Dissolved Air Flotation with Saturation of Liquid in Spray-Type Saturator

A Eskin
Department of Construction Engineering Systems, Far Eastern Federal University, 8 Sukhanova St., Vladivostok 690090, Russian Federation
E-mail: eskin aa@dvfu.ru

Abstract. A new method of dissolved air (pressure) flotation with the spraying of liquid is presented in the paper. The liquid to be treated is sprayed in the saturator with a hydraulic nozzle which makes it possible to increase the contact surface between the liquid and the gas in comparison with the traditional sparged-air saturator system. The proposed method increases the gas content of the liquid entering the flotation unit for treatment. The paper presents the results of experimental research in terms of the efficiency of liquid saturation in a pressure vessel using whirl and spiral nozzles. The volumetric method was used to determine the amount of air released during the dissolved air flotation based on which the sparging rate was calculated. It is shown that, when the liquid is sprayed, the amount of dissolved air increases by an average of 33% compared to a sparged-air pressure vessel. The sparging rate increases with the increase of saturation pressure and essentially depends on the area of the flotation unit. At the saturation pressure above 2 bar, the sparging rate in the center of the flotation unit becomes significantly higher than that in the wall-adjacent area.

1. Introduction
In Russia, 2017 is declared the year of ecology [1]. For the protection of water resources, the government of the Russian Federation has worked out a number of measures [2], which include the construction and reconstruction of wastewater treatment facilities for various industrial enterprises, the increase of the water reuse rate, etc. One of the tasks, which will improve the environmental efficiency of the industrial production, is the development of new and the intensification of existing wastewater treatment methods.

According to the data presented by the Russian Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet) [3], the quality of surface waters is deteriorating in the Russian Federation. This is primarily due to the development of the fuel and energy industry and the limited use of environmental and resource-saving technologies. Petroleum products are among the most common pollutants, with a significant exceedance of MPC.

A comparative analysis of existing methods for the treatment of oily waters is presented in [4-8]. The technological workflow of treatment is chosen depending on the type of oil product, its concentration in the contaminated liquid and its quality, as well as the required concentration after the treatment. For industrial enterprises with the concentration of petroleum products in wastewater of more than 100 mg/l, a three-stage treatment workflow is recommended: pre-treatment by sedimentation, treatment by flotation and post-treatment by sorption.
By flotation is meant the process of extraction of hydrophobic particles due to their adhesion to gas bubbles and subsequent removal of the formed complex to the surface in the form of concentrated froth product. Flotation generally is classified by the method of creating gas emulsion in water [9,10]. The comparison of various flotation methods is presented in Table 1.

Table 1. The properties of gas emulsions obtained by various flotation methods.

| Method                        | Dispersed (induced) air flotation | Air flotation | Hydrodynamic flotation | Dissolved air (pressure) flotation | Electro-flotation |
|-------------------------------|-----------------------------------|--------------|------------------------|-----------------------------------|------------------|
| Average diameter of bubbles, μm | 500-5000                          | 400-10000    | 750-2500               | 50-100                           | 100-200          |
| Gas content, m³ air/m³ liquid | 0.025-0.3                         | 0.06-0.2     | 0.02-0.3               | 0.001-0.003                      | 0.002-0.005      |
| Concentration of bubbles, pcs/ml | 15                                | 2            | 71                     | 9052                             | 1982             |

The effectiveness of flotation treatment of oily wastewater increases with the decrease of the average diameter of bubbles and the increase of their concentration [11,12]. As can be seen from Table 1, dissolved air (pressure) flotation is most effective.

The experimental studies showed that the dependence of the extraction efficiency of petroleum products by dissolved air flotation from the saturation pressure in the saturator is a quadratic function with the maximum in the range of 2.5-4 bar [13]. The presence of the maximum is explained by the fact that when the saturation pressure increases, simultaneously with the increase of the amount of dissolved air the coalescence rate of nucleus bubbles increases as well, which ensures the growth of their mean diameter and reduces the treatment efficiency. Consequently, the efficiency of dissolved air flotation can not be increased by increasing the saturation pressure.

