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Research Article

STUDY MASS TRANSFER PROCESS IN CAPTURING OF HYDROGEN FLUORIDE GASES

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ABSTRACT

The article investigates the mass transfer process that occurs as a result of liquid droplets moving in a gas flow. Additionally, the absorption of hydrogen fluoride from dusty gas into soda ash droplets was examined. The study experimentally analyzed the influence of gas velocity and liquid flow on the mass transfer coefficient and the purification efficiency of a rotary-filter gas cleaner, considering different types of filters and liquid injection nozzles. To ensure the process is carried out effectively, optimal values for the variable parameters, specifically liquid flow and gas velocity, were recommended.

KEYWORDS

Population growth, food demand, mineral fertilizers, exhaust gases, environmental degradation, hydrogen fluoride, gas purification, superphosphate production, rotor-filter apparatus, mass transfer process.

INTRODUCTION

As the global population continues to grow, the demand for food, particularly agricultural products, is increasing. Mineral fertilizers are widely used to support agricultural production. However, the processes and equipment used in the production of these fertilizers are often outdated and in need of modernization, leading to the release of various exhaust gases into the atmosphere. These emissions contribute to environmental degradation, including ozone layer depletion and global warming. Therefore, addressing the issue of exhaust gas purification through the development of waste-free technologies and the modernization of existing machinery and equipment is a pressing concern.

The production of mineral fertilizers generates various dusty gases, such as nitrogen, phosphorus, and fluorine compounds. In particular, hydrogen fluoride gas, emitted during the production of dusty superphosphate, poses a significant environmental threat. This necessitates the development of effective methods and devices for gas purification. For instance, Fergana Azot JSC operates a facility for the production of superphosphate mineral fertilizers, where hydrogen fluoride gas is released into the atmosphere. The primary aim of this study is to capture this gas, reintegrate it into the technological process, and utilize it as a raw material for other industrial applications.

METHOD

This study investigates the mass transfer process resulting from the interaction between liquid droplets and gas within a device, aiming to identify the optimal gas velocity and fluid consumption for purifying secondary hydrogen fluoride gas produced during superphosphate fertilizer manufacturing. The effects of gas velocity and fluid consumption on the mass transfer coefficient were analyzed. Additionally, the study experimentally examined the impact of varying nozzle diameters, which influence the perforation of the filter material and the spraying of the absorption liquid onto the working surface.

The mass transfer process in the gas phase within a rotor-filter apparatus exhibits complex hydrodynamic and mass transfer characteristics, making it challenging to comprehensively describe the process and develop an accurate mathematical model. To address this, mass transfer processes in devices with similar hydrodynamics and phase contact surfaces were studied. Based on these findings, computational equations for the gas-phase mass transfer process in the experimental apparatus were proposed.

The effect of the consumption of absorption liquid and gas streams on the process of substance transfer in the experimental device is significant. The following equations (1) and (2) are used to calculate these factors influencing the process [1].

Liquid flow through injection nozzles is determined by the next equation, m^3/h;

$$Q_{LIQ} = \omega \pi R^2 \cdot 3600 \qquad (1)$$

where, R- the diameter of the fluid nozzle hole , mm; ω-liquid velocity, m/s.

The sheber was installed in the gas inlet tube in order to obtain different values of gas velocity. According to the different gas velocities, flow of gas is determined through the formula, m^3/h;

$$Q_G = \pi \cdot \left(\frac{D}{2000}\right)^2 v \cdot 3600 \qquad (2)$$

where, *D*–tube diemeter for Pito-Prandtl, m.

