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Determination of parameters of the water-air mixture generated by an ejection aeration system with a dispersing agent

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Abstract. The ejection way of water aeration is considered in the work. The various devices used for dispersing the water-air mixture in order to obtain finely dispersed bubbles, have been analyzed, their advantages and disadvantages have been indicated. An original dispersing device, characterized by simplicity of implementation, versatility and a number of other advantages, which allows to obtain the required parameters at lower power consumption compared with analogues, has been proposed. It has been experimentally shown that the proposed dispersing device makes it possible to obtain fine bubbles with sizes less than 100 microns, and the obtained density distribution functions are polymodal. The dependences of bubble sizes and aeration intensity on the ratio of the jet diameter at the outlet of the ejector to the geometric parameters of the dispersant are obtained.

1. Introduction

There are many technological processes in which aeration systems are used, and for the most suitable behavior of such processes it is necessary to obtain and maintain certain hydrodynamic parameters. The aeration systems are used in waste-water treatment, while the effectiveness of treatment depends on the hydrodynamic regime and parameters such as the intensity of aeration and the size of the generated bubbles. Such indicators as the possibility of obtaining the required parameters, reliability, energy efficiency [1-4] should be taken into account, during the aeration system choosing.

Water aeration using ejector devices has become widespread due to the simplicity of their design, high reliability, and economical use. The ejector is a type of two-phase jet device. Aeration by ejectors is based on the use of the energy of the working fluid which moves linearly at a speed of about 15-17 m/s through a nozzle having a certain shape and size for obtaining a pressure fall creating an ejection of the gas or liquid phase [5].

Many technological processes, which use ejectors for water aerating, require a high intensity of aeration, which is achieved by the gas content increasing (the ratio of air flow to water flow) and the generation of fine bubbles of less than 500 microns. However, according to the results of experimental studies presented in [6, 7], it can be concluded that with an increase in gas content, an increase in the size of the bubbles occurs, which in some cases has negative consequences for the implemented processes. The average size of the bubbles generated by the ejectors of the simplest structures is
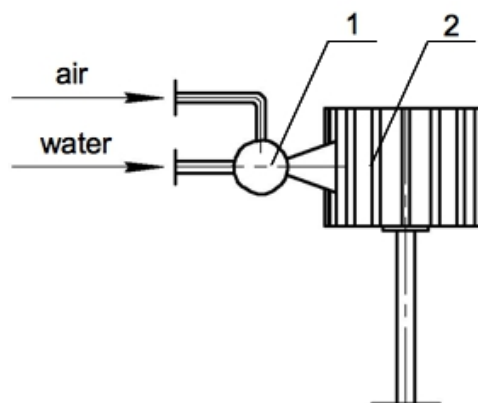
1000–3000 µm [8]. Massive bubbles with high ascending speeds are in close proximity to the ejector. In this regard, they are not uniformly distributed throughout the volume of the aerated liquid.

Both improved designs of the ejectors themselves and special dispersing devices are used [9-19] for improving the dispersion of the water-air mixture.

In works [10-14] the Venturi ejector is described. The dispersion of bubbles in it occurs due to the fact that a shock wave is created in the diverging part of the Venturi tube and the bubbles are broken up under the influence of pressure. The average size of the bubble is about 100-400 microns. In [10, 15], a microbubble generator with turbulence is presented, jet disintegration in which is caused by flow swirling and difference in flow velocity in different parts of the mixing chamber. The average size of the bubbles is 20–200 µm, however, fine bubbles with a size less than 100 µm can be collected only with low gas content. In the generator of microbubbles with a spherical body described in [10, 16], flow turbulization occurs, which makes it possible to obtain bubbles with sizes of 120–490 µm. The bubble generator with a porous tube allows to obtain bubbles with a size less than 500 microns due to the air suction through the porous tube. The average size of the bubbles is less than 500 microns. The disadvantage of this method is pores plugging [10, 17]. The use of a static mixer installed behind the ejector was proposed in [3]. The bubbles fragmentation to the required size (30-80 microns) occurs due to multiple reorganization of the velocity field and to changing the direction of current lines of the mixed components, thus a significant interface increase is achieved and dispersion occurs. However, the disadvantage of the method is the dependence of the dispersion quality on the water and air flow, an increase in hydraulic resistance. In papers [18, 19], it was proposed to use a disk mounted opposite the ejector outlet, while the bubbles dispersion occurs during the impact on its surface. The dispersion of bubbles in contact with a solid surface is the most technically simple solution that does not require additional energy consumption, but the presence of massive bubbles larger than 1 mm is the disadvantage.