According to the data presented in [14,15] only 20-45% of air from the theoretically possible amount dissolves in a typical saturator with preliminary dispersion of air in the pump. It is possible to increase the efficiency of air dissolution by increasing the contact surface between the liquid and gas phases; some methods of achieving this are presented in [15,16].

The contact surface can be increased by using a spray-type saturator. The research group of the Department of Construction Engineering Systems of the Far Eastern Federal University proposed a saturation method [16,17], in which the treated liquid is sprayed through the nozzle into the saturator in the form of a torch, while the drops formed have a small volume-surface mean diameter, which significantly increases the contact surface between the phases and ultimately increases the degree of air saturation of the liquid to be treated. The developed method is called dissolved air (pressure) flotation with the spraying of liquid.

2. Experimental

The aim of the experiment is to determine the efficiency of air absorption in a spray-type saturator. The efficiency of absorption is determined by the difference in the concentration of air in the liquid before and after the saturator. At this point, it is not possible to directly determine the concentration of air dissolved in liquid in the saturator under excess pressure, but the saturation efficiency can be estimated indirectly by measuring the amount of air released during pressure reduction.

It is advisable to use the sparging rate as a response, which shows how much gas passes through a unit of area of the flotation chamber per unit of time.
In order to determine the sparging rate, one should know the gas content of the liquid stream. The issue of determining the gas content is important for various industries and it is considered in [18-20]. At present, there are quite a number of methods for measuring the gas content, among which there are three main ones: conductometric, acoustic and volumetric methods.

The volumetric method is based on the separation of the gas-liquid disperse system into two macrophases, followed by the measurement of the volume of the separated gas phase. Initially, it was planned to measure the amount of air released from the surface of the flotation unit by a flowmeter. Carrying out such a measurement requires an expensive thermal flowmeter, sealing the flotation unit and the absence of the liquid level fluctuation, which makes this method a very complex engineering task. In this connection, it was decided to carry out the gas content measurement using a measuring cylinder. The measuring cylinder, filled with liquid, was immersed in the upper part of the flotation unit, so that most of it protruded above the surface of the water. During the experiment, the bubbles, coming up, entered the cylinder, as a result of which the liquid was displaced by the gas phase (Figure 2). Knowing the cross-sectional area of the cylinder, the volume of air and the time for which the volume was filled, the sparging rate is determined as:

\[ q = \frac{V_g}{F \cdot t} \]

where \( q \) is the sparging rate, \( V_g \) is the volume of released air, 50 cubic centimeters; \( F \) is the clear area of the measuring cylinder, 20 square centimeters; \( t \) is the time of filling the specified volume with air, seconds.

The advantages of this method are high accuracy, the ability to measure the local values of the sparging rate, low cost.

The experimental study was carried out using the installation shown in Figure 1. The flotation unit (1) was filled with water. The compressed air from the compressor was supplied into the saturator (2) through the nozzle (3), the pressure was controlled according to the pressure gauge (4). A compressor and a blow-off valve (5) were used to achieve the specified pressure. When the flotation unit (1) was filled with water and a predetermined pressure was reached in the saturator, the rotary vane-type pump (7) was switched on, as a result of which the liquid coming from the water separation section (8) of the flotation tank was sprayed through the nozzle (9) in the saturator (2). The nozzles were a BETE WL3-
60 whirl nozzle and a BETE TF8-60 spiral nozzle [21]. The spraying process was monitored through the observation windows in the saturator. The saturated liquid entered the flotation section (10) of the flotation unit, passing through the valve (11). The flow rate was measured with a pulse emitter water meter (12). A constant level of liquid was maintained in the flotation unit by the valve (11). With this, the balance of the flow rate of the liquid at the inlet and outlet of the flotation unit was maintained. Since the rotary vane-type pump used has an almost vertical flow-rate characteristic, the flow rate of the water entering the saturator remains 1 cubic meter per hour, regardless of the air pressure in the saturator. After the valve (11), the fluid pressure drops sharply, resulting in the release of air bubbles. The sparging rate was measured by the air filling rate of the measuring cylinder determined by formula (2).

The sparging rate was also measured when the liquid was saturated in the sparged-air saturator system. The operation of sparged-air vessel was modeled as follows. The air was supplied by the compressor in front of the pump (7). The water-air mixture was supplied to the saturator (2). The liquid level was monitored through the observation window and maintained at a preset level by hand using a safety blow-off valve (5).