As a result of the movement of the droplets formed in the rotor-filter apparatus in the gas phase, a mass transfer is observed, the hydrogen fluoride component in the gas mixture is absorbed into the liquid droplet. To calculate this mass transfer process, it is important to determine the diameter of the drop surface and the volume that varies during the process. When the nozzle diameter varied, the volume of the liquid droplet and the average diameter at which the surface was retained were determined according to the following equation, µm [2,3];

$$d_{32} = \frac{\sum d_X^3}{\sum d_C^2} \tag{3}$$

бунда, dx–the diameter of the droplet forming the main part of the fraction *i*, m;

dc– is the surface diameter of the drop, m;

The velocity of the gas passing through the hole in the drum-coated filter material is determined according to the following equation, m / s [4];

$$w_{hol} = \frac{w_{app}}{\sum F_{hol}} \tag{4}$$

where, w_{app} – gas velocity in experimental apparatus, m/s; ΣF_{hol} – surface of filter's holes, m^2;

The mode of motion of the gas passing through the filter holes is determined by the following equation;

$$\mathrm{Re}_G = \frac{w_{hol} \cdot d_D}{\nu_G} \tag{5}$$

where, w_{hol} – velocity of gas passing through the hole, m/s; ν_G - kinematic viscosity coefficient of the gas, m^2/s; d_D– drop diameter, µm.

The dependence of the rate of component transition in the gas phase on the physicochemical properties of the phases and the process parameters is expressed in the form of criterion equations. The criteria equation proposed by Fresling was chosen to calculate the process of mass transfer in the gas phase in a rotor-filter apparatus. This equation was confirmed on the basis of tests conducted on the mass transfer between a liquid drop and a gas [2].

$$Nu_G = 2 + 0{,}552 \cdot \mathrm{Re}_G^{0,5} \cdot \mathrm{Pr}_G^{0,33} \tag{6}$$

where, Re_G – fluid motion regime of passed gas through the filter;

Pr – quantity of Prandtl for gas phase.

Mass transfer coefficient in absorption of hydrogen fluoride component into the liquid drops is calculated by the following equation, m/s [5,7];

$$\beta_G = \frac{Nu_G \cdot D_G}{d_D} \tag{7}$$

where, Nu_G – Nusslet's quantity for gas phase; D_G – diffusion coefficient in absorption of hydrogen fluoride component into the fluid drops, m^2/s.

In the mass transfer process is occurred between hydrogen fluoride component of gas mixture and fluid drops, the transport number and purification efficiency of apparatus are calculated by the following formula, [4,5,6,7];

$$n = \frac{\beta_G \cdot F_K}{G_G} = \ln\left(\frac{1}{1-\eta}\right) \qquad (8)$$

F_K – contacting surface of phases, m^2; G_G–gas flow, m^3/h; η– purification efficiency, %.

RESULTS

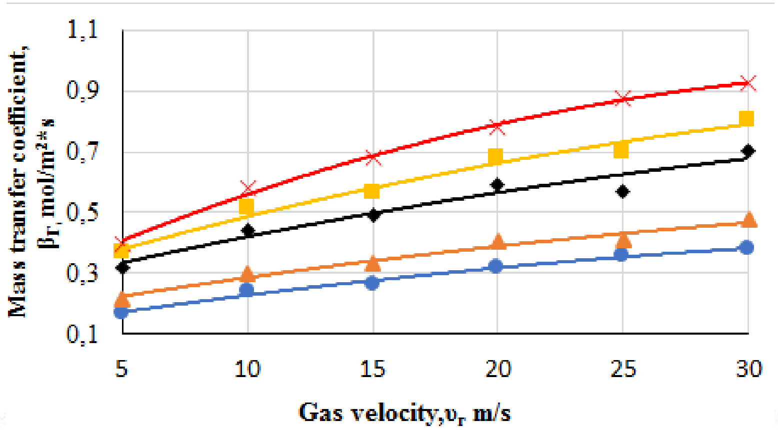
The experiment in order to determine the mass transfer coefficient was carried out following two stages, firstly measuring gas and fluid flows, secondly impact of that flows to the mass transfer and cleaning efficiency of apparatus.

In the first stage of experiment, in order to measure the gas velocity BA06-TROTEC measurement with the 1,1-30 m/s working range and 0,3% inaccuracy was used. Different gas velocities were obtained having installed the sheber into the gas input tube. Sheber forms the 0^0, 30^0, 45^0, 60^0, 90^0 angels in the input tube after fan [1].

The gas flow rate to the apparatus was increased by 5m/s and the speed change interval was set at 5 ÷ 30m/s.

