



## INTRODUCTION

The development of modern energy-efficient and highly efficient devices for the absorption purification of secondary gases released during industrial production processes and the return of the necessary component of the gas mixture to the production process and use as raw materials is an urgent task today. This requires in-depth study and analysis of the hydrodynamic and metabolic processes that affect the gas purification efficiency and energy consumption of existing devices [1- 3].

### Research methodology:

In the article, the liquid film layer formed on the working surface of the filter material (poronite) of the device was studied in order to select the optimal absorbent for cleaning the secondary hydrogen-fluoride gas [5] generated during the production of superphosphate mineral fertilizer in the wet gas cleaning rotor-filter device [4] and to determine the optimal values of liquid consumption. The influence of its physico-chemical properties, the holes opened in the filter material, and the different values of the diameter of the nozzle that scatters the absorbent liquid on the working surface on the change of the liquid film layer was determined experimentally.

The rotor-filter device belongs to the type of exchange devices that form a film layer. Therefore, the thickness of the liquid film formed on the working surface of the filter is calculated according to the following theoretical equations. It was determined according to the equation for

measuring the consumption of liquid flowing through the nozzle, m<sup>3</sup>/h;

$$Q = \omega_v \pi R^2 \cdot 3600 v \quad (1)$$

where R is the diameter of the fluid nozzle hole, mm;  $\omega$  is the fluid velocity, m/s.

Liquid consumption obtained as a result of measurement, mass irrigation density using its physical parameters can be calculated from the following theoretical equation, kg/m·s; [6].

$$G = \rho_v \frac{n \cdot Q_v}{3600 \cdot P} \quad (2)$$

where  $Q_v$  is the liquid flow rate, m<sup>3</sup>/hour; P is the perimeter of the surface on which the liquid film is formed, m;  $\rho_v$  is the liquid density, kg/m<sup>3</sup>; n is the number of nozzles spraying the liquid onto the working surface, pcs.

The change of the liquid film layer strongly affects its hydrodynamic regimes, so the hydrodynamic regime of the film flow is determined and the thickness calculation formula is selected according to the regime [6].

$$Re_{LF} = \frac{4 \cdot G}{\mu} \quad (3)$$

where m is the dynamic viscosity coefficient of the liquid, Pa·s.

When calculating the liquid film in the rotor-filter device, the following equation recommended by N.N. Egorov and G.V. Minard in their research work is used,  $\mu$ m, [6];

$$s_{LF} = \sqrt{\frac{3 \cdot G \cdot \mu_l}{\rho_l^2 \cdot g}} \quad (4)$$

This equation (4) can be used to experimentally determine the thickness of the liquid film in a rotor-filter device.

The given equation (4) is valid only when calculating experimental values, and the error coefficient does not exceed 4%. But in the theoretical calculation of the process, the error of the values calculated in this equation is 4÷5% higher. Therefore, it is appropriate to use the following equation in the theoretical calculation of the thickness of the liquid film,  $\mu\text{m}$  [6];

$$s_a = \left( \frac{\nu_l^2}{g} \right)^{1/3} = \left( \frac{\mu_l^2}{\rho_l^2 \cdot g} \right)^{1/3} \quad (5)$$

where  $n$  is the coefficient of kinematic viscosity of the liquid,  $\text{m}^2/\text{s}$ .

It is recommended to use equation (5) in the theoretical determination of the thickness of the liquid film in the rotor-filter device[7].

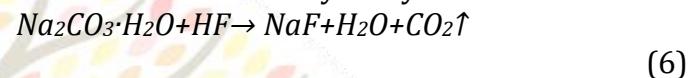
### Research results:

Experimental studies on determining the thickness of the liquid film in the rotor-filter device were conducted in two stages on the analysis of the physico-chemical properties of the absorbent and the effect of the film thickness on the consumption and viscosity of the absorbent.

#### First stage:

Taking into account the erosiveness of secondary hydrogen fluoride (2HF) gas and its

rapid adaptation to an active environment, sodium hydroxide ( $\text{Na}_2\text{CO}_3$ ) was selected as the absorbent according to the requirements of GOST 5100-85 [2,8,9,10]. A chemical equation for the absorption of hydrogen fluoride (2HF) gas into an aqueous solution of sodium hydroxide ( $\text{Na}_2\text{CO}_3$ ) was constructed, and the absorption of sodium hydroxide ( $\text{Na}_2\text{CO}_3$ ) into 10; 20; and 30% aqueous solutions was chemically analyzed.



