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EFFICIENCY ASSESSMENT OF GAS-LIQUID EJECTION APPARATUS WITH DIFFERENT EJECTOR DIAMETERS

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Abstract. *The article describes the analysis of gas-liquid ejection apparatuses designs. The authors consider the trends of design for innovative apparatuses, anddwell on implementation for devices using the process of liquid atomisation. The conducted experimental studies allow us to assess the efficiency of gas-liquid ejection apparatus. The article considers the experimental dependences of the "sulphite number" on the pressure drop across the nozzle and the ejector diameter.*

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Introduction

A variety of apparatuses with different designs are used in the chemical industry and related sectors to perform mass transfer processes and chemical transformations in liquid-gas systems.

Yaroslavl state technical university (YSTU) scientists have developed a gas-liquid ejection apparatus with several technological and constructive advantages in comparison with other ones for processes in the "gas-liquid" system [1].

Some designs of the most common gas-liquid apparatuses used in industry have been previously reviewed [2]. The chemical method based on the determination of the "sulphite number" is one of the reliable ways to assess the efficiency of gas-liquid apparatuses.

Gas-liquid apparatuses with gas ejection dispersion perform two major processes: 1) the process of atomising (dispersing) the liquid, and 2) the process of mixing gas and liquid. A huge number of variously designed atomisers are used for the dispersing process [3]. The most common atomisers are nozzles. Atomisation to produce large droplets plays the special role. This kind of atomisation is applied in the food industry for products

granulation; in the chemical industry for mineral fertilizers production [4-5]; in spray dryers for artificial water sprinkling in cooling towers [6-8].

The spraying process in chemical crop protection with agrochemicals is of the great importance. To solve a particular problem there is an optimal droplet size, which depends on many factors. It is known that the more equally concentrated and similar in size droplets from the class of fine droplets (50-150 μm) or medium droplets (150-300 μm) hit the target, the less pesticides are required. The droplet size depends on the atomiser nozzle diameter and pressure. There are different types of atomisation: mechanical, electric, gas [9-10].

YSTU scientists have developed new varieties of gas-liquid apparatuses with gas ejection dispersion. Creation of new designs of such apparatuses is mainly performed in two directions: 1) development of new atomiser (nozzle) designs; 2) development of new mixer designs.

In the first case, in order to intensify the phase mixing process, the atomiser is designed as a nozzle with a swirling liner in the swirling chamber [11]. Also a multi-pass screw can be installed in the atomiser [12]. In the second case, intensification of the phase mixing process in the mixer is achieved by installing a cascade shock-jet device in the mixer, which is a set of truncated cones of different diameters and cone angles [13]. This can also be done by installing transverse baffles in the working volume in the form of a "disc-ring" system, which promote intensive mixing of the contacting phases and increase their contact time [14].

Recently, gas-liquid ejection apparatuses have been used as foam production ones. Foams are widely used in many industries and households, and are of great importance for firefighting, especially for ignition of tanks with easily flammable liquids, for extinguishing fires in closed rooms - in cellars, on ships, and in airplanes. Foams are also used for thermal insulation. The mixer (ejector) in the gas-liquid apparatus for foam production [15] is made in the diffuser form, inside of which star working elements are installed. The peculiarity of the gas-liquid apparatus for foam production [16] is the mixer design. The mixer is made in the form of a design of two cones - diffuser and confuser; inside of which there three-bladed propellers are installed to produce foam of high multiplicity. To achieve maximum foam multiplicity, the distance of the atomiser nozzle to the net pack should be maintained to ensure the projection of the solid angle of the solution atomisation torch is virtually identical to the projection of the working surface of the first net pack [17].

Main body

The purpose of this paper is to determine experimentally the efficiency of a classical gas-liquid ejection apparatus and assess the influence of some geometrical and technological parameters on the efficiency value.

Assessment of mass transfer efficiency in gas-liquid flows is conducted using the "sulphite technique" [18], which is based on the catalytic oxidation of sodium sulfite by air oxygen:

$$Na_2SO_3 + {}^1/_2\, O_2 \xrightarrow{CuSO_4} Na_2SO_4$$

The interaction of sodium sulfite with oxygen takes place in the diffusion zone, where the rate of the process depends entirely on the transition of oxygen from the gas phase to the liquid. The mass transfer coefficient is completely determined by the mass transfer

coefficient in the liquid phase (the diffusion step of oxygen from the phase interface into the liquid volume) due to the low solubility of oxygen in water. Therefore, the increase of sodium sulphite oxidation rate is associated with the enhancement of the mass transfer process in the liquid phase.

