.45 kg/s; b) at Q_M = 1.0 kg/s; c) at Q_M = 1.5 kg/s.



a) b) c)

Fig. 3. The dependencies of turbulent length and vorticity of fluid from the pipe length: a) at Q_M = 0.45 kg/s; b) at Q_M = 1.0 kg/s; c) at Q_M = 1.5 kg/s.

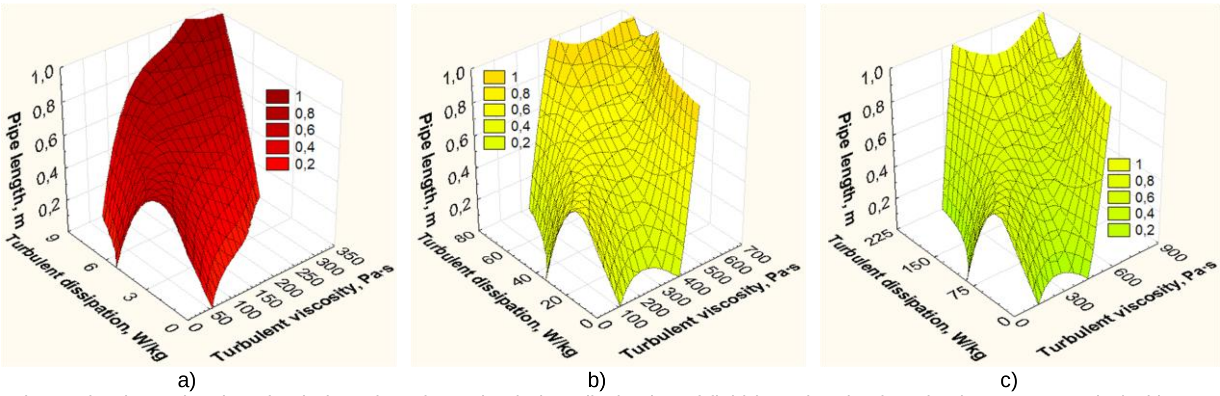


Fig. 4. The dependencies of turbulent viscosity and turbulent dissipation of fluid from the pipe length: a) at Q_M = 0.45 kg/s; b) at Q_M = 1.0 kg/s; c) at Q_M = 1.5 kg/s.

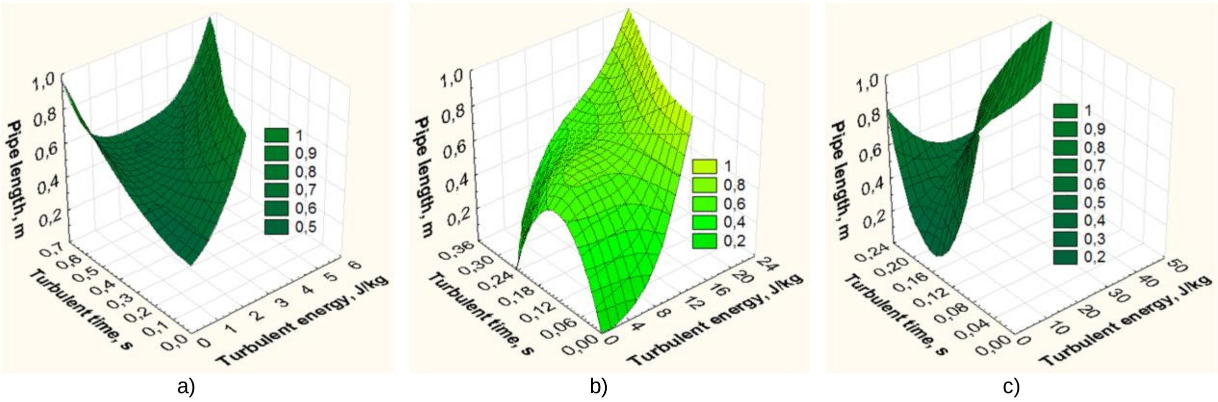


Fig. 5. The dependencies of turbulent energy and turbulent time of fluid from the pipe length: a) at Q_M = 0.45 kg/s; b) at Q_M = 1.0 kg/s; c) at Q_M = 1.5 kg/s.

Based on the analysis of the dependencies graphs of flow velocity and total fluid pressure, turbulent length and vorticity of fluid, turbulent viscosity and turbulent dissipation of fluid, turbulent energy and turbulent time of fluid flow from length of the pipe model, it could be argued that:

1. The values of the considered parameters of turbulent fluid flow increase with increasing of mass flow rate at the distance from the inlet to the outlet of the pipe model. Herewith, turbulent time of fluid in the each section of the pipe model decreases.
2. Pressure, flow velocity, turbulent dissipation and turbulent viscosity of moving fluid have almost the same pattern of changing over entire length of the pipe model. The other parameters of turbulent fluid flow in the pipe model have different regularities.

