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Odour Control By Fibrous Ion Exchangers

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Ammonia is one of the main contaminants of the atmosphere. The most important sources of NH_3 in the environment are animal farms, landfills and food industries. Large ammonia storage facilities used in the mineral fertilizer industry, petrochemical industry and in industrial refrigerators are also significant potential dangers for the environment. The contamination of outdoor air with NH_3 is becoming a national problem for countries with dense populations and extensive agriculture (e.g. The Netherlands).
There are several methods available for control odours – all with a variety of advantages and disadvantages. We propose using fibrous ion exchangers for removal specific odours from air. Ammonia, as a weak base, can be absorbed by acidic forms of cation exchange resins. The sorbent can be regenerated with acid solution with obtaining salts used as fertilizers.
In the paper we present results of laboratory investigations of ammonia sorption from air by fibrous exchange materials. Our experiments proved that fibrous exchangers can be used in large-scale filters for centralized air purification.

1. Introduction

Malodorous substances often have acidic or basic nature. To these categories belong inorganic and organic acids, sulphur and nitrogen oxides, ammonia and amines, scatol and many others (Mills, 1995). Ionized substances are the most toxic components of bad smell.
From chemical point of view it is clear that these substances can be removed from air with ion exchangers by reactions of neutralization because they are solid bases or acids.
Attempts to use ion exchange resins for air purification are known (Hashida and Nishimura, 1973; Vulikh et al., 1970; Vulikh et al., 1981). They showed that ion exchange resins are not suitable for practical air purification technologies because the sorption process is too slow if the size of the resin beads is large enough to provide acceptable aerodynamic resistance and thickness of the filtering layer.
Fibrous ion exchangers (Soldatov et al., 1988; Soldatov et al., 2004a) have been proved suitable for the efficient air purification from ionized impurities in the concentration range 10^{-3} – 10^{2} ppm (the same range as it is actual for malodorous substances). They can be produced in form of non-woven canvas with thickness 1 - 10 mm and the surface density 100 – 1000 g/m^2. Sorption processes on these materials are extremely fast because their mono-filaments usually have effective diameter 5 – 50 µm, which is much smaller than that of the resin beads (500 – 1000 µm). In our previous communication

(Soldatov et al., 2004b) it has been shown that the layer thickness 2 - 3 mm is sufficient for ammonia removal from air flows with linear rate ~ 0.1 m/s.

The aim of the present paper is determining parameters of the air purification process from ammonia on two types of ion exchange fibres: FIBAN K-1(strong acid) and FIBAN K-4 (weak acid) cation exchangers.

The main factors affecting efficiency of air purification process with fibrous ion exchangers are as follows:

- concentration NH_3 in the air,
- the relative air humidity (RH),
- the acidic strength of functional groups of ion exchanger,
- the sorption capacity of fiber,
- hydrophilicity and water uptake by the fiber,
- temperature,
- the thickness of filtering layer,
- the airflow rate,
- the construction of filtering plant.

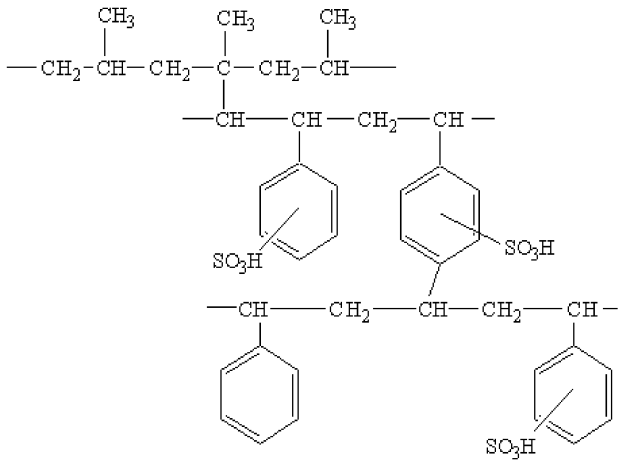
In the earlier publication (Polikarpov et al., 2003) we described the effect of NH_3 concentration in the air, the relative air humidity (RH) and the acidic strength of functional groups of ion exchanger. It appears that the ion exchange fiber with sulfonic group (FIBAN K-1) and carboxylic acid cation exchanger (FIBAN K-4) are strongly different in their sorption properties at low RH. FIBAN K-1 efficiently absorbs NH_3 independently of RH in the range 7 – 90%, while FIBAN K-4 readily absorb it at RH>0.6. The both fibers can be used for efficient air purification from ammonia in the range of its concentration 2 – 200 ppm, airflow rate 0.1 m/s, thickness of the filtering layer 3 mm.

In the present paper we describe the effect on the ammonia sorption of the temperature and filtering layer thickness at the other parameters fixed.

