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Kursk State Technical University
Assoc. Prof. of Dept. of Informatics and Applied Mathematics
T. V. Alyabyeva
D. Sc. in Engineering, Prof, Head of Dept. of Heat and Gas Supply and Ventilation
N. S. Kobelev
Russia, Kursk, tel.: (4712)52-38-14; email: tgv-kstu6@yandex.ru

Voronezh State Technological University
D. Sc. in Engineering, Prof., Head of Dept. of Industrial Energetics
V. V. Shitov
Russia, Voronezh, tel.: (4732)43-76-62; e-mail: rector@vorstu.ru

T. V. Alyabyeva, N. S. Kobelev, V. V. Shitov

INTEGRATED PURIFICATION OF VENTILATED AIR IN AIR LAYERS OF DAMP BUILDING STRUCTURES[1]

Problem statement. Intensive wear of the structure bearing elements in premises with high moisture content in ventilated air is associated with cyclic changes in temperature and humidity indicators of steam-air environment; hence, the problem of ventilated air treatment in such premises is topical.
Results. The design of device for integrated purification of atmospheric ventilated air from fine-dispersed pollutants in premise with high moisture content in indoor air is developed.
Conclusions. The proposed device provides reliable and long-term operation of bearing building elements.

Keywords: fine-dispersed drop pollutants, mechanical and adsorptive purification, atmospheric air, ventilation, moisture content.

Introduction

One of the reasons for heavy wear of load-carrying construction elements, especially in premises with a high content of fine-dispersed and vapor moisture in the air of ventilated air spaces (for example, in covered swimming pools, ice rink stadiums) is cycle changes of tem-

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perature and moisture indicators of steam-air environment. Ventilated space, especially on a glass construction, is always filled with some amount of steam condensated with the decreasing environment temperature, which adversely affects the constructions along the key parameters: length, height, and width. Which is why, the treatment of ventilated air in premises with a high moisture content is among the topical problems [1—3].

The separation of fine-dispersed and vapor steam that are almost frequently found in the atmospheric air sucked by a ventilator makes it necessary to consider and select the most effective and least power-consuming ways and devices for its purification, in order to provide a reliable operation of building constructions with air space and of an entire building as well.

The analysis of famous abstract theorems and technological solutions as well as the study of patent literature conducted by the authors allowed to create a device combining various ways of complex atmospheric air purification before a ventilator mouth.

Step-by-step purification from fine-disperse dust particles, the products of technological processes and bead-like and vapor moisture is conducted on a suggested device (Fig.) in the following way.

The atmospheric air is supplied into a complex purification device (air filter) through screen 3 for separation of large particles of contaminations into the inlet opening 4 of the ventilator inlet fitting in the form of a convergent nozzle 2 of the air filter base 1 which serves as a funnel twirling a moving flow. As a result of swirl during the sucked atmospheric air shift along cam spiral grooves 6 longitudinally located from the inlet 4 to outlet opening 5, we can observe its thermodynamic separation into a peripheral “hot” flow exceeding the environment temperature and axial “cold” flow [3, 4].

Solid particles and bead-like moisture gone through screen 3 in the inlet opening into a converge nozzle 2 are pushed into the “hot” flow by the centrifugal force, while bead-like moisture in the “cold” flow is partiaaly condensated with the subsequent shift of condensation drops into the “hot” flow.

The convergent nozzle 2 made on the internal surface of cam spiral grooves 6 longitudinally located from the inlet opening 4 to the outlet opening 5 with the shape of “a swallow’s tail” contributes to the ingress and subsequent shift of the contaminations in the “hot” flow to the side of the circular groove 7 for subsequent manual or automatic removal.

