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ENVIRONMENTAL SAFETY OF THE AIR ENVIRONMENT OF PREMISES WITH THE EMISSION OF HARMFUL SUBSTANCES OF DIFFERENT DENSITY

Statement of the problem. The existing methods for the definition of the concentration of harmful substances do not always allow one to estimate their allocation in the space of premises. For these purposes the mathematical model was developed and implemented on the computer which gives a chance to use the similarity theory for planning the calculations and generalization of their results. From the model equations non-dimensional criteria, and the solution of the equations of the mathematical model are written with a functional accuracy as a functional connection between both defining similarity parameter and uniqueness conditions. The type of a functional connection is determined experimentally.

Results. A defining similarity parameter and criteria proportions for the mathematical models of processes of ventilation of the air environment of premises with use of substances that are lighter and was more high-gravity air are obtained. The results obtained by means of mathematical models of processes of ventilation allow one to estimate the effect of gravity of harmful substances on their allocation in premises and to allow for it in the process of designing ventilation systems.

Conclusions. The results obtained will allow one to improve the environmental safety of the air environment of premises with the emission of harmful substances with various densities.

Keywords: air exchange organization, harmful substances, environmental safety.

Introduction

The existing methods of determining the concentration of harmful substances do not always allow one to estimate their distribution in premises. For these purposes a model is developed and implemented for us to be able to use the similarity theory for planning calculations and generalizing their results. Dimensionless criteria are obtained using the model equations and the solutions for the mathematical model equations are written to a function accuracy as a functional connection between the determined and determining criteria of similarity and single-valuedness condition. What the functional connection is like is determined experimentally. The single-valuedness condition is the data characterizing geometric correlations and physical parameters as well as initial and boundary conditions of the process.

1. Similarity criteria of the distribution of substances heavier and lighter than the air

Using the similarity theorem, it can be found what characteristics the initial value is dependent on and expand the results obtained on the mathematical model in all similar processes of ventilation. This helps formulate the tasks facing numerical experiments and generalize the obtained results [1, 3, 9, 10, 12, 13, 22, 23, 27, 30].

Let us use the similarity theory to analyze ventilation processes described by mathematical models. In order to describe the velocity fields of air flows, air temperatures and concentration of harmful substances, relative coordinates are used

$$\frac{x}{l_0}, \frac{y}{l_0}, \frac{z}{l_0},$$

where l_0 is a typical size, m.

The above mathematical models yield the following criteria for ventilation processes:

– Fourier criterion for concentration fields:

$$Fo' = \frac{Dt}{l_0^2}; \tag{1}$$

– Reynolds criterion:

$$\mathrm{Re} = \frac{u_0 d_0}{\nu}; \tag{2}$$

– Prandtl criterion:

$$\mathrm{Pr} = \frac{\nu}{a}; \tag{3}$$

– Schmidt criterion:

$$Sc = \frac{\nu}{D}; \tag{4}$$

– Grasgof temperature criterion:

$$Gr_T = \frac{g\beta l_0^3}{\nu^2}\beta\Delta T; \tag{5}$$

– Grassgod concentration criterion:

$$Gr_c = \frac{g\beta l_0^3}{\nu^2}\frac{\Delta\rho}{\rho}, \tag{6}$$

where a is the coefficient of the air heat conductivity, m^2/sec; D is the diffusion coefficient of a harmful substance in the air, m^2/sec; ν is the kinematic viscosity of the air, m^2/sec; β is the air thermal expansion coefficient; g is the gravitational acceleration, m/sec^2; $\Delta T = T_i - T_0$ is the temperature difference; $\Delta\rho$ is a change in the air density during the pollution of the air with a harmful substance, kg/m^3;

– criterion K that characterizes the correlation of the input and heat flows:

$$K = \frac{E_{nc}}{E_{mc}}, \tag{7}$$

where E_{nc} is the energy of the input flows generated by mechanical ventilation:

$$E_{nc} = \frac{\sum_{i=1}^{N}\alpha_i L_i u_{i0}^2}{2V}; \tag{8}$$

E_{mc} is the energy of heat flows generated by heat sources:

$$E_{mc} = g\sum_{i=1}^{N}\frac{\bar{Q}_i z}{c_p T_{i0}\rho}\cdot\frac{1+n_i}{4n_i}, \tag{9}$$

where α_i is the adjustment coefficient for the velocity pressure for the i-ty flow; L is the air volume in the i-th flow, m^3/sec; V is the area of the premises, m^3; n_i is the adjustment coefficient for the i-th heat source.