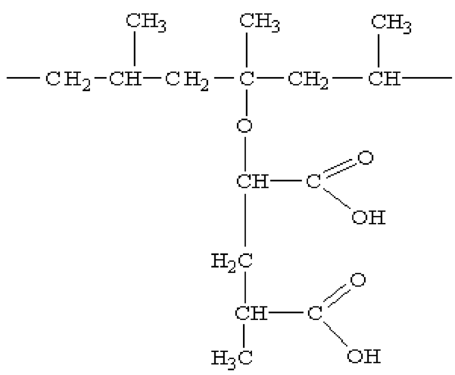
2. Experimental

The ion exchange fibers were synthesized at the experimental production plant of the Institute of Physical Organic Chemistry National Academy of Sciences of Belarus (Minsk, Belarus). They were used as non-woven fabrics with thickness 3 mm and surface density 340 g/m^2.

FIBAN K-1 is a product obtained by direct radiochemical grafting of styrene and divinylbenzene into industrial polypropylene staple fiber with diameter 22 µm and following sulfonation of the graft fiber. The diameter of the ion exchange fiber was 40 µm, exchange capacity 3.0 meq/g, water uptake 0.7 g_{H2O}/g. The structure of representative fragment of the fiber is:



FIBAN K-4 was prepared by post-irradiation grafting of polyacrylic acid into the same polypropylene fiber from aqueous solutions of acrylic acid. Its properties are as follows: diameter of the filaments 40 μm, exchange capacity 4.2 meq/g, water uptake in H^+-form = 0.7 g_{H2O}/g. The structure of the polymer fragment is:



In more details properties of these materials were described elsewhere (Mediak et al., 2001).

The ammonia sorption was studied in dynamic conditions. The air with fixed NH_3 concentration, relative humidity and temperature was passed through a certain number of the ion exchanger shits at a constant flow rate. The experimental conditions are presented in the due places of the text. The scheme of experimental laboratory set-up and details of the experimental measurements were described elsewhere (Kosandrovich and Soldatov, 2004).

3. Results And Discussion

3.1. Temperature effect

A moderate temperature variation does not significantly change properties of the ion exchanger, but it strongly affects activity of water in the gas phase at its fixed concentration. At usually accepted normalizing of the activity it is equal to the relative humidity P/P_0. Therefore, if concentration of the water vapour is fixed, changing temperature causing variation of P/P_0 and, in so doing, may strongly affect NH_3 sorption.

The air in working area (for example in pig farms) usually has temperature about 20˚C while the atmospheric air can be below 0˚C what can significantly complicate the process of its purification. If, in our example, the incoming air has temperature -5˚C and $P/P_0 = 1$ then the water concentration is 3.3 g/m^3. After its heating to 20˚C in the room its relative humidity would become 0.19 what is well below the working limit for the most of ion exchangers.

A strong dependence of sorption activity to NH_3 from relative humidity has been observed for FIBAN K-4. In the experiments with this material at 15 and 25˚C at the same relative humidity ($P/P_0 = 0.56$) we observed that the sorption curves coincide in spite of a large difference in concentration of water vapours (at t = 15˚C $C_{H2O} = 7.18$ g/m^3; at t = 25˚C $C_{H2O} = 12.90$ g/m^3). Fig. 1 shows that the NH_3 sorption is determined only by relative humidity independently of the temperature.

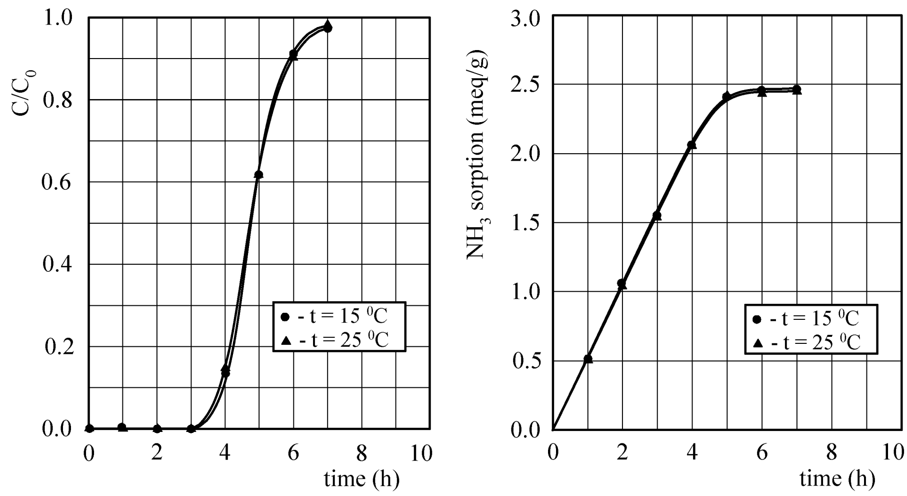


Fig. 1. Ammonia sorption on ion exchanger FIBAN K-4 in dependence of the temperature. Condition of the experiment: thickness of ion exchange layer – 6 mm; initial concentration of ammonia – 18 mg/m^3; airflow rate – 0.08 m/s.