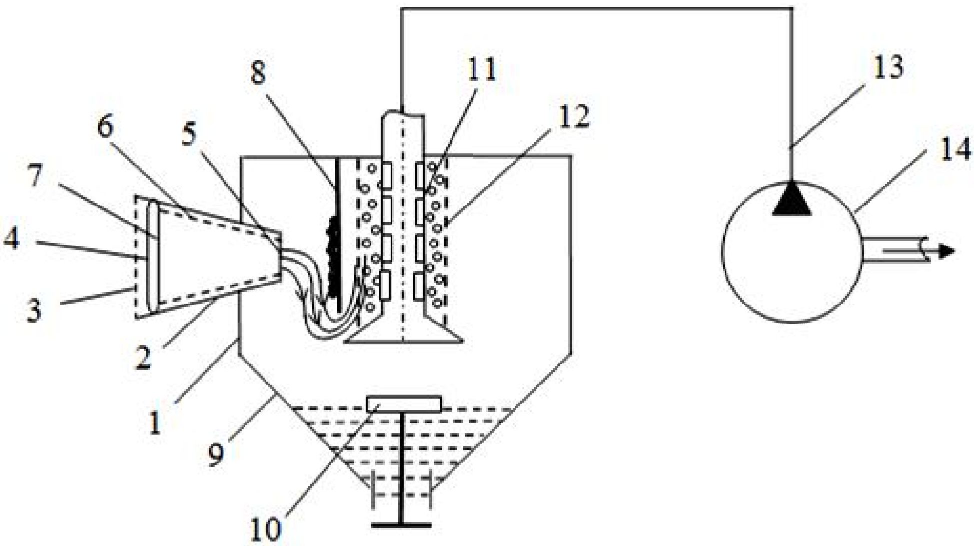

Fig. Complex purification air filter for the atmospheric air sucked by a ventilator:
1 is a base; 2 is an air filter inlet fitting in the form of a convergent nozzle; 3 is a screen for separation of large particles of atmospheric air; 4 is an inlet opening of the convergent nozzle; 5 is an outlet opening of the convergent nozzle; 6 are cam spiral grooves longitudinally located from the inlet to outlet opening of the convergent nozzle; 7 is a circular groove joining together the cam grooves; 8 is a baffle wall; 9 is conical end of the air filter; 10 is a ball float type condensate extractor; 11 is an air filter outlet fitting in the form of a perforated cylinder; 12 is a screen container filled with an adsorbing substance in the form of a holder set on an outlet fitting; 13 is a ventilator inlet duct; 14 is a ventilator with a delivery pipe supplying the ventilating air into a ventilated space

From the outlet from the convergent nozzle 2 the sucked atmospheric air suddenly expands with the Joule-Thomson effect [5] being observed. This leads to further decrease of the general air temperature. The air then beats against the baffle wall 8 forming a boundary layer with a "spot" of the already condensated and fine-dispersed atmospheric moisture coming out of the convergent nozzle 2.

As a result of impingement attack of a flow of the sucked atmospheric air to the baffle wall 8, heat is released which partially evaporates the moisture "spot" almost without any heat exchange with a base construction material of the air filter 1. This allows to consider the heat exchange process almost adiabatic, i. e. without any heat exchange with the environment [6].

2. Description of the heat and mass exchange processes

Let us determine the fields of temperature, speed and flows of the mass to describe the heat and mass exchange processes. For that, let us single out an elementary volume with ribs d_x' d_y, d_z in contacting mass of the moist sucked air and moisture "spots" placed on the baffle wall 8 and let us write the equation for its heat balance. Let us also assume that all the heat q delivered is spent on enthalpy h change of the specified volume (expansion work is 0) [7]:

$$\rho \frac{\partial h}{\partial \tau} = -\left\{ \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} + \frac{\partial q_z}{\partial z} \right\} = -divq. \quad (1)$$

In a moving environment, a substance is transferred both by molecular diffusion and convection. As a result, when the examined volume of fine-dispersed and condensated moisture mixture with density $\delta_{см}$ with speed $\omega_{см}$ is transferred, whose limit value $j_{см}$ is determined by the equation

$$j_{см} = \rho_{см} \cdot \omega_{см} = \left(\rho_{вв} + \rho_{п} + \rho_{вл} \right) \cdot \omega_{см} = \sum \rho_{i} \cdot \omega_{см}, \quad (2)$$

where $\rho_{вв}$, $\rho_{п}$, $\rho_{вл}$ is the density of moist air, steam and moisture beating against the baffle wall respectively.