Changing the design of the ejector and installing special dispersing devices allows to obtain the required size of the bubbles in some cases. However, a number of drawbacks should be noted: the complexity of some technologies, the insufficient degree of dispersion, and achievement of the required parameters only with certain system settings. Thus, the problem of the water-air mixture dispersing is relevant, but it requires further study of this process and the development of the most optimal solutions.

In order to ensure the required parameters using an ejection aeration system and eliminate the drawbacks of existing technologies, it is proposed to use the original dispersing device (figure 1) described in [20].
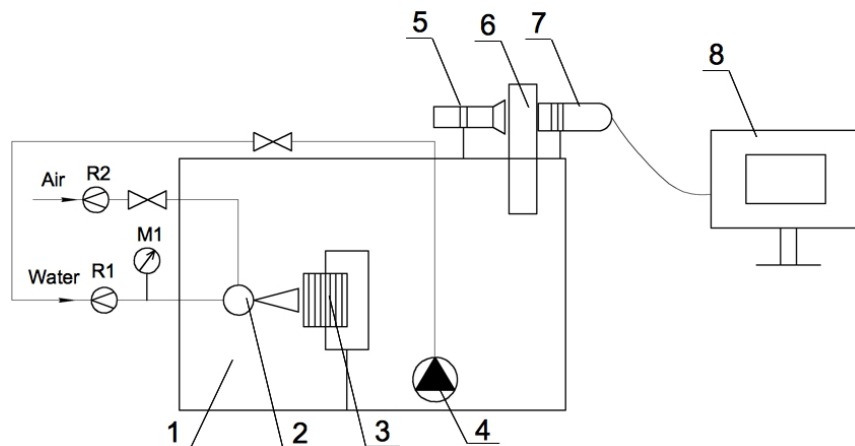

Figure 1. The dispersing device:1 – ejector, 2 – disperser.

Bubbles are dispersed by contact of the water-air mixture jet, which leaves the ejector and passes through the guide element with the riffled disperser.

2. Materials and methods

To study the process of dispersion of bubbles, generated by an ejection aeration system with the original device for dispersing and determining the dispersion composition of the water-air mixture, a laboratory setup has been created, the scheme of which is shown at figure 2.

Figure 2. Laboratory setup scheme:1 – aeration chamber; 2 – ejector; 3 – disperser; 4 – pump, 5 –light source; 6 – tank; 7 – USB microscope; 8 – computer; R1 – rotameter for water flow; R2 –rotameter for air flow; M1 – manometer.

The laboratory setup consists of an aeration chamber 1, an ejector 2, a disperser 3, a drowned pump 4. To observe the bubbles and fix them on the aeration chamber 1, a small transparent tank 6 is mounted, which is partially immersed in the water. On one side of the tank, a USB microscope 7 connected to computer 8 is installed, on the opposite side opposite the microscope objective – the light source 5. Water consumption in all experiments was 360 l/h, air flow 100 l/h. The outlet jet velocity was 5.1 m/s. The diameter of the jet at the ejector outlet was 5 mm. The geometric parameters of the dispersers are presented in table 1.

Table 1. Geometric characteristics of dispersers

No	The dispersers diameterd_d(mm)	The dispersersheight h_d (mm)
1	10	20
2	15	20
3	20	20
4	30	20
5	40	10
6	40	20
7	40	40
8	75	20

When the laboratory setup was in operation, bubbles with a size of more than 500 μm floated directly above the dispersant, and fine bubbles, which are of the greatest interest, overspread through the aeration chamber. Bubbles exposure was carried out using a USB microscope in accordance with the method [21]. As a result of statistical image processing, bubble density distribution functions were obtained. The number of bubbles buoyed to the surface per unit of time was also determined. As

a result, dependences of the bubbles average size and the aeration intensity on the ratio of the disperser diameter to the jet diameter at the ejector outlet (d_d/d_j), and the height of the disperser to the jet diameter at the ejector outlet (h_d/d_j) were obtained.

Based on the obtained data, the intensity of aeration of the bubbles of each group was calculated by the formula (1):

$$q_i = f \cdot n_i \sum_{j=1}^{m} \frac{n_j \pi d_j}{6}, (1)$$

where
f — the number of bubbles buoyed to the surface per second;
n_i - the fraction of bubbles of the i-th group;
n_j is the fraction of bubbles of each size;
d_j – the size of the bubbles of each group.