The most general view [2, 4—9, 11, 14—16, 28, 29] of the criterion correlation of ventilation processes is as follows

$$\frac{c_i - c_{np}}{c_0 - c_{np}} = \Phi_c\left(Fo', \mathrm{Re}, Gr_T, \mathrm{Pr}, Gr_c, Sc, K, \frac{x_i}{l_0}, \frac{y_i}{l_0}, \frac{z_i}{l_0}\right). \qquad (10)$$

The mathematical model is used to calculate the concentration fields of harmful substances which are heavier and lighter than the air using the example of ventilated premises with the width of 12 m, height of 6 m, length of 24 m and the area of 1728 m^3 and technological equipment that emits harmful substances. The order of the air exchange was 5 h^{-1}. The input air is supplied by the air distributor into the upper area from both sides of the premises at the velocity of 1 m/sec. The air is removed from the lower area from both sides of the premises at the height of 1 m at the velocity of 0.7 m/sec (Fig. 1). The temperature of the input air, envelope structures and surfaces of the technological equipment is 290 K.

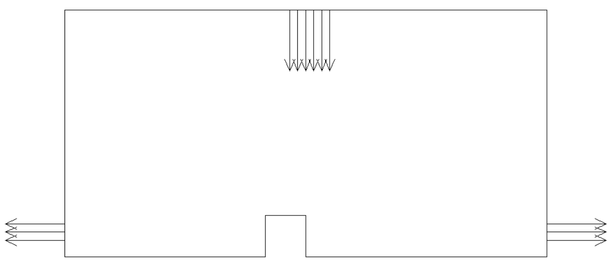


Fig. 1. Schematic of the supply and removal of the air in the section of the premises

Two series of calculations were carried out. In the first series the technological equipment emitted ammonia which is a gas which is lighter than the air and in the second series that was acetone vapors whose density is higher than that of the air. The similarity criteria of the processes were as follows:

$$Re = 1\cdot10^4;$$

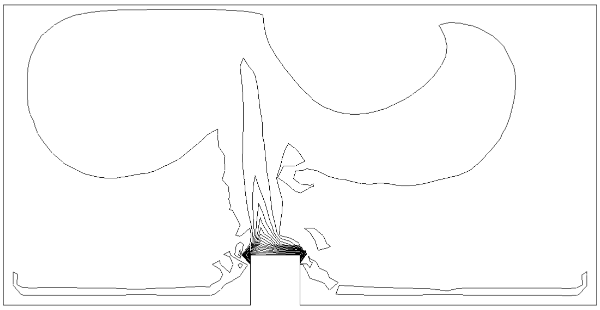
$$Gr_cSc = 1.5\cdot10^{10} - 4\cdot10^{10};$$

$$0 < Fo' < 9\cdot10^{-4}.$$

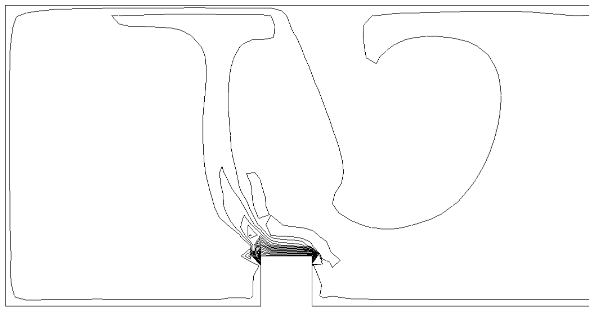
The ammonia consumption was $G/c_{пдк}$ = 0.2 m^3/sec, of acetone $G/c_{пдк}$ = 0.1 m^3/sec.

The results of the calculation of non-stationary fields of the ammonia concentration for the section are in Fig. 2—3.

a)



b)



c)

