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About the Modeling of Detachable Flows on the Entrance of the Round Soaking-up Branch Pipe

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Abstract: Mathematical modeling methods of detachable flows on the entrance of the soaking-up channel on the basis of discrete vortex features of ring and polygonal forms are discussed. The tasks in stationary, non-stationary axisymmetric and quasiaxisymmetric statement are considered. The comparison of speed predicted values with experimental data of other authors is done. The conclusion about usage possibility of vortex polygonal elements for flows investigation in operation ranges of stitched and exhaust devices at their interaction, in three-dimensional areas is done.

Key words: Detachable flows · Discrete vortexes · Flows near the soaking-up channel

INTRODUCTION

A round branch pipe is an element of many technological installations, in particular in local exhaust ventilation round soaking-up umbrellas are used for catching dust-gas emissions, in the aircraft equipment round air inlets are used, various nozzles and samplers [1,2] also have a round form. Therefore investigation of flows at absorption or the expiration from such branch pipes represents considerable interest for science and technology. Tens of thousands of scientific works are devoted to the expiration of turbulent streams, to soaking-up torches much less. Measurement of stream separation on the entrance of soaking-up channels approaches predicted values to data gotten after experiment [3-21]. The found outlines of vortex areas allow to develop recommendations about profiling of a branch pipe entrance edges and decrease of its aerodynamic resistance [3, 7-9, 12]. Usage of thin profiles and screens allows, due to the stream effect, to reduce volumes of the air arriving into the aspiration systems [13-21]. For numerical investigations of detachable currents well a method of discrete vortexes works fine [4-6, 8-15, 18-21, 24, 25]. In works [9, 13, 18, 19, 21] stationary problem definition for calculation of detachable flows on the entrance of slit-like and round soaking-up channels was used and in works [4-6, 7-13, 18, 20] non-stationary problem definition was used. In these works as discrete vortex features infinitely thin rectilinear vortex cords and ring vortexes were used. In this work for creation of discrete model for these vortex elements a polygonal vortex framework that will allow to pass to the solution of three-dimensional tasks on soaking-up torches taking into account a stream separation are added. The purpose of work is development and research of various mathematical modeling methods of detachable flows on the entrance of a round soaking-up pipe using ring and polygonal discrete vortex features.

Axisymmetric Task in Stationary Statement: Let's consider area of the flow (Fig. 1) on the entrance of the round soaking-up channel. From a sharp edge C there is a failure of a stream and a free surface of current is formed. It is necessary to define its location, stream speed in any set point.

The mathematical problem definition consists in solution of two-dimensional Laplace equation for potential function φ:

$$\Delta\varphi = 0,$$

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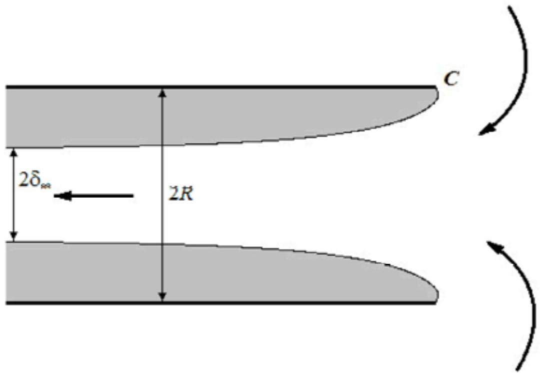

Fig. 1: Detachable flow on the entrance to the round pipe in the meridional surface

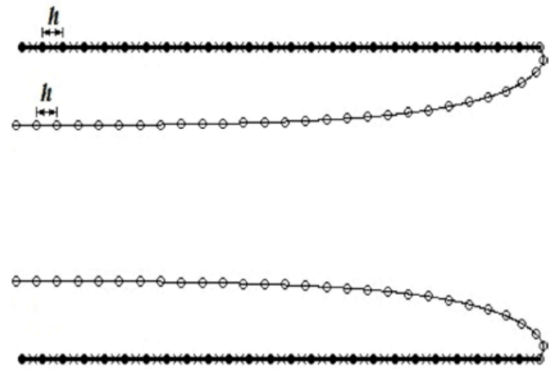

Fig. 2: Flow discrete model (daggers - control points; the painted-over circles - the attached vortex rings; circles - free vortex rings)

at set points of a boundary normal speed component as $\left.\frac{\partial\varphi}{\partial n}\right|_S = v_n(x) - U_n$, where x – limit point S. Function expresses influence of the free vortexes being on a free surface of current which location is not known in advance.