Absorption liquid was selected according to the GOST-3846-10 and supplied through the nozzle with diameters $d_ш$=1mm; $d_ш$=2mm; $d_ш$=3mm; Also, according to GOST-13045-81, the flow rate of the absorption fluid passing through the rotometer RS-5 with a scale of 0-100 was measured for each nozzle in a volumetric manner for the beaker. According to him, when the diameter of the nozzle hole $d_ш$= 1mm, a change in fluid flow according to rotameter readings in the range $Q_{сую}$=0,068÷0,160 m^3/h was observed. According to the rotameter, when the diameter of the nozzle hole $d_ш$ =2mm, the liquid flow rate in the range $Q_{сую}$=0,071÷0,168 m^3/h and when the diameter $d_ш$=3mm, the fluid flow rate $Q_{сую}$=0,072÷0,178 m^3/h [2].

In the second stage of the experiment, it was analyzed that the liquid droplets formed as a result of disintegration of the liquid film and secondary decomposition of the liquid falling into the drum through the filter holes of the hydrogen-fluoride component gas move in the gas flow and occur. At this stage of the experiment, the rate of hydrogen-fluoride component gas mixture with the diameter of the hole of the filter material $d_Ф$=2;3;4mm and the consumption of the absorbing liquid Na2CO3 sprayed into the apparatus through the nozzle $d_ш$=1;2;3mm were studied. The results obtained are illustrated in the form of diagrams given in Figures 1; 2; 3 below [3,4,5,6-17].



d_{Sh}=1 mm and Q_{liq}=0,068÷0,160 m^3/h;

Figure 1. Changing of the mass transfer coefficient depends on the gas velocity, d_F=2 mm-const.

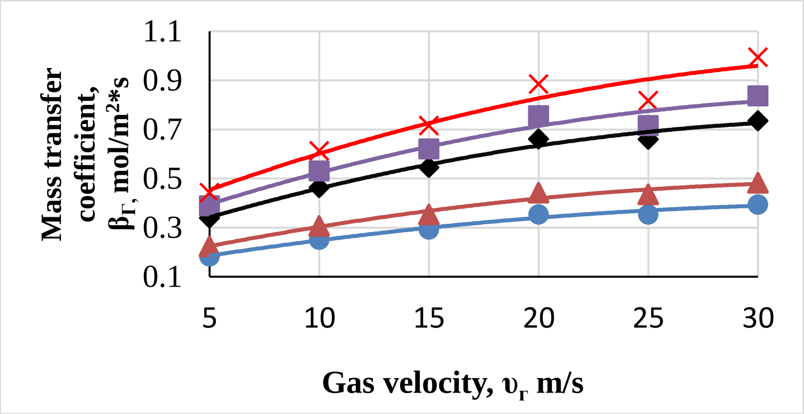
$$y = -0,0001x^2 + 0,013x + 0,1116 \quad R^2 = 0,9919 \tag{9}$$

$$y = -0,0001x^2 + 0,0143x + 0,1571 \quad R^2 = 0,9757 \tag{10}$$

$$y = -0,0002x^2 + 0,0197x + 0,2404 \quad R^2 = 0,9423 \tag{11}$$

$$y = -0,0002x^2 + 0,025x + 0,261 \quad R^2 = 0,9779 \tag{12}$$

$$y = -0,0005x^2 + 0,0373x + 0,2339 \quad R^2 = 0,9963 \tag{13}$$



d_{Sh}=2 mm and Q_{liq}=0,071÷0,168 m^3/h;

Figure 2. Changing of the mass transfer coefficient depends on the gas velocity, d_F=2 mm-const.