3. Results and discussion

As a result of statistical processing, it was found that the original density distribution functions are non-uniform (the coefficient of variation for all cases is more than 0.33). Next, homogeneous aggregates within the sample were selected, and two normal distributions were obtained. The coefficients of variation of the selected distributions were less than 0.33, therefore, the resulting samples are homogeneous. For the obtained distributions, $\chi^2 < \chi^2_{\text{кр}}$ with a significance degree of 0.95, therefore, the difference from the normal distribution is random, which does not contradict the hypothesis about the normal data distribution. Thus, the distribution density function for each of the groups of bubbles will be (2):
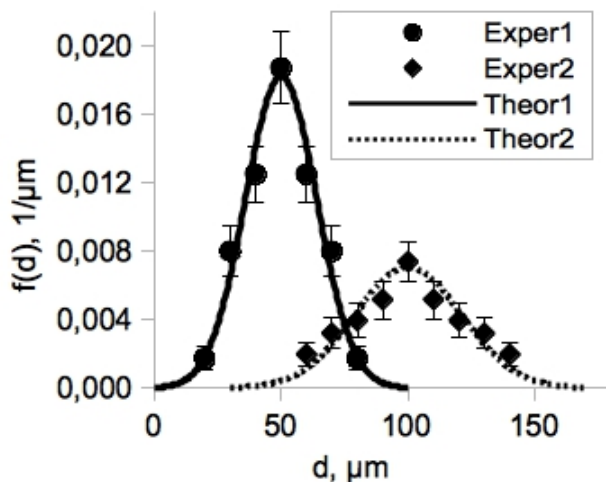
$$f(d) = \frac{1}{\sigma_i \sqrt{2\pi}} \exp\left[\frac{-\left(d_i - d_{mi}\right)^2}{2\sigma_i^2} \right], (2)$$

where
d_i — the bubble size of each group, micron;
d_{mi} — average bubble size, μm; σ_i is the standard deviation of the bubble size of each group from the mean, μm.
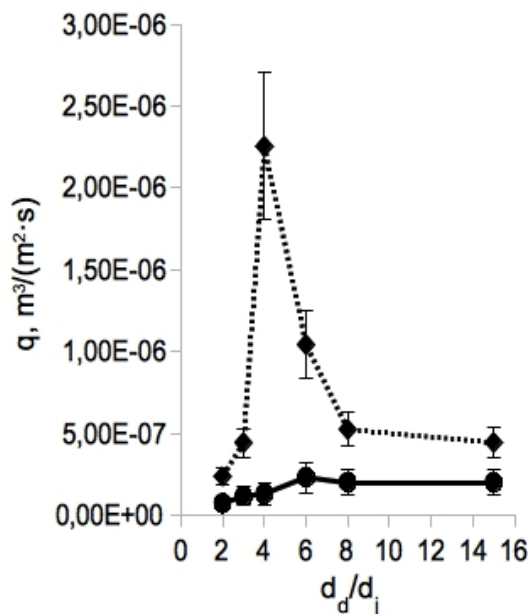
The theoretical and experimental density distribution functions of the bubbles size for a disperser with a diameter of 40 mm ($d_d/d_j = 8$), height 40 mm ($h_d/d_j = 8$) are presented at figure 3.
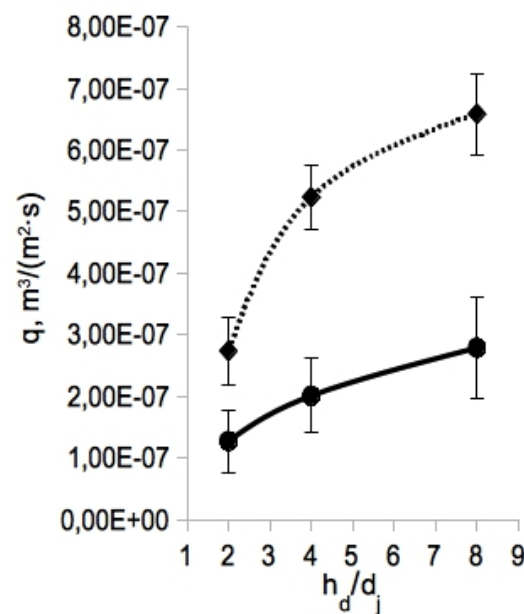

Figure 3. Theoretical and experimental functions of density distribution of bubble sizes for a dispersant with a diameter of 40 mm ($d_d/d_j = 8$), height 40 mm ($h_d/d_j = 8$).

The dispersed composition of bubbles with this disperser is characterized by two average sizes: $d_1 = 50$ μm, ($\sigma = 14$ μm), the proportion of bubbles 56%, $d_2 = 100$ μm ($\sigma = 21$ μm), the proportion of bubbles 33%. The proportion of bubbles, which have size of more than 145 microns, is about 15%. The appearance of such bubbles is random and does not have a significant impact on the process. Similarly, the distribution density functions for other dispersers have been obtained. Based on the obtained data, the dependences of the aeration intensity and the size of the bubbles of each group have been determined.