This equation is reduced to the boundary singular integrated equation:

$$\int_S G(x,\xi)\omega(\xi)ds(\xi) = v_n(x) - \mu\int_\sigma G(x,\xi)d\sigma(\xi),$$

where $\omega(\xi)$ – circulation density of the attached vortex layer; $\mu = const$- circulation density of the free vortex layer which has been continuously placed on a surface, being formed at stream failure from a sharp edge; ξ – any point of border S. Function $G(x.\xi)$ is numerically equal to speed size in a point $x(x_1,x_2)$ along the direction of a single vector $n = \{n_1,n_2\}$, caused by a vortex of single circulation, located in the point. $\xi(\xi_1,\xi_2)$.

For an axisymmetric task in cylindrical system of coordinates:

$$\begin{cases} G(x,\xi) = \dfrac{(A_1 b + A_2 a)}{b}\cdot\dfrac{4}{(a-b)\sqrt{a+b}} \\ E(t) - \dfrac{A_2}{b}\cdot\dfrac{4}{\sqrt{a+b}}F(t) \quad at\ b \neq 0, \\ G(x,\xi) = \dfrac{\xi_2^2 \cdot n_1}{2a\sqrt{a}} \qquad at\ b = 0, \end{cases} \tag{1}$$

$$2x_2\xi_2 = b > 0,\ a = (x_1-\xi_1)^2 + \xi_2{}^2 + x_2{}^2 > 0,$$

$$A_1 = \frac{\xi_2{}^2 n_1}{4\pi}$$

$$A_2 = \frac{\xi_2}{4\pi}\left[(x_1-\xi_1)n_2 - x_2 n_1\right]$$

$$F(t) = \int_0^{p/2}\frac{d?}{\sqrt{1-t^2\sin^2 ?}},$$

$$E(t) = \int_0^{p/2}\sqrt{1-t^2\sin^2 ?}\,d?,\ t = \frac{2b}{a+b}$$

The vortex layer modeling a pipe surface, is replaced with infinitely thin vortex rings of constant intensity $I\left(\xi^k\right), k=\overline{1,N}$ (Fig. 2). The vortex lying on a sharp edge C, is considered free that follows from the theorem stated in work [25]: intensity of the attached vortex layer is in a point of stream failure equals to zero. Between the attached vortexes control points settled down. Let's enter designations: $\xi^k(\xi_1,\xi_2)$ – point of an arrangement of k attached vortex; $x^p(x_1,x_2)$ – p control point. Then speed in a point x^p along the single direction n, induced by vortex $I(\xi^k)$, located in the point ξ^k, will be defined from expression $v_n\left(x^p\right) = G\left(x^p,\xi^k\right)I\left(\xi^k\right)$.

It was supposed that on the free surface of current which is flowing down from the edge C, intensity of vortexes is constant and equal to γ. The distance between free vortexes is a constant and equal value h. The first approach for the free line of current got out as follows. The first 3 vortex rings settled down in the plane of the entrance aperture of the channel starting from a sharp edge, at uniform radius reduction with step h, the others with a constant radius and their shift into the pipe with the same step of h.

Let's designate N as a quantity of the attached vortexes; ζ^k– as a location point of free vortex; N_s - as a quantity of free vortexes located on a free surface of current, being broken from a sharp edge C.

The system of linear algebraic equations for definition of unknown intensions $I(\xi^q)$ of the attached vortexes looks like:

$$\sum_{q=1}^{N} G\left(x^p,\xi^q\right) I\left(\xi^q\right) = -\gamma \sum_{k=1}^{N_S} G\left(x^p,\zeta^k\right), \tag{2}$$

where $p = 1,2,...N$.