It follows from this result that under conditions of different temperatures inside and outside of the working area it is necessary either correct the air humidity in the absorber or use another material, not sensitive to changing humidity, for example FIBAN K-1.

3.2. The effect of filtering layer thickness

The experimental data on influence of thickness of the filtering layer on the breakthrough and sorption curves of the both ion exchangers are presented in figs. 2, 3.

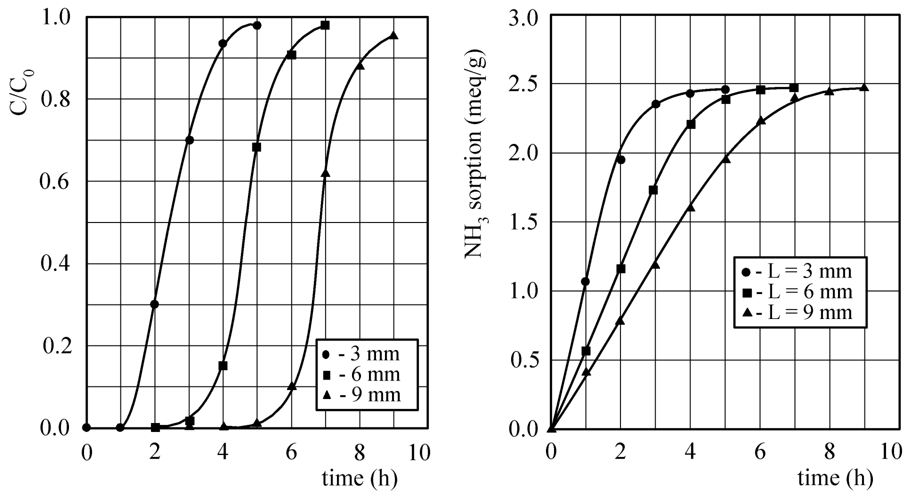


Fig. 2. Sorption and breakthrough curves of ammonia on ion exchanger FIBAN K-4 under various thickness of the filtering layer. Condition of the experiment: relative air humidity – 56%; initial concentration of ammonia – 18 mg/m^3; airflow rate – 0.08 m/s.

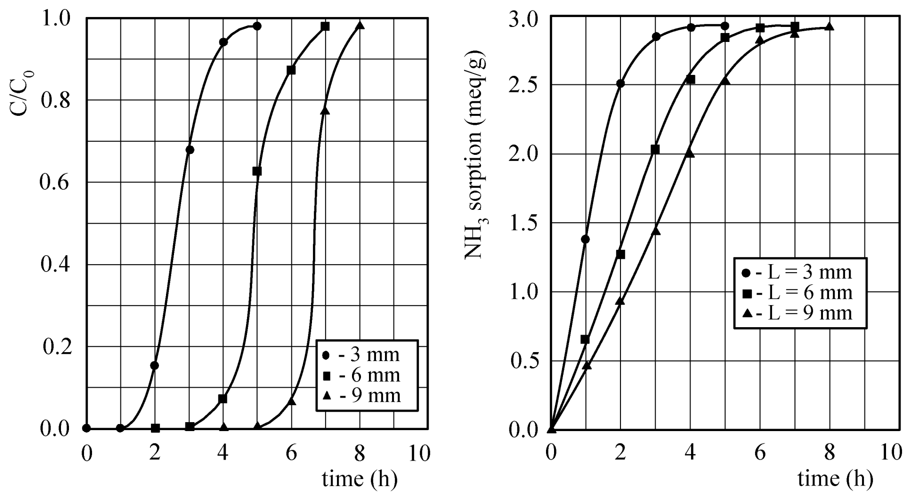


Fig. 3. Sorption and breakthrough curves of ammonia on ion exchanger FIBAN K-1 under various thickness of the filtering layer. Condition of the experiment: relative air humidity – 50%; initial concentration of ammonia – 18 mg/m^3; airflow rate – 0.09 m/s.