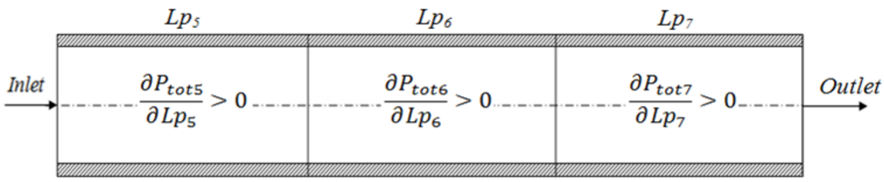
Let us consider flow pattern of fluid in the second pipe model. Total length of the pipe model was divided into 10 equal sections. Length of the each section was 100 mm (0.1 m). Herewith, *0* was taken by the inlet of the pipe model, and *1* was taken by the outlet. Let us write down the parameters changing of turbulent fluid flow in the each section of the pipe model in the functions form (the tables II – IV): $P_{tot}(L_p)$, $\varepsilon_t(L_p)$, $L_t(L_p)$, $u(L_p)$, $t_t(L_p)$, $v_t(L_p)$, $k_t(L_p)$ and $\omega(L_p)$.

TABLE II. THE PARAMETERS CHANGING OF TURBULENT FLUID FLOW IN THE FIRST TO THE FOURTH SECTIONS OF THE PIPE MODEL.

	Lp_1	Lp_2	Lp_3	Lp_4	
Inlet 0	$\frac{\partial P_{tot1}}{\partial Lp_1} = 0$	$\frac{\partial P_{tot2}}{\partial Lp_2} = 0$	$\frac{\partial P_{tot3}}{\partial Lp_3} = 0$	$\frac{\partial P_{tot4}}{\partial Lp_4} = 0$	Outlet
	$P_{tot1} = 202950e^{9.9557 \cdot 10^{-10} Lp_1}$	$P_{tot2} = 202950e^{1.0151 \cdot 10^{-9} Lp_2}$	$P_{tot3} = 202950e^{1.0382 \cdot 10^{-9} Lp_3}$	$P_{tot4} = 202950e^{1.1346 \cdot 10^{-9} Lp_4}$	
	$\varepsilon_{t1} = 0.2983e^{0.0002 Lp_1}$	$\varepsilon_{t2} = 0.2984e^{0.0001 Lp_2}$	$\varepsilon_{t3} = 0.2989e^{0.0001 Lp_3}$	$\varepsilon_{t4} = 0.3008e^{1.1637 \cdot 10^{-5} Lp_4}$	

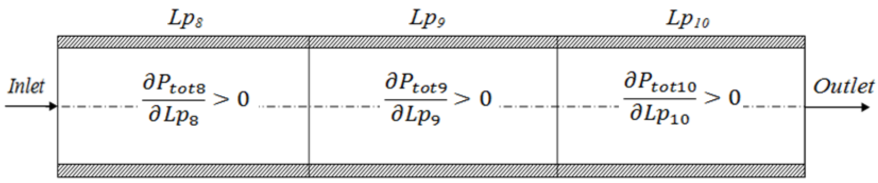
$L_{t1}=0.0017e^{-9.3762\cdot10^{-6}Lp_1}$	$L_{t2}=0.0017e^{-7.9763\cdot10^{-6}Lp_2}$	$L_{t3}=0.0017e^{-6.2387\cdot10^{-6}Lp_3}$	$L_{t4}=0.0017e^{-3.9188\cdot10^{-6}Lp_4}$
$u_1=0.0036e^{0.0029Lp_1}$	$u_2=0.0037e^{0.0028Lp_2}$	$u_3=0.0037e^{0.0027Lp_3}$	$u_4=0.0038e^{0.0024Lp_4}$
$t_{t1}=0.0711e^{-6.6033\cdot10^{-5}Lp_1}$	$t_{t2}=0.0711e^{-5.3932\cdot10^{-5}Lp_2}$	$t_{t3}=0.0711e^{-3.9038\cdot10^{-5}Lp_3}$	$t_{t4}=0.0709e^{-2.6339\cdot10^{-6}Lp_4}$
$v_{t1}=0.1475e^{3.6208\cdot10^{-5}Lp_1}$	$v_{t2}=0.1475e^{2.9879\cdot10^{-5}Lp_2}$	$v_{t3}=0.1475e^{2.2173\cdot10^{-5}Lp_3}$	$v_{t4}=0.1478e^{-8.4752\cdot10^{-7}Lp_4}$
$k_{t1}=0.022e^{0.0001Lp_1}$	$k_{t2}=0.022e^{8.3904\cdot10^{-5}Lp_2}$	$k_{t3}=0.022e^{6.2324\cdot10^{-5}Lp_3}$	$k_{t4}=0.0221e^{6.6643\cdot10^{-6}Lp_4}$
$\omega_1=0.1942e^{0.0017Lp_1}$	$\omega_2=0.1944e^{0.0017Lp_2}$	$\omega_3=0.1951e^{0.0016Lp_3}$	$\omega_4=0.193e^{0.0017Lp_4}$