The "sulfite number" K_s, which shows the amount of oxygen absorbed by a unit of reaction volume per unit time, was chosen to evaluate the intensity of gas dissolution in the gas-liquid reaction mixture.

The values of "sulphite numbers" for different gas-liquid apparatuses vary over a wide range. For example, K_s = 0.5 kg $O_2/(m^3 \cdot h)$ for a reactor with a high-speed mechanical mixer (about 1700 rpm), while for gas-liquid tubular turbulent apparatuses it is much higher (from 18 to 21 kg $O_2/(m^3 \cdot h)$) [19].

Fig. 1 shows a schematic diagram of the experimental setup for determining the efficiency of the gas-liquid ejection apparatus.

Sodium sulphite solution is fed into liquid atomiser 3 by centrifugal pump 6 under pressure; it is atomised, then air is sucked into ejection chamber 2. The resulting gas-liquid mixture passes through ejector 4, where intensive contact of sodium sulphite and air takes place. Then the gas-liquid mixture hits the disperser 5 at high speed. When the gas-liquid flow hits the disperser, the gas bubbles are crushed and the mixture is distributed over the reaction volume of the apparatus, where the next phase of liquid-gas contact takes place.

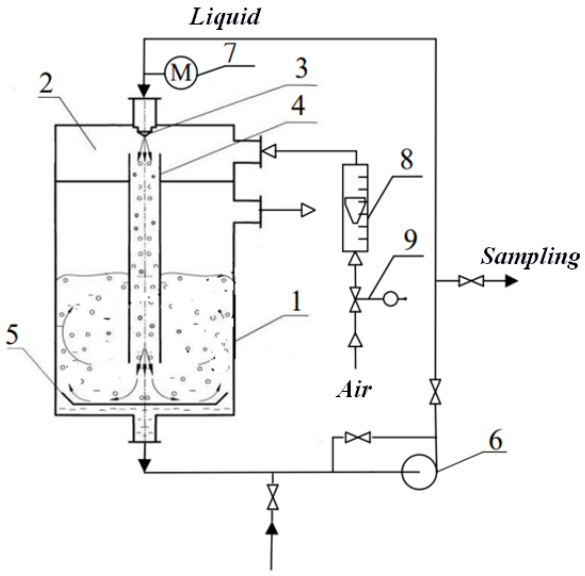

Fig. 1. Scheme of experimental installation: 1 - apparatus body; 2 - ejection chamber; 3 - nozzle; 4 - ejector; 5 - dispersant; 6 - centrifugal pump; 7 - pressure gauge; 8 - rotameter; 9 - air flow regulator

The order of the experiments is as follows: we prepared an aqueous solution of Na_2SO_3 with a concentration of 0.4 mol/dm^3, which was poured into the apparatus. Before the experiments we added aqueous solution of the catalyst - $CuSO_4$ solution. We conducted the experiments on an apparatus with an inner diameter of 300 mm, the diameter of the nozzle was 12 mm. We used ejectors with diameters of 25, 38, and 58 mm. During the experiment, the pressure upstream of the nozzle p_n was varied, which was measured by manometer 7.

Liquid flow rate through the nozzle was determined by the formula

$$Q_{ж} = \mu_p \cdot \frac{\pi \cdot d_n^2}{4} \sqrt{\frac{2 \cdot p_n}{\rho_l}}, \quad (1)$$

where μ_p is the flow coefficient through the nozzle; d_n is the nozzle diameter, m; p_n is the pressure upstream of the nozzle, Pa.

We selected the air flow rate so that the injection ratio, i.e. the ratio of the air flow rate to the liquid flow rate, was 1.3. The air flow rate was set with the air flow regulator 9 and measured with the rotameter 8.

Samples of the solution were taken into glass hermetically sealed flasks of 100 ml capacity using a syringe after starting the pump and reaching the set mode, during which the liquid was thoroughly mixed, and the concentration fields in the working volume were equalised. We sampled at different time intervals, which varied from 1 to 12 min depending on the expected reaction rate. The gas flow rate was kept constant throughout the duration of the experiment. We rinsed the vessel with hot water at the end of the experiment, then conducted further experiments with the planned values of regime and geometrical parameters.