The results of determining the intensity of dispersed bubbles aeration, which are determined by the formula (1), are presented at figures 4, 5.

Figure 4. The dependence of the intensity of aeration on the ratio of the disperser diameter to the jet diameter: bubbles of the first group (solid line), bubbles of the second group (dashed line).
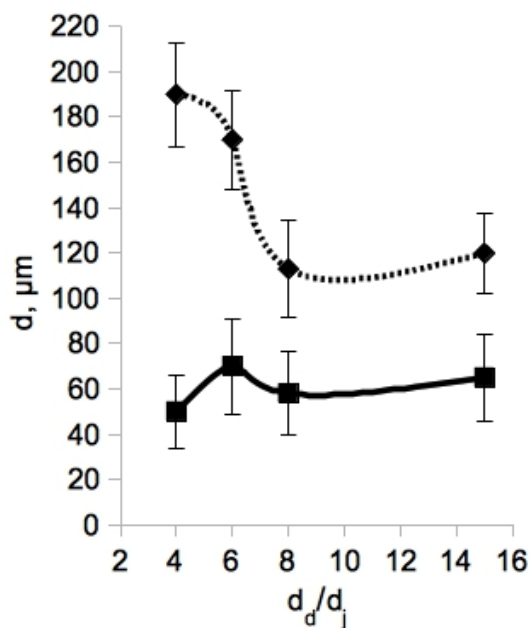
Figure 5. Dependence of the aeration intensity on the ratio of the disperser height to the jet diameter: bubbles of the first group (solid line), bubbles of the second group (dashed line).

With an increase in the d_d/d_j and h_d/d_j ratios, the number of dispersed bubbles increases and the intensity of aeration from them increases. The use of a disperser at $d_d/d_j \leq 3$ and $h_d/d_j \leq 2$ is impractical due to the small number of dispersed bubbles.
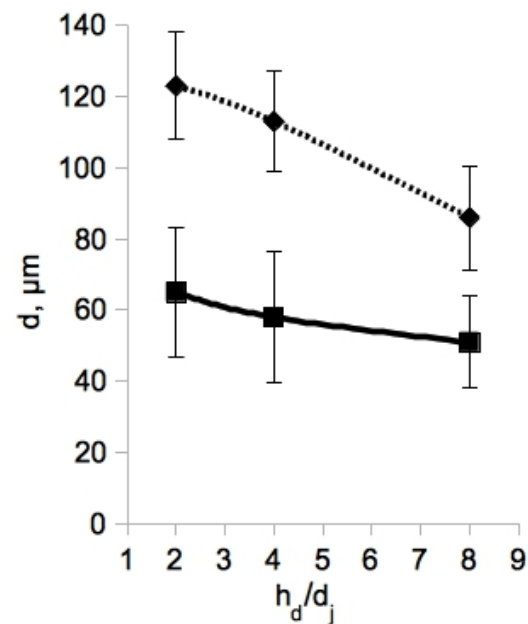
Thus, when designing a disperser, it is recommended to take its height $h_d \geq 4d_j$, and the diameter – $d_d \geq 6d_j$.

The dependence of the bubble size on the ratio of the disperser diameter to the jet diameter (d_d/d_j) is shown at figure 6. The dependence of the bubble size on the ratio of the disperser height to the jet diameter (h_d/d_j) is shown at figure 7.

After analyzing the obtained dependences, it can be concluded that as the ratio d_d/d_j increases to 8, the size of the bubbles decreases due to an increase in the area of contact of the jet with the disperser. The size of the bubbles of the second group varies in the range from 110 μm to 190 μm, and the size of the bubbles of the first group remains approximately constant about 55-65 μm. The size of the bubbles of the second group varies in the range from 90 μm to 125 μm, and the size of the bubbles of the first group is 50-65 μm with h_d/d_j increasing.

Figure 6. Dependence of the bubble size on the ratio of the disperser diameter to the jet diameter: bubbles of the first group (solid line), bubbles of the second group (dashed line).

Figure 7. Dependence of bubble size on the ratio of the disperser height to the jet diameter: bubbles of the first group (solid line), bubbles of the second group (dashed line).

4. Conclusion

It was experimentally shown that the use of a disperser when using an ejection aeration system with a disperser allows to obtain fine bubbles with sizes less than 100 microns. The dispersed composition of bubbles is characterized by several aggregates with their mean sizes. The dependences of bubble sizes on the ratios of the geometric parameters of the disperser to the diameter of the ejector outlet jet allow to control the process of obtaining a water-air mixture of a given dispersion composition, taking into account the necessary distribution in the aeration chamber.

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