TABLE III. THE PARAMETERS CHANGING OF TURBULENT FLUID FLOW IN THE FIFTH TO THE SEVENTH SECTIONS OF THE PIPE MODEL.



$P_{tot5}=202950e^{1.3425\cdot10^{-9}Lp_5}$	$P_{tot6}=206630e^{-6.5981\cdot10^{-5}Lp_6}$	$P_{tot7}=735640e^{-0.0026Lp_7}$
$\varepsilon_{t5}=0.3067e^{-0.0002Lp_5}$	$\varepsilon_{t6}=0.0034e^{0.0181Lp_6}$	$\varepsilon_{t7}=0.5027e^{0.0088Lp_7}$
$L_{t5}=0.0017e^{-2.6022\cdot10^{-7}Lp_5}$	$L_{t6}=2.7591\cdot10^{-5}e^{0.0167Lp_6}$	$L_{t7}=0.059e^{0.0026Lp_7}$
$u_5=0.0043e^{0.0012Lp_5}$	$u_6=0.0002e^{0.0131Lp_6}$	$u_7=0.0033e^{0.0089Lp_7}$
$t_{t5}=0.0704e^{7.6711\cdot10^{-5}Lp_5}$	$t_{t6}=0.0202e^{0.0051Lp_6}$	$t_{t7}=0.6355e^{-0.0012Lp_7}$
$v_{t5}=0.1485e^{-5.4355\cdot10^{-5}Lp_5}$	$v_{t6}=0.0001e^{0.0279Lp_6}$	$v_{t7}=18.214e^{0.0063Lp_7}$
$k_{t5}=0.0224e^{-0.0001Lp_5}$	$k_{t6}=7.3856\cdot10^{-5}e^{0.023Lp_6}$	$k_{t7}=0.3194e^{0.0076Lp_7}$
$\omega_5=0.1961e^{0.0017Lp_5}$	$\omega_6=0.4569e^{-0.0031Lp_6}$	$\omega_7=0.0874e^{0.0024Lp_7}$

TABLE IV. THE PARAMETERS CHANGING OF TURBULENT FLUID FLOW IN THE EIGHTH TO THE TENTH SECTIONS OF THE PIPE MODEL.



$P_{tot8}=14195000e^{-0.0038Lp_8}$	$P_{tot9}=2162300e^{-0.0046Lp_9}$	$P_{tot10}=7624400e^{-0.0067Lp_{10}}$
$\varepsilon_{t8}=6.6458e^{0.004Lp_8}$	$\varepsilon_{t9}=21.802e^{0.0019Lp_9}$	$\varepsilon_{t10}=34.5148e^{0.0011Lp_{10}}$
$L_{t8}=0.1082e^{0.0014Lp_8}$	$L_{t9}=0.1879e^{0.0004Lp_9}$	$L_{t10}=0.2273e^{0.0001Lp_{10}}$
$u_8=93.1834e^{-0.01Lp_8}$	$u_9=0.0442e^{0.0036Lp_9}$	$u_{10}=0.0396e^{0.0038Lp_{10}}$
$t_{t8}=0.4028e^{-0.0004Lp_8}$	$t_{t9}=0.3915e^{-0.0003Lp_9}$	$t_{t10}=0.3813e^{-0.0003Lp_{10}}$
$v_{t8}=96.7102e^{0.0032Lp_8}$	$v_{t9}=300.0135e^{0.0012Lp_9}$	$v_{t10}=450.542e^{0.0005Lp_{10}}$
$k_{t8}=2.6755e^{0.0036Lp_8}$	$k_{t9}=8.5355e^{0.0016Lp_9}$	$k_{t10}=13.1607e^{0.0008Lp_{10}}$
$\omega_8=3236300e^{-0.0297Lp_8}$	$\omega_9=7.6045e^{-0.0078Lp_9}$	$\omega_{10}=0.0003e^{0.0092Lp_{10}}$

