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"SALT IN A POROUS MATRIX" SORBENT AND SAWDUST AS AIR DRIERS FOR VENTILATION SYSTEMS

Yu. G. Korobeinikov,[a] A. V. Fedorov,[a] E. A. Buluchevskii,[b] and A. V. Lavrenov[b]

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The processes of moisture desorption by a sorbent-drier of the type of "salt in a porous matrix" and sawdust in convective flow, as well as under the acoustoconvective action, have been investigated. It has been shown that at a flow velocity of 31 m/sec the sorbent has a rather prolonged drying stage with a constant rate, and at a flow velocity of 13 m/sec this drying stage ends faster. It has been established that the velocity of the convective flow strongly influences the drying process of the sorbent, and the action of the acoustic field therewith produced no marked effect on the drying process. Moisture desorption from sawdust proceeds with a variable rate, and its intensity markedly increases under the action of the acoustic field. The influence of acoustic vibrations on the rate of moisture removal has a nonmonotonic character.

The kinetics of the process of humidification of the sorbent-drier has been investigated. On the basis of the investigations made, a basic circuit for ventilating closed rooms by dried air with the use of sawdust or an IK-011-1 sorbent-drier has been proposed.

Keywords: *acoustoconvective drying, sorbent, sawdust, Hartmann oscillator.*

Moisture contained in the atmospheric air often has a negative impact on the economic activity of man. For instance, under the severe climatic conditions in Russia and the Republic of Belarus, water sorbed in the structural materials of the walls of buildings and structures freezes in winter, leading to cracking and impairment of the strength of structures. Atmospheric moisture may promote corrosion of metals in stored materials and articles and caking of powders. Under its action the growth of bacteria and micromycetes may intensify and packing paper may be destroyed. For these reasons, systems of induced ventilation of rooms often have to incorporate devices for removing moisture from the inflowing air.

The application of solid absorbers is one of the simplest and most effective ways for drying gas flows. However, the use of traditional adsorbers (silica gels, aluminum oxide, zeolites) requires considerable expenditures of heat for the regeneration, as a result of which the application of such materials for drying ventilation flows is seldom reasonable.

The urgency of the development of technologies and materials for drying gases, as well as the search for new, energy-saving and intensive methods for regenerating sorbents, is now apparent. Therefore, the main goals of the present work are the determination of the kinetic curves of water sorption by a sorbent-drier of the "salt in a porous matrix" type, as well as the investigation of the kinetics of moisture desorption by a sorbent drier and sawdust in an acoustoconvective flow.

Experimental. *General characteristic of sorbent drier of the type of "salt in a porous matrix."* For such a sorbent-drier, we used an IK-011-1 technical air drier [1]. The sorbent is a matrix from γ-oxide of aluminum, into whose pores a hygroscopic salt, calcium chloride, was introduced. The material is obtained by the method of impregnation followed by drying at 150°C. The basic properties of the IK-011-1 sorbent drier of brand A with cylindrical granules are as follows:

Diameter of granules, mm	2.8 ± 0.5
Length of granules, mm	0.9 ± 3.0
Bulk density, kg/m^3	≥700
Strength coefficient, kg/mm	≥1.2
Mass fraction of calcium chloride, %	15 ± 3

[a]S. A. Khristianovich Institute of Theoretical and Applied Mechanics, Siberian branch of the Russian Academy of Sciences, 4/1 Institutskaya Str., Novosibirsk, 630090, Russia; email: Fedorov@itam.nsc.ru; [b]Institute for Problems of Hydrocarbon Processing, Siberian branch of the Russian Academy of Sciences, Omsk, Russia. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 82, No. 2, pp. 252–257, March–April, 2009. Original article submitted May 14, 2008.

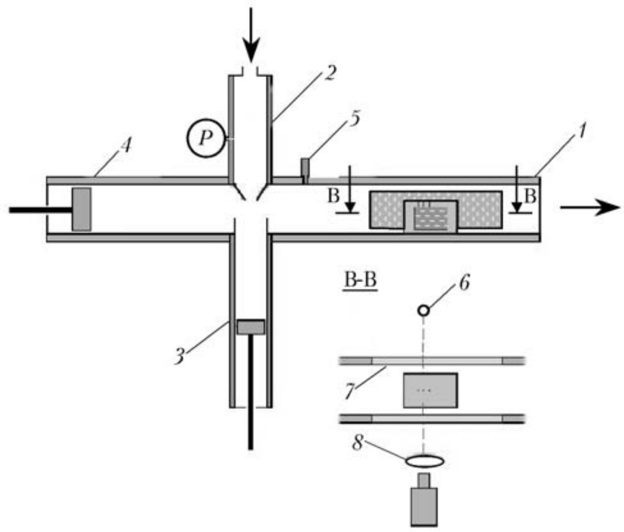


Fig. 1. Scheme of the apparatus for acoustoconvective drying: 1) channel of the drying apparatus; 2) nozzle of the sound source with compressed air supply; 3) resonator of the sound source with a frequency regulation piston; 4) adjusting piston; 5) pressure and temperature sensors in the working gas flow; 6) light source; 7) optical windows; 8) video camera; *P*, pressure cell in the settling chamber of the nozzle.