After definition of unknown circulation $I(\xi^q)$, where $q = 1,2,...N$ speed in any point $x(x_1,x_2)$ of area along any set direction is calculated with a formula:

$$v_n(x) = \sum_{q=1}^{N} G\left(x,\xi^q\right) I\left(\xi^q\right) + \gamma \sum_{k=1}^{N_S} G\left(x,\zeta^k\right).$$

On the first iteration, after definition of unknown circulation of vortexes, the surface of current which is flowing down from a sharp edge is under construction. After it moves away from a soaking-up aperture of a pipe on distance more than 10 calibers (caliber is a pipe radius), its construction stops. For creation of the current surface differential equation is integrated $dx/v_x = dy / v_y$. Creation of the current surface begins from the sharp edge. Free ring vortexes have on this surface evenly with a step equal to h.

After definition of the second approach for current free surfaces it is necessary to solve again the system of the equations (2) and to define circulation of the attached whirlwinds. Then the third approach of current free surfaces is under construction etc.

This iterative process proceeds until values of a stream δ_∞ / R compression coefficient of a soaking-up branch pipe on the previous and subsequent iteration won't differ at a size of the set accuracy of ϵ [epsilon].

If the distance from a point up to one vortex is less than a discretization radius $h/2$, the speed caused by this vortex, is defined from the following expression:

$$v_n(x) = 8\pi \frac{(x_1-\xi_1)n_2 - (x_2-\xi_2)n_1}{h^2}.$$

An example of current lines calculation is given in Fig. 3.

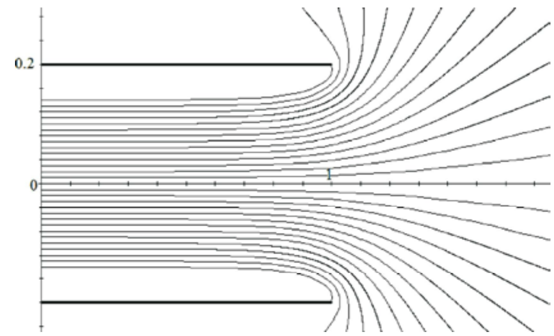

Fig. 3: Current lines on the entrance of the round pipe of radius of 0.2m

Axisymmetric Task in Non-stationary Statement: In this case for discrete model of border the soaking-up opening is added (Fig. 4) and sampling with a step Δt is made. Black circles are attached vortexes, daggers are settlement (control) points, hollow circles are free vortexes.

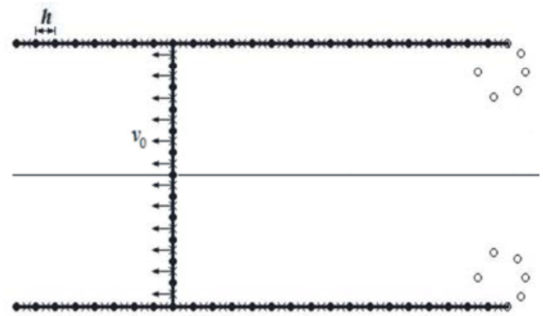

Fig. 4: Discrete model for non-stationary axisymmetric model in the meridional plane

Let's notice that here on center line the vortex of zero radius (in a numerical case radius turns out almost zero) is located. I.e. in fact, this vortex isn't presented.

The system of the equations for calculation of unknown circulation of the attached vortexes in a time point $t = m\Delta t$ with use of a condition of a non-circulated current looks like:

$$\begin{cases} v_n^p = \sum_{k=1}^{n} I^k G^{pk} + \sum_{\tau=1}^{m} G^{p\tau}\gamma^\tau, \\ \sum_{k=1}^{n} I^k + \sum_{\tau=1}^{m} \gamma^\tau = 0, \end{cases}$$

где ; $v_n^p = v_n(x^p), I^k = I(\xi^k), G^{pk} = G(x^p,\xi^k), G^{p\tau} = G(x^p,\zeta^\tau), \gamma^\tau$ - circulation of the free vortex descended from a sharp edge in a time point τ and located in the point ζ^τ; $G^{P\tau}$ - function of influence on p settlement point of a vortex γ^τ и G^{Pk} is determined by a formula (1). The system turns out solvable because of a condition of a non-circulated current. At the initial moment it looks like:

$$\begin{cases} I^1G^{11}+...+I^{n-1}G^{1,n-1}+I^n\cdot 0=v_n^1, \\ \dots \\ I^{N-1}G^{N-1,1}+...+I^{N-1}G^{N-1,N-1}+I^{N-1}\cdot 0=v_n^{N-1}, \\ I^1+I^2+...+I^{N-1}+I^N=0. \end{cases}$$

Thus, this system is equivalent to vortex rejection with a zero radius and to rejection of a condition of non-circulated current.