The data in the figures show that the both materials remove ammonia from the air at $P/P_0 = 0.50 - 0.55$ with a high efficiency. If the layer thickness is 9 mm the working capacities at breakthrough points $C/C_0 = 0.05$ are 2.8 and 2.0 m-mole NH_3 per gram of FIBAN K-1 and FIBAN K-4 respectively. That makes 97 % and 40 % of their full sorption capacity. In spite of the lower working capacity of the carboxylic acid fiber it may appear more practical in purification systems because it can be easily regenerated by acid solution and the technology of its production is easier and cheaper.
Dependencies of the protection time, τ, corresponding to the breakthrough capacities on the filtering layer thickness, L, can be used for calculation of the most important technical characteristic of the filtering layer that is the length of the mass transfer unit (Harjula and Lehto, 1995).
The parameters needed for calculating the above quantity were found from dependences $\tau = f(L)$ using Shilov´s equation as illustrated by Fig. 4.

$$\tau = K \cdot L - \tau_0 = L/u - \tau_0 = K(L - h) \qquad (1)$$

where:
τ_0 - is the time required for formation of the stationary sorption front in the filter medium,
K - is coefficient of protection action,
h – the quantity characterizing the value of unused (to the breakthrough time) capacity of the filter,
L_0 - is the length of the mass transfer unit.

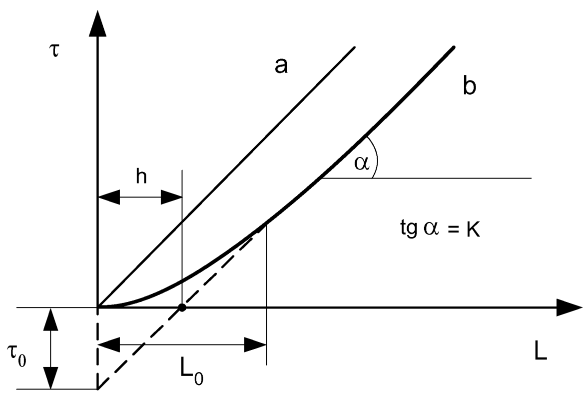


Fig. 4. Graphic definition of parameters of the Shilov´s equation.

Experimental dependences of $\tau = f(L)$ for fibrous ion exchangers are presented in Fig. 5.

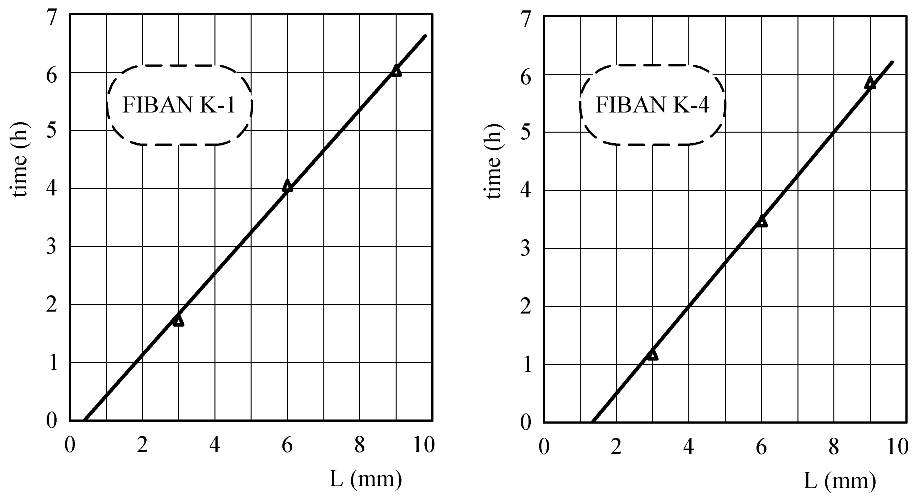


Fig 5. Experimental dependences $\tau = f(L)$ for FIBAN K-1 and FIBAN K-4 ion exchangers.

Parameters of equation 1 are given in Table 1.

Table 1. Dynamic characteristics of ion exchangers FIBAN K-1 and FIBAN K-4.

Ion exchanger	τ, h	L, mm	K, h/mm	u, mm/h	τ_0, h	h	f	L_0, mm
FIBAN K-1	1,75 4,00 6,00	3 6 9	0,71	1,41	0,33	0,47	0,28	1,66
FIBAN K-4	1,14 3,43 5,86	3 6 9	0,79	1,27	1,24	1,58	0,44	3,62

The length of mass transfer unit is the lowest for the strong acid cation exchanger. It is at least by the power of magnitude smaller than that for the granular ion exchangers of the same chemical nature (Bolto and Pawlowski, 1987; Soldatov et al., 1999).

It follows from the data obtained that the minimal thickness of the filtering layer under described external condition of the process is approximately 3 mm for FIBAN K-1 and 7 mm for FIBAN K-4 materials (double length of the mass transfer unit). The both materials can be used for efficient air purification from ammonia well below the level of admissible concentration and odour threshold.

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