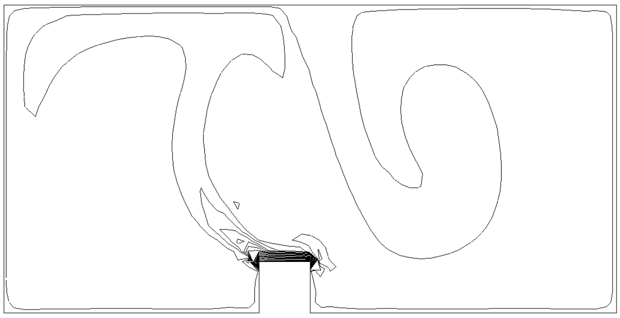
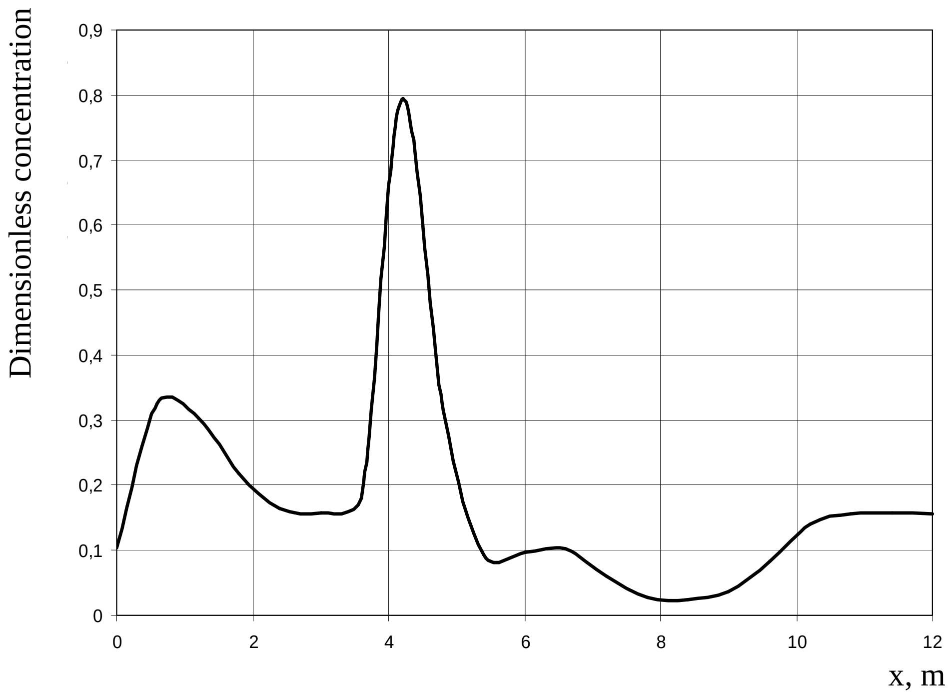


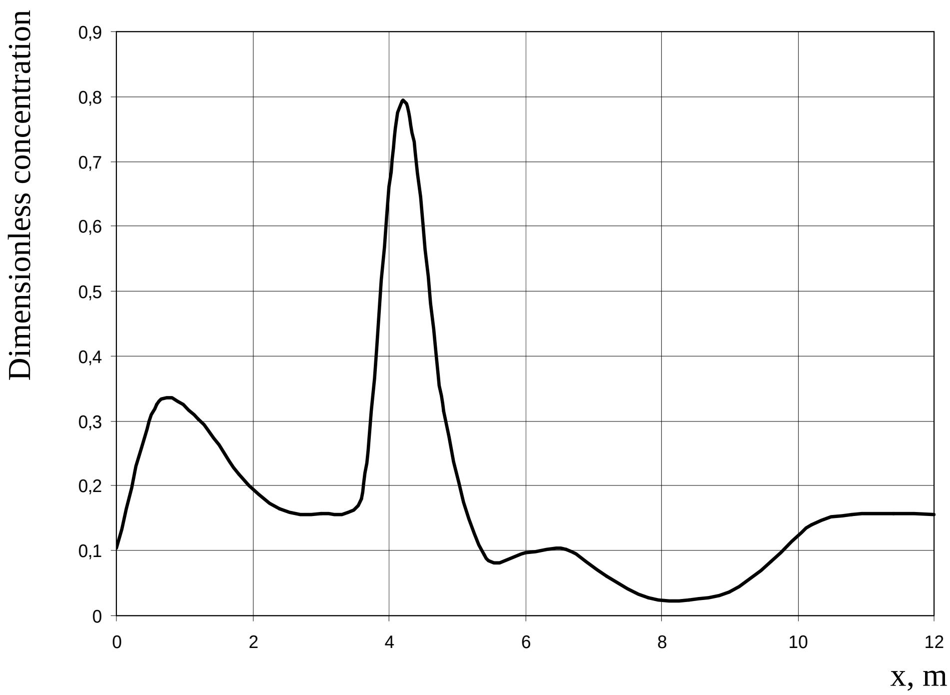
Fig. 2. Ammonia concentration field. There are 9 levels of the dimensionless concentration from 0.1 to 0.9; $Re = 1{\cdot}10^4$; $Gr_cSc = 1.5{\cdot}10^{10}$: a) $Fo' = 1.5{\cdot}10^{-5}$; b) $Fo' = 4.2{\cdot}10^{-5}$; c) $Fo' = 8.3{\cdot}10^{-5}$