Let's notice that at an arrangement of active section (the soaking-up section) between settlement points, inadequate results turn out.

Thus, in each settlement timepoint the system of the equations for definition of unknown intensivnost of the attached vortexes is solved; new positions of free vortexes are determined on use of formulas $x'=x+v_x\Delta t$, $y'=y+v_y\Delta t$ and the step on time is made. At achievement by free vortxes of active section they are removed from consideration. Calculation is conducted until free vortexess will fill all settlement area (Fig. 5) and a current it is possible to consider as established. Let's notice, that in this case also the size of speed doesn't become a constant, it pulses eventually that allows to define turbulent characteristics of a current: longitudinal and cross pulsations of speeds (Fig. 6).

Quasiaxisymmetric Task in Non-stationary Statement: Usage of a vortex polygonal framework complicates calculations, but gives a chance to solve three-dimensional problems.

Influence on any point $x(x_1,x_2,x_3)$ k of the vortex n-coal frame of single intensity (Fig. 7) is defined from expression:

$$\boldsymbol{G}(x,k)=\frac{1}{4p}\sum_{i=1}^{N}\frac{\left[(\boldsymbol{r}_{i+1}^k-\boldsymbol{r}_i^k)\times\boldsymbol{r}_i^k\right]}{\left|\boldsymbol{r}_{i+1}^k-\boldsymbol{r}_i^k\right|^2\left|\boldsymbol{r}_i^k\right|^2-\left((\boldsymbol{r}_{i+1}^k-\boldsymbol{r}_i^k)\cdot\boldsymbol{r}_i^k\right)^2}\left(-\frac{(\boldsymbol{r}_{i+1}^k-\boldsymbol{r}_i^k)\cdot\boldsymbol{r}_{i+1}^k}{\left|\boldsymbol{r}_{i+1}^k\right|}+\frac{(\boldsymbol{r}_{i+1}^k-\boldsymbol{r}_i^k)\cdot\boldsymbol{r}_i^k}{\left|\boldsymbol{r}_i^k\right|}\right) \quad (3)$$

где $\boldsymbol{r}_i^k=\left\{A_{1i}^k-x_1, A_{2i}^k-x_2, A_{3i}^k-x_3\right\}$, $A_i^k(A_{1i}^k, A_{2i}^k, A_{3i}^k)$ - i-top of a k polygonal frame.

Then the speed v induced by an intensity $I(k)$ frame in a point x along the direction n is calculated by means of scalar work:

$$v_n(x)=\left(\boldsymbol{G}(x,k)\cdot\boldsymbol{n}\right)I(k)\cdot$$

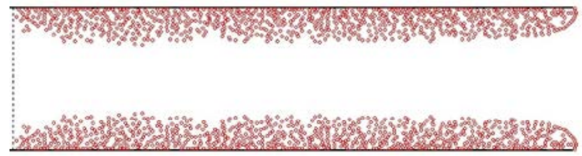

Fig. 5: Vortex structure of the current on the entrance of a round branch pipe of radius of 0.2m

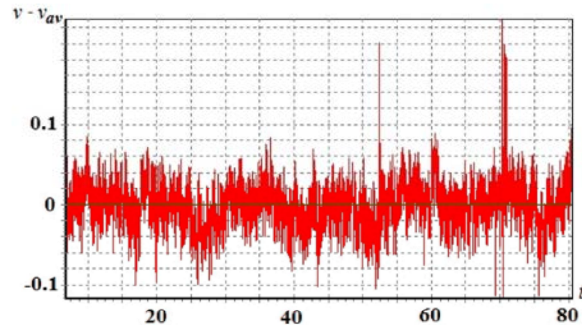

Fig. 6: Longitudinal pulsations of axial speed on the entrance of the pipe (V_{av}= 1.16072 m/sec)