Apparatus for acoustoconvective drying. The apparatus for acoustoconvective drying of materials is schematically represented in Fig. 1. A sample was placed in a rectangular-section drying chamber 1. The air inlet and outlet from the apparatuses is shown by arrows. For a sound source, we used a Hartmann oscillator 3. The mode of operation of the apparatus was determined by the working gas stagnation pressure in the settling chamber of the nozzle *P* and the position of pistons 3 and 4. The level of acoustic field intensity in the drying chamber was measured by a pressure detector 5.

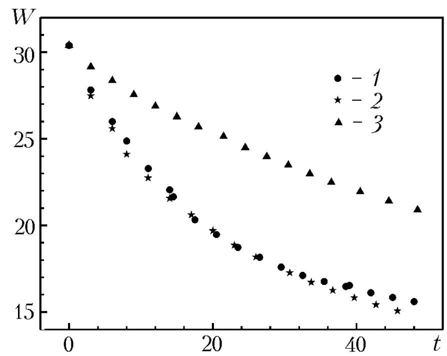
*Conditions of experiments on moisture desorption.*The IK-011-1 sorbent was moistened through sorption from a moisture-saturated air flow under dynamic conditions up to a moisture content of 30% (with reference to a dry material). Sawdust was moistened by direct soaking of a predried material in water.

Moisture desorption was realized as follows. A portion of the sorbent (IK-011-1 or sawdust) was placed in a container made of dense Kapron. This container was fastened to a base located in the channel of the drying apparatus. Drying of the sorbent was carried out at 23^{o}C in two regimes: acoustoconvective drying (with an acoustic field intensity of 167 dB and frequency f = 415 and 295 Hz) and convective drying. In so doing, the mean velocity of the convective flow in these regimes was the same and equal to 31 m/sec. Moreover, convective drying was also carried out at a flow velocity of 13 m/sec. The current weight of the material was measured on an EK-i/EW-i electronic balance.

Conditions of experiments on water sorption by the IK-011-1 sorbent. The process of water sorption from the air flow was investigated under the following conditions: the linear velocity of the air flow calculated for the free cross-section of the channel with a drier was 1.0–1.2 m/sec and typical of such technical devices, the relative humidity of the flow was 80%, as well as 100% at an ambient temperature of 20–25^{o}C.

As a working channel in which a sample of the IK-011-1 drier was placed, a glass pipe of diameter 16 mm was used. Air was supplied into the working channel by an air compressor. Before the beginning of the kinetic experiment the sample of the IK-011-1 drier was activated directly in the working channel at a temperature of 150^{o}C in a dry air current (dew point −60^{o}C) until a constant mass was reached with subsequent cooling down to the ambient temperature of 20–25^{o}C.

The relative humidity of the air flow of 100% at the inlet to the working channel with the IK-011-1 drier was provided by bubbling the flow through a free water layer. The relative humidity of the air flow of 80% at the inlet to the working channel with the IK-011-1 drier was achieved by mixing a saturated air flow with a dry air flow (dew point −60^{o}C). The humidity of the air flow was measured by an IVA-6 humidity meter.



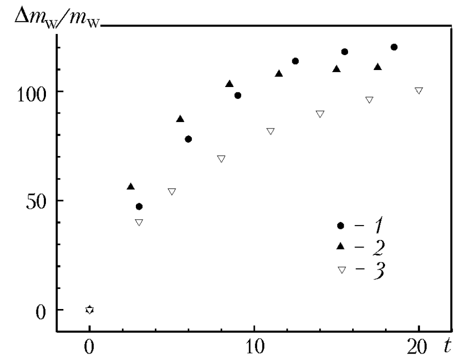


Fig. 2. Change in the moisture content of the IK-011-1 sorbent in the drying process: 1) acoustoconvective drying; 2, 3) convective drying at a flow velocity of 31 and 13 m/sec, respectively, *W*, %; *t*, min.

Fig. 3. Kinetic drying curves of sawdust: 1, 2) acoustoconvective drying at f = 415 and 290 Hz; 3) convective drying. $\Delta m_w/m_w$, %; *t*, min.