It can be seen from equation (6) that when hydrogen fluoride was absorbed into a solution of calcium technical soda in water, water and sodium fluoride solution and carbonate anhydride gas were formed.

The following experimental work was conducted to determine the physical properties of 10%, 20%, and 30% aqueous solutions of technical soda ( $\text{Na}_2\text{CO}_3$ ), which were selected as the absorption liquid.

First, 10%, 20% and 30% solutions of calcium technical soda in water were prepared. The pH and temperature of the prepa

red absorbents were determined using a HANNA pH/ORP-meter, and the dynamic viscosity was determined using a HAAKE viscotester 2plus and the density was determined using an ALT1840 hydrometer. The values of the laboratory analysis results are given in Table 1.

Table 1

Hydrogen ion concentration, dynamic viscosity, density, and temperature of 10%, 20%, and 30% solutions of  $\text{Na}_2\text{CO}_3$  in water.

Nº	Mass fraction of $\text{Na}_2\text{CO}_3$ in the mixture	pH head	$\mu, \text{mPa} \cdot \text{s}$	$\rho, \text{kg/m}^3$	$t, ^\circ\text{C}$
1	10%	10.03	1.56	1095	25.3
2	20%	10.15	3.5	1200	25.3
3	30%	10.20	4.5	1280	25.3

### Second stage:

In the second stage of the experiment, the process of formation of a film layer on the working surface of the filtering mesh material (paronite) of the rotor-filter device was studied.

In the research work of A.S. Isomidinov [2,11,12], the resistance coefficient of the working surface of the filter was determined depending on the ratio of the active surface of the filtering

material to the passive surface. A simplified equation for determining the resistance coefficient was recommended and correction factors were introduced [2, 13,14]. The general appearance of the working fluid nozzle and the filtering material (poronite) and the dependence of the correction coefficient  $\Delta k$  on the ratio of the active surface of the filter to the passive surface  $\sum S_{act}/\sum S_{pass}$  are presented in Figures 1; 2 and 3.



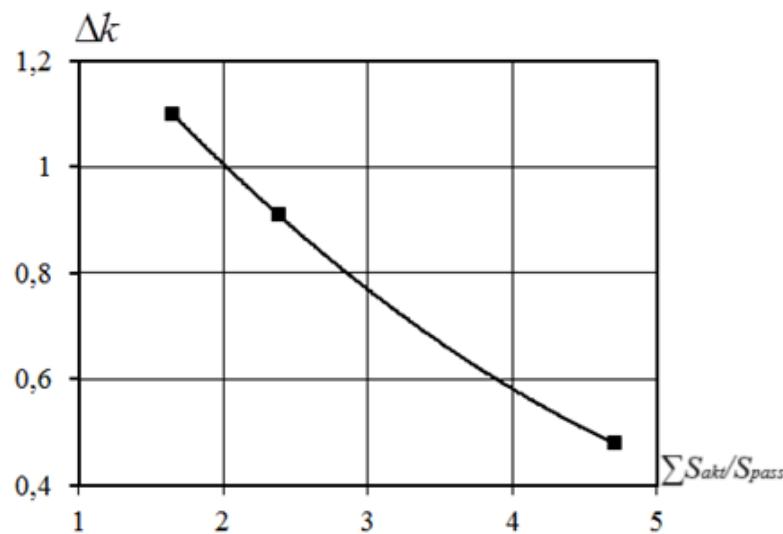
a)  $d_n=1\text{mm}$ ; b)  $d_n=2\text{mm}$ ; c)  $d_n=3\text{mm}$ .

**Figure 1. Overview of nozzles that spray the working fluid:**



$d_f=2\text{mm}$ ;  $d_f=3\text{mm}$ ;  $d_f=4\text{mm}$ ;

**Figure 2. Overview of filter material (paronite).**



**Figure 3. Correction factor  $\Delta k$  to the ratio of filter active surface to passive surface  $\sum S_{act}/\sum S_{pass}$  dependency**

Figure 3 shows that an increase in the active surface area leads to a decrease in the correction coefficient ( $\Delta k = 1.1$  when  $\sum S_{act}/\sum S_{pass}=1.68$ ;  $\Delta k = 0.91$  when  $\sum S_{act}/\sum S_{pass}=2.38$  and  $\Delta k = 0.48$  when  $\sum S_{act}/\sum S_{pass}=4.7$ ). This is due to the direct proportionality of the total resistance coefficient to the active surface area. In addition, it is emphasized that the resistance coefficient increases with the thickness of the liquid film on the filter surface, which in turn depends on the diameter of the pores of the filtering material.