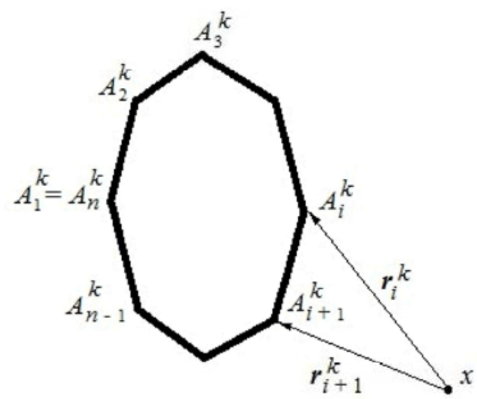

Fig. 7: To definition of influence on a point of x k vortex n-coal frame

Let's designate further $G^{pk}=\left(\boldsymbol{G}(x^p,k)\cdot\boldsymbol{n}\right)$, whereas before x^p - p control point. Control points settle down in the middle between a polygonal vortex framework, on a surface of a pipe or in the center of the triangular and quadrangular vortex framework located in active section of the pipe (Fig 8).

Let's notice that on all frame intensity I is invariable in all points of a vortex polygon.

In a time point $t = m.\ \Delta t$ the system for definition of unknown intensity of the attached vortex framework has the following appearance:

$$\sum_{k=1}^{N}G^{pk}I^k+\sum_{\tau=1}^{m}G^{p\tau}\gamma^{\tau}=v^p, \quad (4)$$

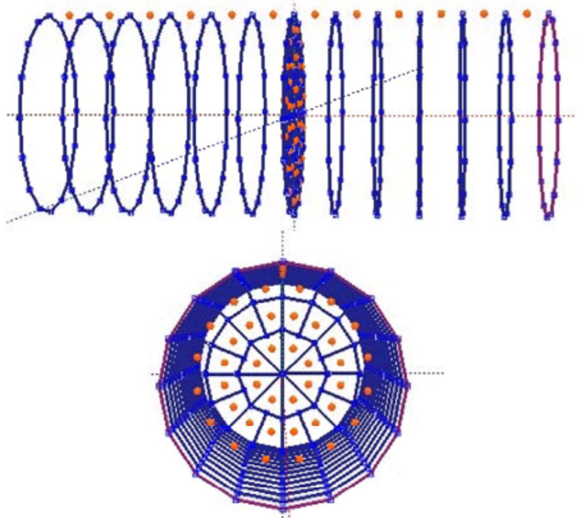

Fig. 8: Discrete model for a quasiaxisymmetric task

and speed in defined moment in an internal point *x* along the set direction *n* is defined at present by a summation way on this point of all attached and free framework:

$$\sum_{k=1}^{N} G^{pk} I^{k} + \sum_{\tau=1}^{m} G^{p\tau}\gamma^{\tau} = v^{p}, \tag{5}$$

where G^k - function of influence on p. x *k*-vortex frame, I^k - its circulation, G^τ - function of influence on a point *x* a vortex frame descended from a sharp edge in time point τ [tau].

In the following time point there is a descent of new vortexes, old move in the stream direction, unknown circulation of the attached vortexes by a solution of system (4), are defined etc. until the set goal isn't reached.

The new position of free frame top is defined from a formula ,

$$x' = x + v_x \cdot \Delta t,\ y' = y + v_y \cdot \Delta t,\ z' = z + v_z \cdot \Delta t$$

where (*x,y,z*)- coordinates of its previous location, $\{v_x, v_y, v_z\}$- components of the speed vector in this point (are defined with usage of formulas (3), (5) along the directions $\vec{n} = \{1,0,0\}$, $\vec{n} = \{0,1,0\}$, $\vec{n} = \{0,0,1\}$ respectively).

If some point is located in relation to this vortex frame at distance smaller discretization radius, influence of this vortex frame on this point isn't considered.

In each time point into a stream the polygonal vortex frame with the intensity, equal intensity of the polygonal vortex frame lying on a cut of a stitched opening will descend. Circulation of this vortex free frame will already not change eventually. Its location changes only.