3. Results

Preliminary experiments showed that the sparging rate is not the same in different zones of the flotation unit – there is a gradient of the concentration of the gas phase directed from the periphery of the chamber to its center. The sparging rate was measured at two points – at the center of the flotation unit and in the wall-adjacent area (Figure 2).

The data by the spraying of liquid in the saturator was compared with the data obtained by the conventional method of saturating the liquid with sparged air using the pumped compressed air. During the experiment, the filling time of 50 cubic centimeters of the cylinder was recorded. At each point 3-4 parallel experiments were conducted. The results of the experiment when spraying liquid with a whirl nozzle are presented in Figures 3-4.

![Figure 3.](image_url)

**Figure 3.** The dependence of the sparging rate in the center of the flotation unit on the saturation method and pressure in the saturator. WL – a spray-type saturator with a whirl nozzle BETE WL3-60; TF – a spray-type saturator with a spiral nozzle BETE TF8-60; "Sparging" is a sparged-air saturator. \(Q_{\text{liquid}} = 1 \text{ cubic meter per hour, } t_{\text{liquid}} = 15 \degree \text{C.} \)

For the range of saturation pressures studied, the sparging rate, regardless of the area of the flotation unit and the saturation method, increases with the rise of pressure. However, numerically the sparging rate significantly differs in different areas of the flotation unit and depends on the method of saturation of the liquid.
The sparging rate in the center of the flotation unit when using a spray-type saturator, regardless of the nozzle type, is higher than when using a sparged-air saturator (Figure 3). However, this fact does not show the effectiveness of the spray-type saturator in comparison with the sparged-air saturator, since in this case the increase of the sparging rate occurs due to the increase of the mean diameter of bubbles.

**Figure 4.** The dependence of the sparging rate in the wall-adjacent area of the flotation unit on the saturation method and pressure in the saturator. WL – a spray-type saturator with a whirl nozzle BETE WL3-60; TF – a spray-type saturator with a spiral nozzle BETE TF8-60; "Sparging" is a sparged-air saturator. \( Q_{\text{liquid}} = 1 \) cubic meter per hour, \( T_{\text{liquid}} = 15 \) °C.

The highest sparging rate in the wall-adjacent area of the flotation unit is observed when using a saturator with BETE TF8-60 spiral nozzle (Figure 4). The sparging rate with the use of BETE WL3-60 whirl nozzle is on average 16% lower compared to the TF nozzle.

For the TF nozzle, the volume-surface mean diameter of the drops is 343 μm (at a flow rate of 0.273 cubic meter per hour), for the WL nozzle, at the same flow rate, the mean diameter is 649 μm [21]. This confirms that the saturation efficiency rises with the increase of the contact surface between the phases.

On average, the sparging rate with a sparged-air saturator is 28% lower than when using a WL whirl nozzle and 39% lower than when using a TF spiral nozzle. An increase in the sparging rate with the same flow rate can be explained by the increase in the number of air bubbles, an increase of the mean bubble diameter, or a simultaneous increase of the number and diameter. In order to determine, which of the mechanisms is the determining one, it is necessary to carry out an experimental research of the mean diameter of the bubbles depending on the method of saturation of the liquid.

### 4. Conclusion

Based on the results of the theoretical study, the following conclusions can be made:

1. The sparging rate rises with the increase of the saturation pressure in the saturator in the center and in the wall-adjacent area of the flotation unit, regardless of the method of saturation of the liquid. For the wall-adjacent area, the sparging rate ceases to increase at saturation pressure above 5.5 bar.
2. At saturation pressure below 2 bar, the sparging rate does not depend significantly on the area of the flotation unit. When the saturation pressure is increased above 2 bar, the sparging rate in the center of the flotation unit increases in quadratic dependence and becomes significantly higher than the sparging rate in the wall-adjacent area.
3. When a spray-type saturator is used, the sparging rate is 25-40% higher than when using a sparged-air saturator.
The obtained data show that it is possible to improve the efficiency of oily wastewater treatment by using dissolved air (pressure) flotation with the spraying of liquid.

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