The analysis of Fig. 2 shows that the ammonia concentration is unevenly distributed along the premises under the effect of air flows. At $Fo' < 2{\cdot}10^{-5}$ ammonia is distributed over its emission sources; at $Fo' > 2{\cdot}10^{-5}$ ammonia starts to distribute along the entire premises and the area of maximum concentration shifts to the left; at $Fo' > 7{\cdot}10^{-5}$ ammonia distribution along the premises becomes stationary.

Fig. 3 indicates that average dimensionless ammonia concentrations in the operating area of the premises in the stationary mode vary in the range of 0.05…0.3, and are 0.8 over the emission source. Along the height of the premises average dimensionless ammonia concentrations rise from 0.15 in the operating area of the premises to 0.4 in the upper area. In the second series the technological equipment emitted acetone vapors whose density is higher than that of the air.



a)



b)

Fig. 3. Distribution of average ammonia concentrations: $Re = 1{\cdot}10^4$; $Gr_cSc = 1.5{\cdot}10^{10}$; $Fo' = 8.3{\cdot}10^{-5}$: a) along the operating area of the premises; b) along the height of the premises

The similarity criteria of the processes was $Re = 1{\cdot}10^4$; $Gr_cSc = 1.5{\cdot}10^{10} - 4{\cdot}10^{10}$; $0 < Fo' < 9{\cdot}10^{-4}$.

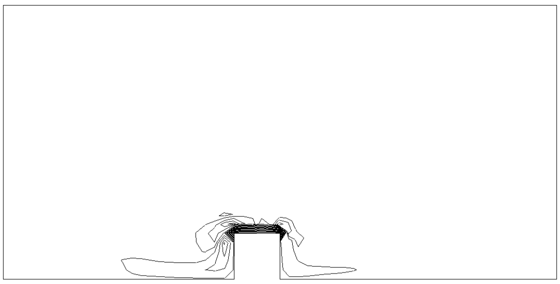
The acetone concentration was $G/c_{пдк} = 0.1$ m^3/sec.

The results of the calculation of non-stationary concentration fields of acetone for the section of the premises are in Fig. 4—5.

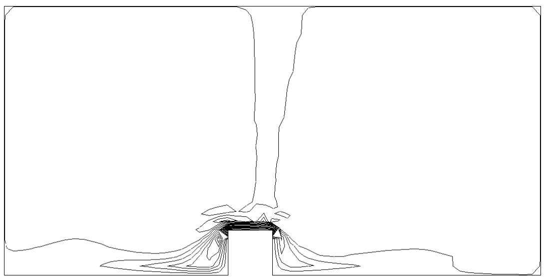
The analysis of Fig. 4 shows that acetone is mainly in the lower area of the premises. At $Fo' > 5{\cdot}10^{-5}$ the distribution of acetone along the premises becomes stationary.

Fig. 5 shows that average acetone concentration in the operating area of the premises varies in the range of 0.15…0.35. In the operating area the concentration of acetone reaches 0.5 and 0.3 in the upper area.

a)



b)



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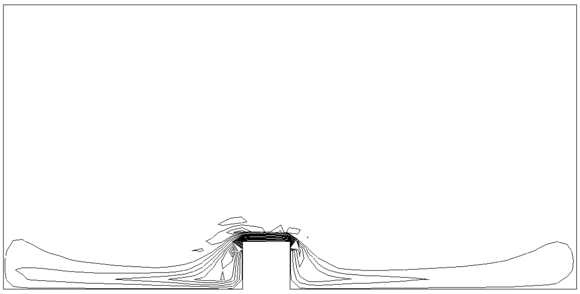

Fig. 4. Concentration field of acetone. There are 9 levels of dimensionless concentration from 0.1 to 0.9; $Re = 1{\cdot}10^4$; $Gr_cSc = 4{\cdot}10^{10}$: a) $Fo' = 1.5{\cdot}10^{-5}$; b) $Fo' = 4.2{\cdot}10^{-5}$; c) $Fo' = 8.3{\cdot}10^5$