Thus the heat flow density in the mixture is described by the equation on the basis of $h = c_p T$ where c_p is the heat capacity of the moist air.

$$\frac{\partial t}{\partial \tau} + \omega_x \frac{\partial t}{\partial x} + \omega_y \frac{\partial t}{\partial y} + \omega_z \frac{\partial t}{\partial z} = a\nabla^2 t - \frac{(c_{рвл} - c_{вв})}{c_p \rho_{см}} \left\{ \frac{\partial (T \cdot j_{xi})}{\partial x} + \frac{\partial (T \cdot j_{yi})}{\partial y} + \frac{\partial (T \cdot j_{xi})}{\partial z} \right\}, \quad (3)$$

where a is a thermal diffusivity coefficient; $c_{рвл}$, $c_{вв}$ are heat capacities of fine-dispersed atmospheric and condensated moisture and of the moist air.

Assuming that a substance transfer during the moist air contact with the moisture “spot” on the baffle wall is carried out mostly by concentration diffusion, we have

$$\left. \begin{aligned} j_{xi} &= -D \frac{\partial p_i}{\partial x} = -\rho_{см} \cdot D \frac{\partial m_i}{\partial x}, \\ j_{yi} &= -D \frac{\partial p_i}{\partial y} = -\rho_{см} \cdot D \frac{\partial m_i}{\partial y}, \\ j_{zi} &= -D \frac{\partial p_i}{\partial z} = -\rho_{см} \cdot D \frac{\partial m_i}{\partial z}, \end{aligned} \right\} \quad (4)$$

where m_i is a local mass content equal to the relation between the concentrations and densities of the air steam component and the mass: $m_i = \rho_i / \rho_{см}$.

Inserting the values j_{xi}, j_{yi}, j_{zi} into Equation (3), we get:

$$\frac{\partial t}{\partial \tau}+\omega_x\frac{\partial t}{\partial x}+\omega_y\frac{\partial t}{\partial y}+\omega_z\frac{\partial t}{\partial z}=a\nabla^2 t+D\frac{(c_{рвл}-c_{вв})}{c_p\rho_{см}}\left\{\frac{\partial}{\partial x}\left(T\frac{\partial m_i}{\partial x}\right)+\frac{\partial}{\partial y}\left(T\frac{\partial m_i}{\partial y}\right)+\frac{\partial}{\partial z}\left(T\frac{\partial m_i}{\partial z}\right)\right\}. \quad (5)$$

The temperature field in the elementary volume of the contact of the treated air and the moisture “spot” depends on the speed components ω_y, ω_z ω_x and the mass content m_i. The evaporation temperature in the differential equation solution is then defined as

$$T_и=T_{ж}-\frac{rDP_n}{230\lambda_{ж}}\left(\frac{\Delta P}{P_n}\right)^{\frac{5}{6}}, \quad (6)$$

where $T_{ж}$ is the liquid “spot” temperature on the baffle wall; P_n is a steam liquid mixture pressure in the boundary moisture “spot” layer on the baffle wall, Pa; r is a hidden steam generation heat, Joule/kg; D is a diffusion coefficient; ΔP is a difference between the steam liquid mixture pressure and the pressure over the moisture “spot” surface in the state of saturation Pa; $\lambda_{ж}$ is a liquid thermal conductivity coefficient, watt/(m·^{0}C).

Moist atmospheric air purified from solid dust particles and other substances generated as a result of technological processes as well as from bead-like fine-dispersed moisture saturated with steam envelopes the baffle wall 8 and comes into the screen container 12 that is filled with an adsorbing substance, e. g. by silica gel, and constructed as a removable carrier on a perforated cylinder of the air filter outlet fitting 11.

Due to the air filter operation peculiarities caused by mechanical and vibrational effects on adsorbing substance leading to the intensive destruction of the adsorbent grain surface, the relation between the volume of the ventilation air purified from vapor contaminations and adsorbent mass G_{ad} subjected to the vibrational effect is experimentally found and determined by the expression

$$G_{ад}=\frac{\tau_{ад}\cdot G_{вв}\cdot(d_n-d_к)}{Z_{ад}}, \quad (7)$$

where $\tau_{ад}$ is the time of adsorptional purification of the ventilation air; $G_{вв}$ is the consumption of the moist ventilation air purified from the bead-like moisture; d_n and $d_к$ are air moisture content before and after the container with the adsorbent; $Z_{ад}$ is the adsorbent moisture capacity.