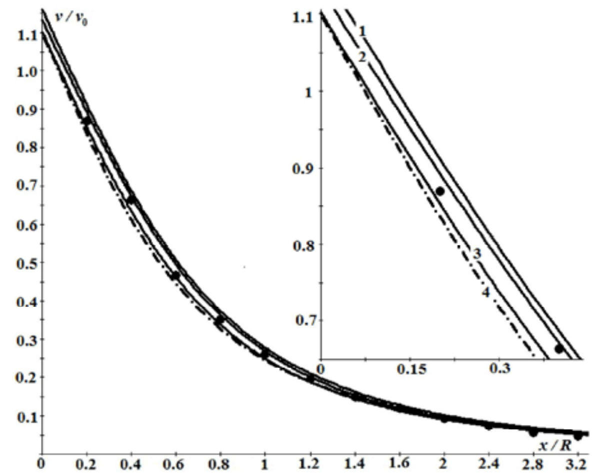

Fig. 9: Change of dimensionless axial speed during removal from the entrance of the round pipe: 1- axisymmetric task in non-stationary statement at Δt = 0.01; 2- quasiaxisymmetric task in non-stationary statement at Δt = 0.01; 3- axisymmetric task in stationary statement; 4- calculations with a formula (6); black circles are experimental data [22].

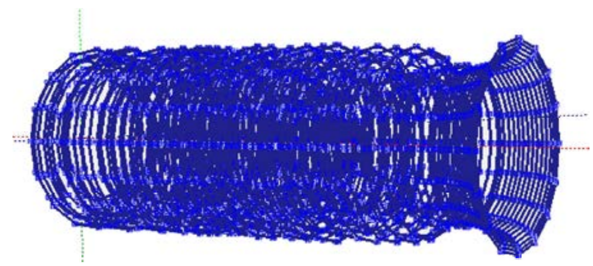

Fig. 10: Current vortex structure in the pipe in a time point 1.65 at a step on time 0.01 and a step of discretization 0.005

Results of Calculation and Their Discussion: For check of adequacy and reliability of the considered models it was done a calculation of axial speed depending on distance to the entrance of the soaking-up opening. Comparison was made with experimental data of Alden J.L. [22] and calculations with V.N.Posokhin's formula [26]:

$$v = 1.1\left(1 - \frac{1}{\sqrt{1 + 0.655/x^2}}\right) \tag{6}$$

Remoteness x has been made dimensionless by division into pipe radius; speed shared on average speed in the soaking-up channel.

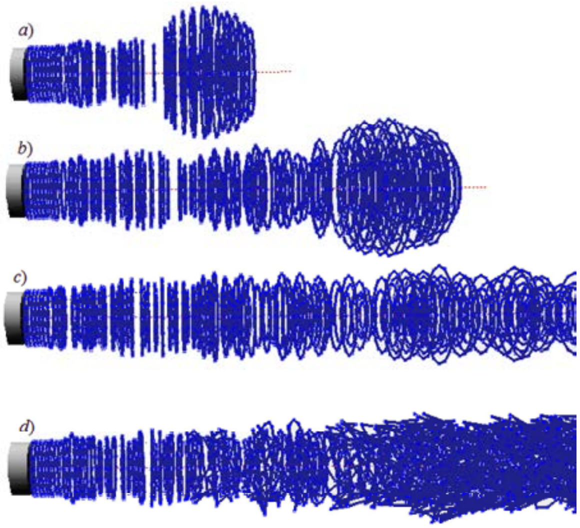

Fig. 11: Current vortex structure at the stream expiration from the pipe with a radius of 0.1 at a step of discretization 0.00495, distance between the next 16-angle attached vortex features 0.01m and a step on time 0.03sec: *a*) $t = 2.22$; *b*) $t = 4.14$; *c*) $t = 8.88$; *d*) $t = 12.36$;

In all models the distance between the next attached vortexes equaled to 0.01m; step of discretization equaled to 0.005m. Almost full coincidence to experimental data is shown by the calculations executed within stationary model (a curve 3 in fig. 7). The same model with high precision allows to determine coefficient of compression of a stream and coefficient of local resistance (k.l.r.) of the entrance of the pipe by a formula $\zeta = (1 - 1/(\delta_\infty / R)^2)^2$. Calculated value k.l.r. $\zeta \approx 1.08$ also differ from experimental $\zeta = 1$ [23] on 8%. This feature of model allows to investigate influence of various screens and profiles at a value ζ [14, 19, 20].