The sorption process was stepwise. The duration of the sorption process at each step was 5 min. After each step the air supply was terminated and the increase in the sample mass compared to the initial mass was determined with analytic accuracy (10^{-4} g).

Results and Discussion. *KInetics of moisture desorption by the IK-011-1 sorbent and sawdust.* The experimental results for the moisture desorption by the IK-011-1 sorbent are given in Fig. 2. It is seen that the convective flow velocity strongly influences the drying kinetics of the sorbent and, in so doing, the discrete component of the acoustic field makes no appreciable contribution to this process (in the considered range of moisture content). The latter is likely due to the fact that sorbed water is contained in the composition of the calcium chloride hydrates, i.e., is chemically bound. The absence of water in the free state makes impossible the demonstration of the main acting factors of the acoustic field (pressure and velocity fluctuations). Therefore, in drying this material water desorption occurs only through evaporation.

At a flow velocity of 31 m/sec there is a rather prolonged stage of drying at a constant rate, and at a flow velocity of 13 m/sec this drying stage is shorter. This means that the so-called "first" stage of drying where the moisture desorption rate is largely determined by the processes proceeding on the surface of the material being dried is realized [2]. For the sorbent under consideration this fact seems to be natural since there are thin walls and a well developed inner surface.

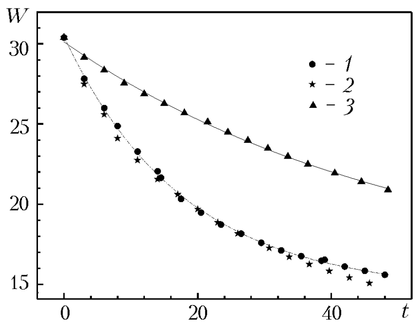
As mentioned above, the drying process strongly depends on the convective flow velocity. This is due to the influence of the latter on the heat transfer coefficient from air to sorbent, as well as on the rate of carry-over of water molecules from the evaporation surface. As the flow velocity is increased from 13 to 31 m/sec, the rate of drying (estimated from the change in the moisture content in 20 min during the period of an approximately constant drying rate) increases by a factor of 1.83 (Fig. 2). Since almost the whole of the heat supplied to the sorbent in this period is expended in drying, it may be assumed that the heat transfer coefficient also increases by the same factor. Then we obtain the dependence

$$\mathrm{Nu} \sim O\,(\mathrm{Re}^{0.7})\,.$$

For comparison, note that, for example, in drying wood the dependence of the Nusselt number on the Reynolds number is of the form [3]

$$\mathrm{Nu} = 0.072\mathrm{Re}^{0.8}\,.$$

The results of experiments on the drying of sawdust are presented in Fig. 3. It is seen that the acoustic field makes a significant contribution to the process of drying sawdust (e.g., in 10 min of drying with the application of the acoustic field about 40% more moisture is removed than in convective drying). The influence of an increase in the vibration frequency has a nonmonotonic character.



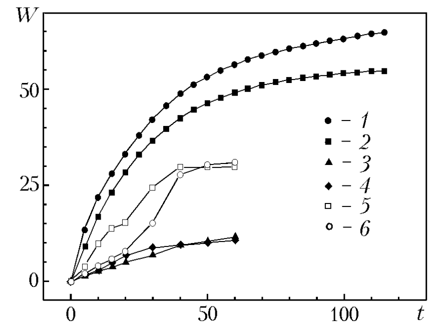


Fig. 4. Approximation of the experimental data on the IK-011-1 sorbent drying by the solution of the linear kinetic equation: 1) acoustoconvective drying; 2, 3) convective drying at a flow velocity of 31 and 13 m/sec, respectively, *W*, %; *t*, min.

Fig. 5. Dependence of the moisture content of different driers on the duration of the sorption process: 1, 2) IK-011-1 at a relative air humidity of 100 and 80%, respectively; 3) A1; 4) KSM; 5) T1; 6) T2; *W*, %; *t*, min.

As was shown in our work [4], the kinetic drying curves can be described fairly well by the solution of the linear kinetic equation of the relaxation type

$$\frac{dW}{dt} = -\frac{W - W_e}{\tau}.$$

Figure 4 compares the solution of this equation to the experimental data obtained. A good agreement between the results is seen.