In the presented functions are conditionally designated: P_{tot1}, P_{tot2}, P_{tot3}, …, P_{tot10} – total pressure of fluid in the first, the second, the third, …, the tenth sections of the pipe model, Pa; L_{p1} = (0;0.1], L_{p2} = (0.1;0.2], L_{p3} = (0.2;0.3], L_{p4} = (0.3;0.4], L_{p5} = (0.4;0.5], L_{p6} = (0.5;0.6], L_{p7} = (0.6;0.7], L_{p8} = (0.7;0.8], L_{p9} = (0.8;0.9], L_{p10} = (0.9;1.0] – the length ranges of the each section of the pipe model, m (the values in the range are location coordinates of the corresponding section, starting from the inlet of the pipe model); ε_{t1}, ε_{t2}, ε_{t3}, …, ε_{t10} – turbulent dissipation of fluid in the first, the second, the third, …, the tenth sections of the pipe model, W/kg; L_{t1}, L_{t2}, L_{t3}, …, L_{t10} – turbulent length of fluid flow in the first, the second, the third, …, the tenth sections of the pipe model, m; u_1, u_2, u_3, …, u_{10} – flow velocity of fluid in the first, the second, the third, …, the tenth sections of the pipe model, m/s; t_{t1}, t_{t2}, t_{t3}, …, t_{t10} – turbulent time of fluid flow in the first, the second, the third, …, the tenth sections of the pipe model, s; v_{t1}, v_{t2}, v_{t3}, …, v_{t10} – turbulent viscosity of fluid in the first, the second, the third, …, the tenth sections of the pipe model, Pa·s; k_{t1}, k_{t2}, k_{t3}, …, k_{t10} – turbulent energy of fluid in the first, the second, the third, …, the tenth sections of the pipe model, J/kg; ω_1, ω_2, ω_3, …, ω_{10} – vorticity of fluid in the first, the second, the third, …, the tenth sections of the pipe model, 1/s.

In the first four sections, non-gradient flow is observed, i.e. fluid in these sections does not completely fill the cross section of the pipe model. Thickness of a boundary layer (the thin near-wall layer) increases at non-gradient flow of fluid. In the remaining sections of the pipe model, an area with positive pressure gradient was determined in which fluid flow was slowing down. Fluid flow slows in the boundary layer and in the flow core (external flow). Fluid slowing is more quickly in the boundary layer by increasing its thickness.

The general analytical formula was obtained after the analysis of the calculated mathematical equations for determining of the parameters of turbulent fluid flow in the pipe model of the circular cross section:

$$\int Ae^{kx}dx = \frac{A}{k}(e^{kx} - 1),$$

where *A* is numerical coefficient of the function; *k* is power coefficient of the function.

IV. Conclusion

1. Changing pattern of flow velocity and total pressure, and, consequently, turbulent dissipation and viscosity of moving fluid does not depend on mass flow rate.
2. The more mass flow rate of fluid, the more strongly signs of turbulence are observed (the Fig. 3, *c* and the Fig. 5, *c*).
3. At the distance of $^2/_5$ of length from the inlet of the pipe, fluid flow is closer to laminar. At the distance of $^3/_5$ of length from the outlet of the pipe, interaction of direct and reverse fluid flows occurs, which causes vortices, and, consequently, laminar regime turns into turbulent.

References

[1] D. Chemezov, Calculation of pressure losses of liquid at a cylindrical straight pipeline section, ISJ Theoretical & Applied Science, 12 (56), 2017, 19 – 22. DOI 10.15863/TAS.2017.12.56.5

[2] D.A. Chemezov, Hydrodynamic characteristics of water flow in straight and curved sections of a pipeline, Modern materials, equipment and technology [Text]: Materials of the 4th International scientific and practical conference, South-West State University, CJSC «University book», Kursk, 2015, 468 – 471. ISBN 978-5-9906195-4-8.

[3] D. Chemezov, N. Palev, Analytical models of the turbulent fluid flow in a circular pipe, ISJ Theoretical & Applied Science, 09 (41), 2016, 77 – 84. DOI 10.15863/TAS.2016.09.41.12

[4] V. Oshovskiy, A. Dyubanov, Computer modelling of the hydrodynamic effects arising in the narrowing device, Scientific Works of Donetsk National Technical University, 2(21), 2013, 168 – 169. ISSN 2074-6652.

[5] I. Tsukanov, V. Shapiro, S. Zhang, A Mesh free Method for Incompressible Fluid Dynamics Problems, Int. J. Numer. Meth. Eng., 2003, Vol. 58.

[6] D.S. Henningson, P.J. Schmid, Stability and transition in shear flows, New-York, 2001.

[7] A.V. Proskurin, A.M. Sagalakov, Viscous Fluid Flow in a Coaxial Pipe, Izvestiya of Altai State University Journal, 2016, 62 – 68. DOI 10.14258/izvasu(2016)1-10