A little overestimated values of speed (no more than for 3%) dismiss within non-stationary models (curves 1-2). For a quasisymmetric task 64-angle vortex features, a step of discretization 0.00495 were used. Vortex flow thus (Fig. 8) has similar structure, as for an axisymmetric task in non-stationary statement (Fig. 5): near walls of a pipe the returnable area of the flow that the stationary model doesn't catch is formed. Compression coefficient of a soaked-up stream and, respectively k.l.r. within non-stationary models it is difficult to define. As the form of a surface of the current descending from a sharp edge of the pipe, pulses in time. But even when averaging size, a calculated value k.l.r. exceeds experimental more than for 50%. As for account time, the quasiaxisymmetric problem is solved several times more long, than axisymmetric. But there is an opportunity to solve spatial problems in the assumption that borders of a current of other objects being in settlement area, have no essential impact on axial symmetry of a current around a round branch pipe. The developed program allows and to turn a flow, that is to investigate a flow of a stitched turbulent stream (Fig. 11).

In case of modeling of a stitched stream the structure of a current (Fig. 11) is correlated with the calculations of A.V.Dvorak and N.V.Khlapova stated in books [4, 24]. Axial symmetry remains to enough great values of time (Fig. of 11 a-c). Vortex polygons start forming vortex clots, then the slightest violations of symmetry caused by errors of rounding, intensively accrue, taking all stream, except for an initial site of a stream (Fig. of 11 d). This strict axial symmetry on an initial site of a stream and a soaked-up detachable current in the pipe in a certain measure can be justification of applicability of quasisymmetric approach for modeling of spatial tasks.

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CONCLUSIONS

Methods of mathematical modeling and their program and algorithmic support are developed for calculation of axisymmetric and spatial detachable flows in ranges of operation of exhaust channels. Usage of stationary discrete vortexes allows with a sufficient accuracy to define a field of speeds, separation borders of the stream and coefficient of local resistance on the entrance of soaking-up opening. Modeling of non-stationary currents by means of ring vortex features allows to investigate vortex currents in stagnant areas and to define speed pulsations. Usage of vortex polygons gives additional possibility of spatial flows research in areas with stitched and exhaust channels, to reveal regularities of interaction of stitched and exhaust jet flows.

REFERENCES

1. Vanyunina, M.V., R.S. Galeev, Sh. K.H. Zaripov and É.V. Skvortsov, 2005. Aerosol aspiration into a cylindrical sampler from a low-velocity downward flow and from calm air. Journal of Applied Mechanics and Technical Physics 3-2005, 46(2): 250-256.