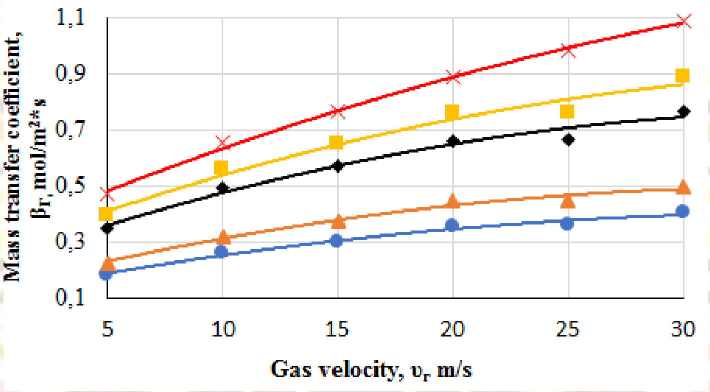
$$y = -0,0002x^2 + 0,0157x + 0,1127 \quad R^2 = 0,9813 \tag{14}$$

$$y = -0,0003x^2 + 0,02x + 0,1315 \quad R^2 = 0,9753 \tag{15}$$

$$y = -0,0004x^2 + 0,0298x + 0,2033 \quad R^2 = 0,9827 \tag{16}$$

$$y = -0,0004x^2 + 0,0324x + 0,2447 \quad R^2 = 0,9542 \tag{17}$$

$$y = -0,0005x^2 + 0,0365x + 0,2828 \quad R^2 = 0,9357 \tag{18}$$



d_{sh}=3 mm and Q_{liq}=0,072÷0,178 m³/h;

Figure 3. Changing of the mass transfer coefficient depends on the gas velocity, d_F=2 mm-const.

$$y = -0,0002x^2 + 0,016x + 0,1134 \quad R^2 = 0,9859 \tag{19}$$

$$y = -0,0003x^2 + 0,0208x + 0,1338 \quad R^2 = 0,9812 \tag{20}$$

$$y = -0,0004x^2 + 0,0289x + 0,2245 \quad R^2 = 0,9781 \tag{21}$$

$$y = -0,0004x^2 + 0,0313x + 0,2627 \quad R^2 = 0,9711 \tag{22}$$

$$y = -0,0003x^2 + 0,0347x + 0,3168 \quad R^2 = 0,9966 \tag{23}$$

Figures 1; 2; 3 show that the diameter of the hole of the filter paronite material is d_F = 2mm, the diameter of the nozzle hole is d_{w}= 1mm and the value of the mass transfer coefficient β_G= 0.170 ÷ 0.399mol/m² ·s change in interval was observed.

It was also observed that when the maximum velocity of the purified gas flow is 30 m/s, the value of the mass transfer coefficient is in the range β_G= 0.382 ÷ 0.927 mol/m²·s. When the diameter of the nozzle hole is d_{Sh}=2мм and the minimum velocity of the purified gas flow is

5m/sec, the value of the substance transfer coefficient $\beta_G = 0.184 \div 0.443 mol/m^2 \cdot s$ is observed to change. It was also observed that when the maximum velocity of the purified gas flow is 30 m/s, the value of the substance transfer coefficient increases to $\beta_G = 0.395 \div 0.995 mol/m^2 \cdot s$. When the diameter of the nozzle hole $d_ш$ = 3mm and the minimum velocity of the purified gas flow was 5m/s, the value of the substance transfer coefficient $\beta_G = 0.184 \div 0.471 mol/m^2 \cdot s$ was observed to change. When the maximum velocity of the purified gas flow was 30 m / s, the value of the substance transfer coefficient increased to

$\beta_G = 0.402 \div 1.09 mol/m^2 \cdot s$ [7,8,9,10,11,12,13,14,15,16,17].

CONCLUSION

In conclusion, As a result of theoretical analysis and values obtained in experiments, the following conclusions were given:

-given above 1; 2; and 3 figures show that, in nozzle diameter dSh=3 мм and gas velocity υG =30m/s, also filtering material hole diameter is dF=2mm the value of mass transfer coefficient is achieved βG =1,09mol/m2·s. It was also found that the minimum value of the mass transfer coefficient is βG = 0.143mol/m2·s when the diameter of the filter material (paronite) hole is dF = 4mm and the diameter of the nozzle hole is dSh = 1mm and the velocity of the purified gas flow is υG = 5m/s. It can be seen that an increase in the velocity of the gas leads to an increase in the mass transfer coefficient;

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