Kinetic sorption of water on the IK-011-1 technical air drier. On the basis of the data obtained we constructed the dependences of the moisture content of the sorbent (mass of the water absorbed by the sample referred to its initial mass and multiplied by 100%) on the total time of the sorption process (Fig. 5). For comparison, Fig. 5 also gives the data on the sorption kinetics obtained earlier at the Catalysis Institute of the Siberian Branch of the Russian Academy of Sciences for driers based on aluminum oxide, KSM silica gel, and cellular alumosilicate blocks. From the data obtained for the IK-011-1 drier it is seen that the initial rate of moisture absorption by this sorption material (the first 20 min of the process) is 4–5 times that of the traditional sorbents based on aluminum oxide and silica gels and is higher by a factor of 1.8–3.6 than that of the cellular alumosilicate blocks. Moreover, it is also distinguished by a higher total sorption capacity for water vapors. In about 40 min of the sorption process all the previously investigated driers reach the limit of their capacity. The IK-011-1 drier continues to sorb water noticeably in up to 80 min of the process. The moisture absorption therewith is no less than 52%, which is 1.7 times higher than for the T1 and T2 driers. Thus, it may be concluded that the IK-011-1 drier can be most promising for use in a ventilation drying system in terms of both the rate of moisture absorption and the time of effective operation.

On the basis of the investigations made we can propose the following basic circuit arrangement for the ventilation of closed rooms by dried air (Fig. 6). The circuit contains two alternately operating sorption blocks with an IK-011-1 drier equipped with a system of acoustoconvective regeneration, ventilation blowers, and automatic three-pass gates. Below is an example of the working cycle of the circuit:

1. Blower 1 conveys ambient air through the sorption block 1 where it is dried and then enters the ventilated space.

2. "Spent" air from the ventilated space enters the sorption block 2 which is in the state of regeneration. From its outlet the air together with water vapors is released into the atmosphere.

3. When saturation of the drier in block 1 is reached or the air humidity exceeds the allowable norm or after the preset time, the process is inverted. The direction of the air flow reverses. Air drying proceeds in the sorption block 2. The sorption block 1 is switched to the regeneration regime.

In using sawdust as a moisture absorber, in the given system it is possible to use the regime of acoustoconvective regeneration. When the IK-011-1 sorbent-drier is used in the regeneration process, heating of the sorbent is

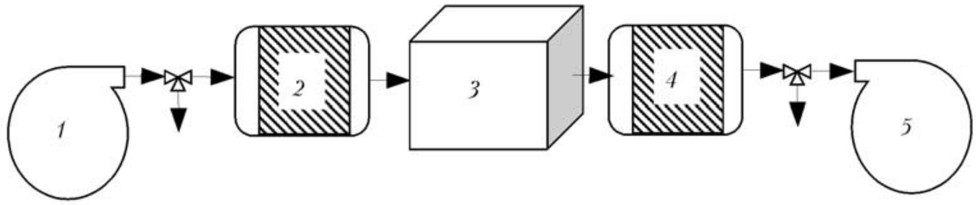


Fig. 6. Schematic diagram of the ventilation of closed rooms by dried air with the use of sorption blocks filled with the IK-011-1 drier and equipped with an acoustoconvective regeneration system: 1) blower No. 1; 2) sorption block No. 1; 3) ventilated space; 4) sorption block No. 2; 5) blower No. 2.

necessary. To this end, convective heat or more intense heating methods (high-frequency currents, microwaves, etc.) can be used.

CONCLUSIONS

1. The rate of drying of the IK-011-1 sorbent strongly depends on the convective flow velocity. A decrease in the flow velocity leads to a decrease in the duration of the period of drying with a constant rate. In the considered range of moisture contents, no influence of the acoustic field on the moisture desorption rate has been revealed. However, this question requires further studies.

2. The process of drying sawdust has no marked stage of constant rate. Exposure to the acoustic field leads to a considerable increase in the drying rate. The influence of the frequency of acoustic vibrations has a nonmonotonic character.

3. The experimental data on the drying kinetics are fairly well described by the solution of the linear kinetic equation of the relaxation type with different characteristic relaxation times from 18 to 50.6 min.

4. The IK-011-1 drier exceeds in the initial rate of moisture absorption (the 20 min of the process) the traditional sorbents based on aluminum oxide and silica gel by a factor of 4–5 and the cellular alumosilicate blocks by a factor of no less than 1.8–3.6. Therefore, it can be most promising for use in the ventilation system of drying in terms of both the moisture absorption rate and the time of effective operation.

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NOTATION

f, acoustic field frequency, 1/sec; m_w, quantity of water expended in soaking the sample, g; Nu, Nusselt number; Re, Reynolds number; t, drying time, min; W, moisture content of samples equal to the ratio of the weight of water in the sample to the weight of the sample, %; W_e, moisture content of samples equilibrium with the medium, %; Δm_w, quantity of extracted water, g; τ, relaxation time in the drying process, min. Subscripts: w, water; e, equilibrium.

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