We determined the concentration of C, mol/dm^3, of each solution sample by iodometric method (reverse titration) and calculated by the formula [2]

$$C(\mathrm{Na_2SO_3}) = \frac{|N(\mathrm{I_2}) \cdot V(\mathrm{I_2})^{com} - N(\mathrm{Na_2S_2O_3}) \cdot V(\mathrm{Na_2S_2O_3})|}{V(\mathrm{Na_2SO_3})}, \quad (2)$$

where $N(\mathrm{I_2})$, $N(\mathrm{Na_2S_2O_3})$ are normalities of prepared standard solutions of iodine and sodium thiosulphate, respectively, mol/dm^3; $V(\mathrm{I_2})^{com}$ is amount of excess iodine, cm^3; $V(\mathrm{Na_2S_2O_3})$ is volume of sodium thiosulphate used for titration of iodine residue, cm^3; $V(\mathrm{Na_2SO_3})$ is volume of sodium sulphite sample taken for analysis, cm^3; $C(\mathrm{Na_2SO_3})$ is required concentration of sodium sulphite, mol/dm^3.

Concentration values were plotted on a graph in concentration-time coordinates. The experimental dependence of the change in the concentration of sulphite solution has the form of a straight line located at an angle α to the abscissa axis, from which the tangent of the slope angle was determined $\frac{\Delta C}{\Delta \tau}$.

"Sulphite number" K_s, kg O_2/(m^3·h), was calculated by the expression

$$K_c = 16 \cdot \frac{\Delta C}{\Delta \tau}. \quad (3)$$

Table 1 and Fig. 2 present the experimental data.

Table 1. Experimental data on gas-liquid ejection apparatus efficiency assessment

Item n/a	Ejector diameter d_e, mm	Pressure in front of the nozzle p_n, MPa	Flow rate of liquid Q_l, m^3/h	Flow rate of air Q_a, m^3/h	"Sulphite number" K_s, kg O_2/(m^3·h)
1	25	0.2	5.9	7.67	12.8
2	25	0.3	7.34	9.54	16.30
3	25	0.4	8.58	11.15	17.4
4	38	0.2	5.9	7.67	14.4
5	38	0.3	7.34	9.54	18.8
6	38	0.4	8.58	11.15	20.4
7	58	0.2	5.9	7.67	6.4
8	58	0.3	7.34	9.54	9.6
9	58	0.4	8.58	11.15	10.9

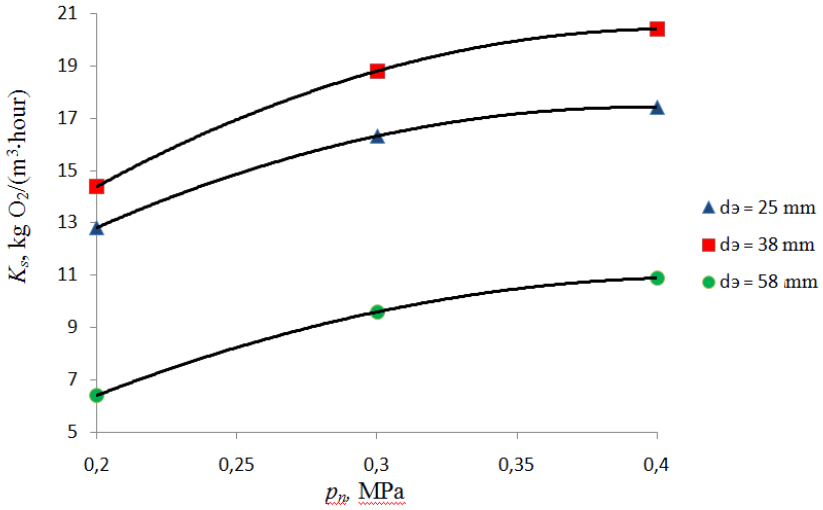

Fig. 2. Dependence of "sulphite number" on pressure upstream of the nozzle and ejector diameter

Conclusions

According to the experimental data obtained we can come to the following conclusions:

1. The "sulphite number" values are comparable to the "sulphite number" values for the most efficient gas-liquid tube turbulence apparatuses.

2. The maximum pressure drop across the nozzle can be assumed within the range of 0.35-0.4 MPa. A further increase in pressure drop does not significantly increase the "sulphite number", but the energy input for dispersion increases significantly.

3. A constricted movement of the gas-liquid flow in the ejector is observed at small values of the ejector diameter, which does not contribute to the obtaining of an optimal interfacial phase contact surface. A good gas-liquid contact is not ensured at large ejector diameter values in the gas-liquid flow. It causes the "sulphite number" values lowering. There is an optimum ejector diameter value at which the interfacial surface and "sulphite number" will be maximized.

4. Theoretical and experimental studies of hydrodynamics and mass transfer in the gas-liquid ejection apparatus have shown its high efficiency. Therefore, its application in various industries is very perspective.

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