2. Gil'fanov, A.K., Sh. K.H. Zaripov and D.V. Maklakov, 2009. Calculation of particle concentration in the problem of aerosol aspiration into a thin-walled tube. Fluid Dynamics, 44(6): 873-881.
3. Posokhin, V.N. and M.V. Katkov, 2001. Experimental studying of vortex zones in flows near soaking-up slot-hole openings//News of higher educational institutions. Aircraft Equipment. 1: 61-63.
4. Belotserkovsky, C.M. and A.S. Ginevsky, 1995. Modelling of turbulent streams and traces on the basis of a method of discrete vortexes. M.:Physmalit.
5. Sabelnikov, V.A. and E.A. Smirnykh, 1985. Numerical calculation of turbulent flow on an initial site of the flat channel with sharp edges with a method of discrete vortexes//Scientific notes of TsAGI. 1985. XVI, 4: 59-64.
6. Zimont, V.L., V.E. Kozlov and A.A. Praskovsky, 1981. Investigation of turbulent flow on an initial site of the cylindrical channel with sharp edges//Scientific notes of TsAGI. XII, 1: 145-152.
7. Posokhin, V. N., N.B. Salimov, K.I. Logachyov and A.M. Zhivov, 2002. To current calculation near a slit-like suction bell//News of higher educational institutions. Stroitelstvo/2002. Message 1: No. 8: 70-76; Message 2: No. 9, 80-85; Message 3: No. 10, 81-85. Logachev, K.I. and A.I. Puzanok, 2004. Computational Modeling of Air-and-coal Flows next to Suction Holes. ECCOMAS 2004 - European Congress on Computational Methods in Applied Sciences and Engineering, e-Book Full Papers, pp: 19.
8. Logachev, K.I. and V. N. Posokhin, 2004. Calculation of a Flow in the Vicinity of a Round Suction Pipe. Izvestiya Vysshikh Uchebnykh Zavedenij. Aviatsionnaya Tekhnika . 1: 29-32.
9. Logachev, K.I., A.I. Puzanok and V.U. Zorya, 2006. Numerical study of aerosol dust behaviour in aspiration bunker. ECCOMAS CFD 2006 - European Conference on Computational Fluid Dynamics, e-Book Full Papers, pp: 11.
10. Averkova, O.A., V. Yu. Zorya and K.I. Logachev, 2007. Behavior of aerosol particles in suction bunker of standard design. Chemical and Petroleum Engineering. 43(11): 686-690.
11. Anzheurov, N.M. and O.A. Averkova, 2008. Software for computing dusty air flows in ventilation systems. Refractories and Industrial Ceramics., 49(3): 229-234.
12. Logachev, K.I. and N.M. Anzheurov, 2003. Flow Analysis of Slit-Type Suction Ports Shielded with Slender Visors. Refractories and Industrial Ceramics, 44(3): 145-148.
13. Averkova, O., A. Logachev, I. Logachev and K. Logachev, 2012. Modeling of gas separated flows at inlet of suction channels on the basis of stationary discrete vortices. ECCOMAS 2012 - European Congress on Computational Methods in Applied Sciences and Engineering, e-Book Full Papers, pp: 20.
14. Logachyov, I.N., K.I. Logachyov Zorya V. Yu. and O.A. Averkova, 2010. Modeling of detachable flows near a soaking-up crack//Computing methods and Programming. 11(1): 43-52.
15. Logachyov, I.N., K.I. Logachyov and O.A. Averkova, 2010. Mathematical modeling of detachable flows at the entrance of the screened flat channel//Computing Methods and Programming. 11(1): 68-77.
16. Logachyov, I.N., K.I. Logachyov and O.A. Averkova, 2010. Mathematical modeling of a jet current of air at an entrance to the flat channel with a peak and the impenetrable screen//Computing Methods and Programming. 11(2): 160-167.
17. Averkova, O.A., I.N. Logachyov and K.I. Logachyov, 2011. Modeling of potential currents with unknown borders on the basis of stationary discrete vortexes//Computing Methods and Programming. 12(2): 213-219.
18. Averkova, O.A., I.N. Logachyov and K.I. Logachyov, 2012. Modeling of separation of a stream on the entrance of soaking-up channels in areas with cuts//Computing methods and programming. 2012. 13, No. 2, 298-306. Averkova, O.A. V. Yu. Zorya, I.N. Logachev and K.I. Logachev, 2010. Numerical simulation of air currents at the inlet to slot leaks of ventilation shelters. Refractories and Industrial Ceramics., 51(3): 177-182.
19. Averkova, O.A., I.N. Logachyov and K.I. Logachyo, 2012. Modeling of separation of a stream on the entrance of slot-hole thinnesses of aspiration shelters//New refractories. 10: 56-60.Alden J.L. Kane J.M. Design of Industrial Ventilation Systems. N.Y. Industrial Press, 1982.
20. Idelchik, I.E., 2008 Handbook of Hydraulic Resistance, 4th Edition Revised and Augmented. Begell House, pp: 861.
21. Streams and bearing surfaces: Modeling on Computer / Babkin V. I. Belotserkovsky C.M. Guljaev V. V. Dvorak A.V. – M: Science, 1989.Belotserkovsky, S. M. and I.K. Lifanov. 1993. Method of Discrete Vortices. CRC Press, USA, pp: 454.
22. Posokhin, V.N., 1984. Calculation of local suctions from warm and the gas-yielding equipment. M.: Ìashinostroyeny.