The main problem with the application of Equation (7) is about calculating the adsorbent moisture capacity $Z_{ад}$ which, according to the investigations conducted by the authors and literature analysis [8] can be calculated according to the formula

$$Z_{ад} = Z_{св}\left(\eta_{с} - \eta_{ис}\right)\cdot \eta_{р} \cdot \eta_{об}\,, \qquad (8)$$

where $Z_{св}$ is a moisture capacity of a fresh not used adsorbent; $\eta_{с}$ is a coefficeint considering the failure or "aging" of the adsorbent caused by the adsorption-desorption processess and equal to 0.7; $\eta_{ис}$ is a coefficient considering the intensity of the adsorbent "aging" caused by the vibrational effects during the air filter operation; experimentally $\eta_{ис} = 0.05 \div 0.15$; $\eta_{р}$ is a coefficient considering the decreasing activity of the absorbing capacity as a result of the layer warming in the adsorption process; $\eta_{об}$ is a coefficient considering the decreasing activity of the steam absorption as a result of incomplete layer treatment (decrease of the terminal speed of the mass exchange processes).

It is possible to accept that

$$\eta_{р} \cdot \eta_{об} = 0.4 \div 0.6 \text{ [9]},$$

then

$$Z_{ад} = Z_{св}\left(0.39 - 0.22\right). \qquad (9)$$

The adsorbent volume calculated with the help of this method is placed in the screen container 12 and on the perforated cylinder of the air filter outlet fitting 11. After the purification to the parameters eliminating the possibility of the moistening in air spaces of building constructions, the ventilation air comes into the ventilator 14 inlet duct 13 and further into the ventilated air space.

The novelty of the technological solution in the complex ventilated air purification is protected by the Russian Federation invention patent [7].

Conclusions

1. The peculiarity of load-carrying construction operation in premises with a high moisture content is the arrival of air with fine-dispersed and vapor moisture to ventilated spaces causing the formation of condensate film on the surface of construction elements which have an adverse effect on the strength parameters of an entire building.

2. A device for complex atmospheric air purification by step-by-step separation of fine-dispersed contaminations in the form of solid particles and bead-like moisture as well as by adsorption air purification at the ventilator inlet opening has been suggested. This provides for reliable and lasting operation of load-carrying construction elements.

References

1. V. N. Melkumov, A. V. Cheremisin and K. A. Sklyarov, "Non-Steady-State Processes of Air Flow Formation by Ventilation Systems in Premises," *Izvestiya OrelGTU. Ser.: Stroitelstvo i transport,* No. 3, 36 (2007).

2. V. N. Melkumov, I. S. Kuznetsov, L. Yu. Guseva and A. V. Cheremisin, "Estimation of Accumulating Ability of Ventilated Amounts to Reduce Required Air Exchange in Premises," Vestnik VGTU*,* No. 1, 205 (2007).

3. V. N. Melkumov and S. N. Kuznetsov, "Dynamics of Air Flow and Temperature Field Formation in Premise," Nauchny Vestnik VGASU. Stroitelstvo I arkhitektura*,* No. 4, 172 (2008).

4. A. P. Merkulov, *Vortex Effect and Its Application in Engineering* (Mashinostroenie, Moscow, 1969) [in Russian].

5. V. V. Nashchokin, *Technical Thermodynamics and Heat Transfer* (Vysshaya shkola, Moscow, 1980) [in Russian].

6. N. S. Kobelev and G. G. Schedrina, "Reduction in Energy Consumption in Fluid Power Production in Difficult Climatic Conditions," Promyshlennaya energetika, No. 9, 34 (2007).

7. A. G. Kasatkin, *Basic Processes and Apparatus of Chemical Technology* (Khimiya, Moscow, 1973) [in Russian].

8. V. N. Kobelev, D. V. Avdyakov, A. V. Medvedev and T. S. Rozhdestvenskay, "Increase in operational reliability of building structures with large area of glazing," in *Safety of Russia Construction. Problems and solutions* (Kursk, 2005), p. 15—18.

9. Ye. N. Serpionova, *Industrial adsorption of gases and vapours* (Vysshaya shkola, Moscow, 1969) [in Russian].

10. Russian Federation Patent 2367503.