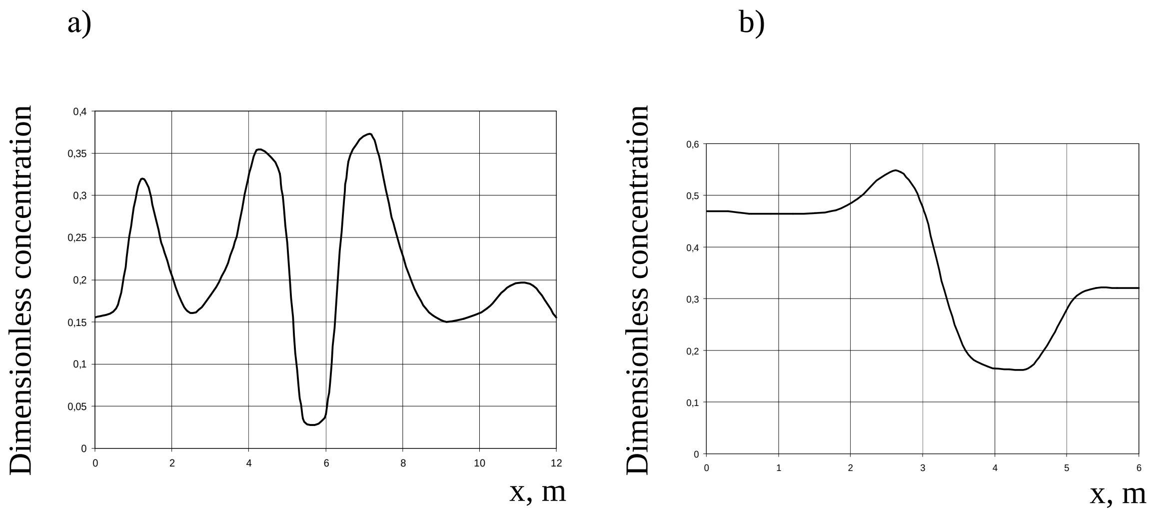

Fig. 5. Distribution of average dimensionless concentrations of acetone: $Re = 1{\cdot}10^4$; $Gr_cSc = 4{\cdot}10^{10}$; $Fo' = 8.3{\cdot}10^{-5}$:

a) along the operating area of the premises; b) along the height of the premises

The employed method permitted to get a full insight into the distribution of harmful substances in the premises.

The obtained results permitted to assess the role different factors play in the formation of concentration fields of harmful substances and take them into account in the process of designing of ventilation systems [17—20, 24—26].

Conclusions

1. In order to determine the concentration of harmful substances, a mathematical model was used, developed and implemented on a PC.

2. The determining similarity criteria and criteria correlation for mathematical models of ventilation of the air of premises using substances lighter and heavier than the air.

3. The results obtained with the help of mathematical models of ventilation permit to assess the influence of the density of harmful substances on their distribution along premises and take them into account in the process of designing ventilation systems.

4. The obtained results permit to enhance the environmental safety of the air of premises where harmful substances of varying density are emitted.

References

1. O metodike rascheta koncentracij prirodnogo gaza pri nalichii utechki iz podzemnogo gazoprovoda / S. N. Kuznecov [i dr.] // Vestnik Voronezh. gos. tehn. un-ta. Ser.: Jenerge-tika. — 2001. — № 7.1. — S. 72—75.

2. **Kuznecov, S. N.** Ob odnom metode rascheta chastotnyh harakteristik pilotnogo ustrojstva / S. N. Kuznecov, V. N. Mel'kumov, I. G. Lachugin // Vestnik Voronezh. gos. tehn. un-ta. Ser.: Jenergetika. — 2001. — № 7.1. — S. 76—78.

3. **Mel'kumov, V. N.** Matematicheskoe modelirovanie diffuzionnyh processov zagrjaznenija okruzhajushhej sredy ot ob'ektov szhizhennogo gaza / V. N. Mel'kumov, B. C. Turbin, N. S. Kotel'nikov // Izvestija vuzov. Stroitel'stvo. — 2002. — № 6. — S. 62—67.

4. **Mel'kumov, V. N.** Issledovanie raboty jelementov pilotnogo ustrojstva / V. N. Mel'kumov. I. G. Lachugin, S. N. Kuznecov // Izvestija vuzov. Stroitel'stvo. — 2002. -№ 1-2. — S. 135—141.