Then, by changing the above equation (4), the equation for determining the thickness of the film layer formed on the working surface of the filter can be found as follows,  $\mu\text{m}$ ;

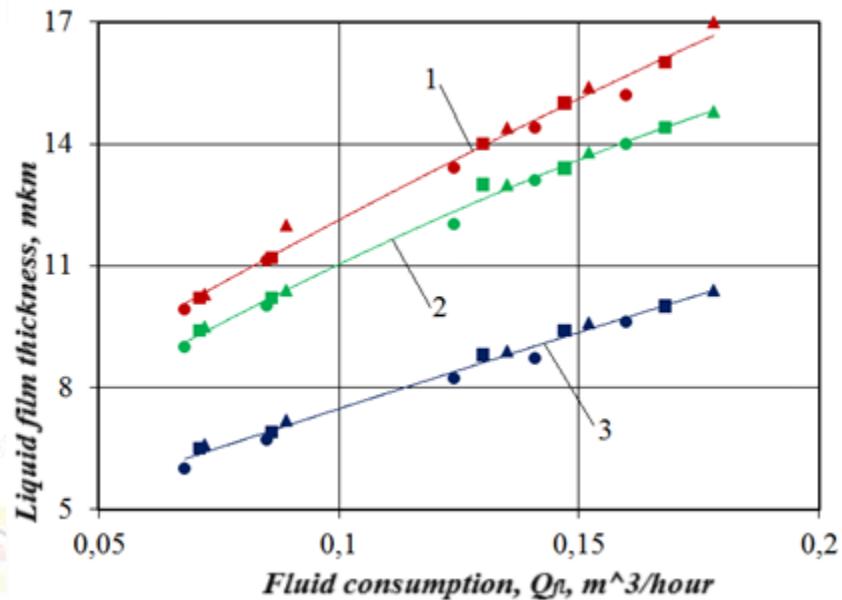
$$s_{PL} = \Delta k \sqrt{\frac{3 \cdot G \cdot \mu_l}{\rho_l^2 \cdot g}} \quad (7)$$

When calculating the thickness of the film on the working surface of the rotor-filter device The following parameters of the variable factors were selected: the diameter of the liquid nozzle hole  $d_{sh}=1$ ; 2 and 3 mm, the diameter of the filter mesh material hole  $d_f=2$ ; 3 and 4 mm, the absorbent flow rate  $Q_v=0.068 \div 0.178 \text{ m}^3/\text{h}$ , the intermediate step  $0.044 \text{ m}^3/\text{h}$ , the solution of calcium technical soda in water 10; 20 and 30%, and the number of rotor revolutions 25 rpm.[15, 16] and (7) was solved according to Eq. When determining the liquid film, the temperature of the external environment was taken into account and set at  $20 \pm 2^\circ\text{C}$ . The graph of the film thickness depending on the absorbent consumption is presented in Figures 4, 5 and 6.

4; 5 and 6 show that for the filter material (paronite) with a hole diameter  $d_f=2 \text{ mm}$  -const and a nozzle hole diameter  $d_n=1$ ; 2 and 3 mm and a 10%, 20%, 30% solution of calcium technical soda in water, an increase in the film layer thickness of  $6.0 \div 10.3 \mu\text{m}$  was observed at the minimum flow

rate of the working fluid, while an increase in the film layer thickness of  $9.6 \div 17 \mu\text{m}$  was observed at the maximum flow rate of the working fluid. The filter material (paronite) with a hole diameter  $d_f=3 \text{ mm}$  -const and a nozzle hole diameter  $d_n=1$ ; In the case of 2 and 3 mm and 10%, 20%, 30% solutions of calcium technical soda in water, an increase in the film layer thickness of  $3.9 \div 6.8 \mu\text{m}$  was observed at the minimum flow rate of the working fluid, and at the maximum flow rate of the working fluid, an increase in the film layer thickness of  $6.2 \div 11 \mu\text{m}$  was observed, and the diameter of the hole of the filtering material (paronite) was  $d_f=4 \text{ mm}$  -const and the diameter of the nozzle hole  $d_n=1$ ; in the case of 2 and 3 mm and 10%, 20%, 30% solutions of calcium technical soda in water, an increase in the film layer thickness of  $1.7 \div 3 \mu\text{m}$  was observed at the minimum flow rate of the working fluid, and at the maximum flow rate of the working fluid, an increase in the film layer thickness of  $2.7 \div 4.9 \mu\text{m}$  was observed. From this it can be concluded that an increase in the liquid flow rate ensures a thickening of the liquid film layer formed on the working surface of the filter. This, in turn, as emphasized above, also depends on the diameter of the filter hole. The larger the diameter of the filter hole, the smaller the thickness of the film layer. Conversely, a decrease in the diameter of the filter hole ensures a thickening of the film layer. In the process we are studying, improving the materialization depends on the materialization surface and the thickness of the film layer. However, it is also necessary to take into account the hydraulic resistance in the device.

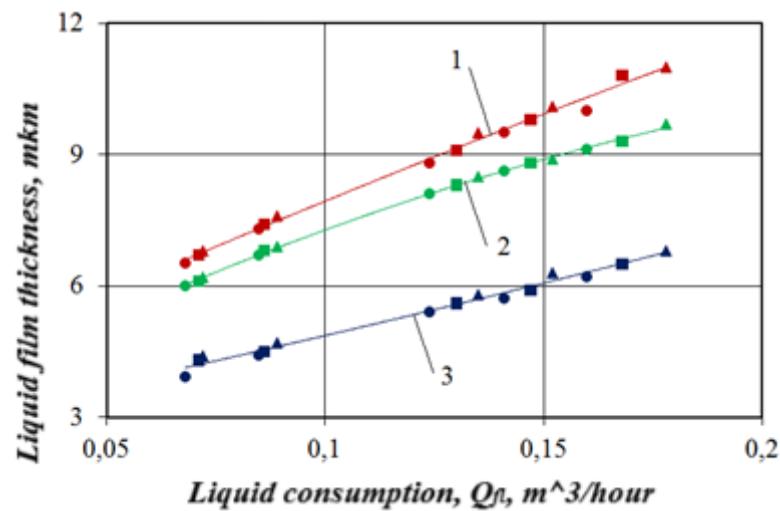
The following empirical formulas were obtained using the least squares method for the graphical relationships presented in Figures 4, 5 and 6.



● – in a 10% solution of  $\text{Na}_2\text{CO}_3$  in water; ■ – in a 20% solution of  $\text{Na}_2\text{CO}_3$  in water; ▲ – in a 30% solution of  $\text{Na}_2\text{CO}_3$  in water.

1 –  $d_n=1 \text{ mm}$  and  $Q_f=0.068 \div 0.160 \text{ m}^3/\text{hour}$ ; 2 –  $d_n=2 \text{ mm}$  and  $Q_f=0.071 \div 0.168 \text{ m}^3/\text{hour}$ ; 3 –  $d_n=3 \text{ mm}$  and  $Q_f=0.072 \div 0.178 \text{ m}^3/\text{h}$ ;

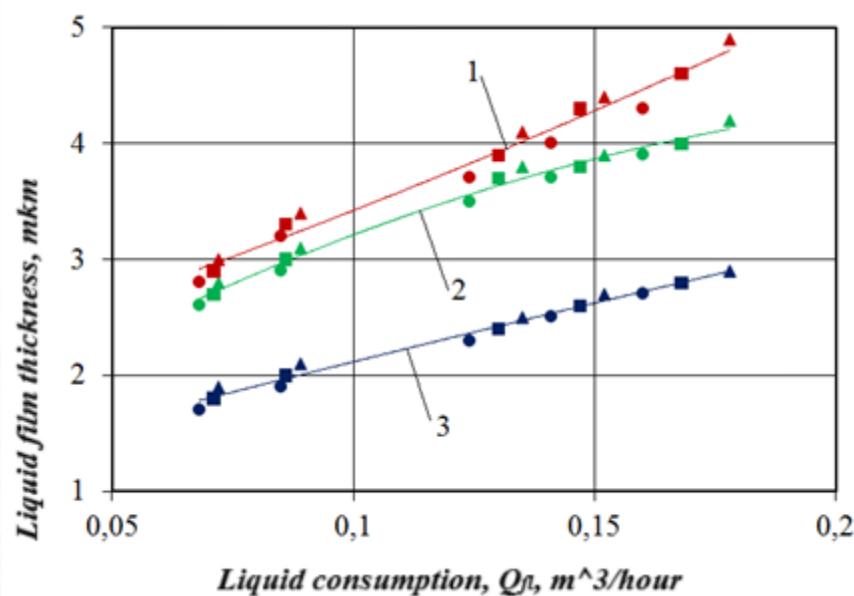
**Figure 4. The graph of the change of the thickness of the film depending on the absorbent consumption,  $d_f=2 \text{ mm-const.}$**



● – in a 10% solution of  $\text{Na}_2\text{CO}_3$  in water; ■ – in a 20% solution of  $\text{Na}_2\text{CO}_3$  in water; ▲ – in a 30% solution of  $\text{Na}_2\text{CO}_3$  in water.