5. **Mel'kumov, V. N.** Kompleksnaja mnogokriterial'naja optimizacija razmeshhenija ob'ektov szhizhennogo gaza / V. N. Mel'kumov, N. S. Kotel'nikov B. C. Turbin // Vestnik Tul'skogo gos. un-ta. Ser.: Jenergetika. — 2002. — № 72. — S. 112—118.

6. **Inshakov, Ju. Z.** Jekologicheskoe vozdejstvie pozharov na okruzhajushhuju sredu / Ju. Z. Inshakov, V. N. Mel'kumov, B. C. Turbin // Pozharnaja bezopasnost'. — 2003. — № 1. — S. 62.—63.

7. **Mel'kumov, V. N.** Verojatnostnyj podhod k opredeleniju kolichestva zadejstvovannoj pozharnoj tehniki na pozharah / V. N. Mel'kumov, Ju. Z. Inshakov // Nauchnyj vestnik Voronezhskogo GASU. Ser.: Inzhenernye sistemy zdanij i sooruzhenij. — 2003. — № 1. — S. 133—135.

8. **Mel'kumov, V. N.** Issledovanie teplovyh harakteristik teploutilizatorov k kotlam maloj proizvoditel'nosti / V. N. Mel'kumov, B. C. Turbin, R. V. Sorokin // Izvestija Tul'skogo gos. un-ta. Ser.: Stroitel'stvo. — 2004. — № 7. — S. 171—177.

9. Nestacionarnye processy formirovanija sistemami ventiljacii vozdushnyh potokov v po-

meshhenijah / V. N. Mel'kumov [i dr.] // Izvestija Orlov. gos. tehn. un-ta. Ser: Stroitel'stvo i transport. — 2007. — № 3-15. — S. 36—39.

10. Ocenka akkumulirujushhej sposobnosti ventiliruemyh ob’emov dlja snizhenija trebuemogo vozduhoobmena v pomeshhenijah / V. N. Mel'kumov [i dr.] // Vestnik Voronezh. gos. tehn. un-ta. — 2007. — T. 3, № 1. — S. 205—207.

11. Raschet avarijnogo postuplenija prirodnogo gaza v proizvodstvennoe pomeshhenie / V. N. Mel'kumov [i dr.] // Vestnik Voronezh. gos. tehn. un-ta. — 2007. — T. 3, № 1. — S. 222—223.

12. Nestacionarnoe pole koncentracij prirodnogo gaza v skvazhine pri ego utechke iz podzemnogo gazoprovoda / V. N. Mel'kumov [i dr.] // Privolzhskij nauchnyj zhurnal. — 2008. — № 4. — S. 98—103.

13. Prognozirovanie fil'tracii gaza v grunte pri ego utechke iz podzemnogo gazoprovoda / V. N. Mel'kumov [i dr.] // Izvestija Orlov. gos. tehn. un-ta. Ser.: Stroitel'stvo i transport. — 2008. — № 3. — S. 61—65.

14. Formirovanie konvektivnyh vozdushnyh potokov pri dejstvii v pomeshhenii istochnika tepla / V. N. Mel'kumov [i dr.] // Vestnik Volgograd. gos. arh.-stroit. un-ta. Ser.: Stroitel'stvo i arhitektura. — 2008. — № 12. — S. 76—80.

15. **Mel'kumov, V. N.** Dinamika formirovanija vozdushnyh potokov i polej temperatur v pomeshhenii / V. N. Mel'kumov, S. N. Kuznecov // Nauchnyj vestnik Voronezhskogo GASU. Stroitel'stvo i arhitektura. — 2008. — № 4. — S. 172—178.

16. **Mel'kumov, V. N.** Matematicheskoe modelirovanie teplofizicheskih parametrov vihrevogo teploobmennika sistemy otoplenija pomeshhenija gazoraspredelitel'nyh punktov / V. N. Mel'kumov, V. A. Lapin, A. N. Kobelev // Nauchnyj vestnik Voronezhskogo GASU. Stroitel'stvo i arhitektura. — 2008. — № 3. — S. 113—118.

17. **Mel'kumov, V.** N. Osobennosti teplomassoobmena potoka dvuhfaznogo teplonositelja na lopasti vihrevogo zavihritelja / V. N. Mel'kumov, V. A. Lapin, A. N. Kobelev // Nauchnyj vestnik Voronezhskogo GASU. Stroitel'stvo i arhitektura. — 2008. — № 3. — S. 119—124.

18. **Mel'kumov, V. N.** Pozharnaja bezopasnost' vzryvoopasnyh pomeshhenij / V. N. Mel'kumov // Nauchnyj vestnik Voronezhskogo GASU. Stroitel'stvo i arhitektura. — 2008. — № 2. — S. 178—182.

19. **Mel'kumov, V. N.** Promyshlennaja bezopasnost' pomeshhenij s jelektrooborudovaniem / V. N. Mel'kumov // Nauchnyj vestnik Voronezhskogo GASU. Stroitel'stvo i arhitek-tura. — 2008. — № 3. — S. 176—182.

20. **Mel'kumov, V. N.** Jekologicheskoe vozdejstvie pozharov na okruzhajushhuju sredu / V. N. Mel'kumov, S. A. Kolodjazhnyj, Ju. Z. Inshakov // Nauchnyj vestnik Voronezhskogo GASU. Stroitel'stvo i arhitektura. — 2008. — № 4. — S. 198—208.

21. **Mel'kumov, V. N.** Razrabotka metoda opredelenija optimal'nogo marshruta prokladki gazoprovoda na osnove geneticheskih algoritmov / V. N. Mel'kumov, S. N. Kuznecov, R. N. Kuznecov // Privolzhskij nauchnyj zhurnal. — 2009. — № 3. — S. 69—74.

22**. Mel'kumov, V. N.** Vzaimodejstvie ventiljacionnyh vozdushnyh potokov s konvektivnymi potokami ot istochnikov teploty / V. N. Mel'kumov, S. N. Kuznecov // Izvestija vuzov. Stroitel'stvo. — 2009. — № 1. — S. 63—70.

23. **Mel'kumov, V. N.** Opredelenie optimal'nogo marshruta trassy gazoprovoda na osnove kart stoimosti vlijajushhih faktorov / V. N. Mel'kumov, I. S. Kuznecov, R. N. Kuznecov // Nauchnyj vestnik Voronezhskogo GASU. Stroitel'stvo i arhitektura. — 2009. — № 1. — S. 21—27.

24. **Mel'kumov, V. N.** Primenenie tehnogennyh othodov pererabotki hrizotila v dorozhnom stroitel'stve / A. Ju. Dedjuhin, I. N. Kruchinin, V. N. Mel'kumov // Nauchnyj vestnik Voronezhskogo GASU. Stroitel'stvo i arhitektura. — 2009. — № 4. — S. 141—147.

25. Prognozirovanie parametrov otkazov jelementov teplovyh setej metodom avtoregressivnogo integrirovannogo skol'zjashhego srednego / V. N. Mel'kumov [i dr.] // Nauchnyj vestnik Voronezhskogo GASU. Stroitel'stvo i arhitektura. — 2009. — № 4. — S. 28—32.

26. Razrabotka metoda opredelenija optimal'nogo marshruta prokladki gazoprovoda na osnove geneticheskih algoritmov / V. N. Mel'kumov [i dr.] // Privolzhskij nauchnyj zhurnal. — 2009. — № 3. — S. 69—74.

27. Monitoring nadezhnosti teplovyh setej / V. N. Mel'kumov [i dr.] // Nauchnyj vestnik Voronezhskogo GASU. Stroitel'stvo i arhitektura. — 2010. — № 1. — S. 52—58.

28. **Mel'kumov, V. N.** Vybor matematicheskoj modeli trass teplovyh setej / V. N. Mel'kumov, I. S. Kuznecov, V. N. Kobelev // Nauchnyj vestnik Voronezhskogo GASU. Stroitel'stvo i arhitektura. — 2011. — № 2. — S. 31—36.

29. **Mel'kumov, V. N.** Zadacha poiska optimal'noj struktury teplovyh setej / V. N. Mel'kumov, I. S. Kuznecov, V. N. Kobelev // Nauchnyj vestnik Voronezhskogo GASU. Stroitel'stvo i arhitektura. — 2011. — № 2. — S. 37—42.

30. **Mel'kumov, V. N.** Metod postroenija optimal'noj struktury teplovyh setej / V. N. Mel'kumov, I. S. Kuznecov, V. N. Kobelev // Vestnik Moskovskogo gos. stroit. un-ta. — 2011. — № 7. — C. 549—553.