1 –  $d_n=1 \text{ mm}$  and  $Q_f=0.068 \div 0.160 \text{ m}^3/\text{hour}$ ; 2 –  $d_n=2 \text{ mm}$  and  $Q_f=0.071 \div 0.168 \text{ m}^3/\text{hour}$ ; 3 –  $d_n=3 \text{ mm}$  and  $Q_f=0.072 \div 0.178 \text{ m}^3/\text{h}$ ;

**Figure 5. The graph of the change of the thickness of the film depending on the absorbent consumption,  $d_f=3 \text{ mm-const.}$**



● – in a 10% solution of  $\text{Na}_2\text{CO}_3$  in water; ■ – in a 20% solution of  $\text{Na}_2\text{CO}_3$  in water; ▲ – in a 30% solution of  $\text{Na}_2\text{CO}_3$  in water.

1–  $d_n=1 \text{ mm}$  and  $Q_f=0.068 \div 0.160 \text{ m}^3/\text{hour}$ ; 2–  $d_n=2 \text{ mm}$  and  $Q_f=0.071 \div 0.168 \text{ m}^3/\text{hour}$ ; 3–  $d_n=3 \text{ mm}$  and  $Q_f=0.072 \div 0.178 \text{ m}^3/\text{h}$ ;

**Figure 3. The graph of the change of the thickness of the film depending on the absorbent consumption,  $d_f=4 \text{ mm-const.}$**

$d_f=2 \text{ mm-const.}$

$$y = -10.778x^2 + 40.327x + 3.5489 \quad R^2 = 0.9854 \quad (8)$$

$$y = -104.39x^2 + 77.593x + 4.3142 \quad R^2 = 0.994 \quad (9)$$

$$y = -54.206x^2 + 73.288x + 5.3362 \quad R^2 = 0.9887 \quad (10)$$

$d_f=3 \text{ mm-const.}$

$$y = -13.694x^2 + 20.593x + 2.6633 \quad R^2 = 0.9825 \quad (11)$$

$$y = -84.554x^2 + 53.337x + 2.7865 \quad R^2 = 0.9987 \quad (12)$$

$$y = -23.67x^2 + 45.745x + 3.5945 \quad R^2 = 0.9936 \quad (13)$$

$d_f=4 \text{ mm-const.}$

$$y = -4.1444x^2 + 11.157x + 1.0424 \quad R^2 = 0.983 \quad (14)$$

$$y = -50.414x^2 + 25.718x + 1.1435 \quad R^2 = 0.9866 \quad (15)$$

$$y = -17.412x^2 + 12.857x + 1.9625 \quad R^2 = 0.9769 \quad (16)$$

## Conclusion

As a result of the processing of the quantities obtained in the theoretical analysis and

experimental tests, the following conclusions were reached:

- Considering the corrosiveness of secondary hydrogen fluoride gas released during the production of superphosphate mineral fertilizer and its rapid adaptation to the active environment, an aqueous solution of technical soda ( $\text{Na}_2\text{CO}_3$ ) was chosen as the absorption liquid;

- an increase in the amount of technical soda ( $\text{Na}_2\text{CO}_3$ ) in the working fluid increased the dynamic viscosity of the fluid by 4.5 MPa·s and the density by 1280 kg/m<sup>3</sup>;

- according to the chemical analysis of the process of substance exchange in the liquid phase in the device, water and sodium fluoride solution and carbonate anhydride gas were formed when hydrogen-fluoride was absorbed into a solution of technical soda in water;

The graphs in Figures 1; 2; and 3 show that the maximum liquid film thickness in the working area is achieved when the nozzle hole diameter  $d_{sh}=3$  mm and the working fluid flow rate is 0.178 m<sup>3</sup>/h and the filter material (paronite) hole diameter  $d_{sh}=2$  mm, and the minimum liquid film thickness in the working area is achieved when the nozzle hole diameter  $d_{sh}=1$  mm and the working fluid flow rate is 0.068 m<sup>3</sup>/h and the filter material (paronite) hole diameter  $d_{sh}=4$  mm.

- a correction coefficient is included in the theoretical equation (5) for calculating the liquid film formed in the membrane exchange devices, and the equation that takes into account the structural specificity of the experimental device and the hydrodynamic process in it(7) was obtained.

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