Determination of the flotation effectiveness of industrial wastewater in a laboratory

M Y Dyagelev¹, A M Nepogodin¹, E V Grakhova²

¹Department “Water supply and water treatment”, Kalashnikov Izhevsk state technical University, 7, Studencheskaya, Izhevsk 426069, Russia
²Department “Industrial and civil engineering” Kalashnikov Izhevsk state technical University, 7, Studencheskaya, Izhevsk 426069, Russia

E-mail: mdyagelev@yandex.ru

Abstract. This article presents the test results of the laboratory flotation equipment LFM–001 for the treatment of simulated wastewater with a high content of oil products and surfactants. To obtain a water–air mixture, tap water with a volume of up to 40 dm³ was used, through which air was passed, with a volume till 5% of the water volume. The size of the resulting bubbles was determined by the pressure established in the aeration tank before the tests and by the flow rate of the air–water mixture in the flotation machine. After a series of tests, in series where a water–air mixture was added to laboratory containers with simulated wastewater, oil particles formed flakes in the presence of a coagulant. These flakes, together with air bubbles of the air–water mixture, floated to the surface of the container and formed a foamed, oily layer 5 mm thick. At the same time, the water in the laboratory vessel, after passing the air–water mixture became more transparent visually than water in other laboratory vessels.

1. Introduction

Nowadays due to the increase in the pace and scale of industry, relevance of measures preventing pollution of water, soil, air and ensuring environmental sanitation in general, becomes extremely important [1]. The efforts of specialists involved in design and construction issues, in particular, sewage treatment plants, are aimed at developing new effective methods and technological schemes for treating industrial wastewater, intensifying the operation of existing sewage treatment plants while reducing the cost of processing 1 m³ of sewage to regulatory requirements [2,3].

One of the promising methods for treating industrial wastewater is flotation. [4-7]. It is characterized by: versatility, high efficiency of wastewater treatment (almost 100%), process continuity, wide range of applications, low capital and operating costs, ease of processing, selectivity of pollution, high speed of the process, the possibility of obtaining flotation sludge (sediment) of low humidity (90–95%) and the possibility of recovering concentrated pollutants.

Flotation is based on the emergence of dispersed particles together with air bubbles. The cleaning process consists of formation “particle – air bubble” complexes, the emergence of these complexes on the liquid surface with a foam layer formation containing impurities, and following removing this layer from the surface of the liquid.

For quite a long time, flotation was not widely used for treating wastewater from insoluble contaminants and a some soluble substances contained in industrial wastewater. However, during
recent decades, everything has changed, and interest in the practical application of the method in wastewater treatment technologies has increased significantly [8]. It happens mainly due to the expansion of variety and quantity of synthetic surface-active substances (SAS) produced in Russia and used in industry and in everyday life.

Wastewater treatment by flotation can be carried out in various ways, i.e. it is the formation of air bubbles that occurs using various methods. There are some types of flotation treatment of industrial wastewater [9]:

- flotation with the release of air from the solution (vacuum, pressure and airlift flotation) – the method is used to treat wastewater containing very small particles of contaminants, the main idea of the method is to create a supersaturated air solution in the wastewater, where air bubbles are releasing from the solution when air pressure decreases, which float pollution. Vacuum, pressure and airlift flotation are distinguished that depends on the method of creating a supersaturated air solution in water;
- flotation with mechanical dispersion of air (impeller machines, pressureless and pneumatic flotation units) – the formation of air bubbles mechanically occurs under the influence of vortex movement created by the movement of an air stream in water environment;
- flotation with air supply through porous materials – passing air through small holes, it is possible to obtain micro bubbles that are able to float the contaminants contained in the liquid; for the implementation of this method, a relatively low speed of air supply from the hole, a sufficient distance between the holes, and the presence of foaming agents in the liquid are needed;
- electroflotation – wastewater is saturated with air due to bubbles constantly emitted from the cathode surface;
- biological and chemical flotation (Possible to apply n in the field of compaction of sewage sludge).

2. Theoretical basis

Nowadays a lot of various technological schemes in industrial wastewater treatment have already been developed, including flotation [10]. The flotation method is used for wastewater treatment of oil refining [11,12], pulp and paper industry [13], as well as food [14], engineering, chemical [15-16], leather, textile, glass and others till gaining regulatory requirements. Flotation allows efficient removal from industrial wastewater various impurities: suspended solids, oil, grease, heavy metal ions. At the same time, the choice of a technological scheme for industrial wastewater treatment, the composition of treatment facilities is determined by the type of production, the capacity of the enterprise, the discharge of generated wastewater, the place of discharge, the quantitative and qualitative composition of wastewater, and the requirements of the regulatory authorities for the quality of treatment.

Pressure flotation is quite widespread in wastewater treatment processes, for example, of petroleum products, oils, fats, surfactants, etc. [17-19]. Pressure flotation is carried out using reagents to intensify the cleaning process, and without adding various chemicals. The widespread use of pressure flotation is due to the relatively high effect of wastewater treatment and simple equipment design process. Pressure flotation allows to treat wastewater with an initial concentration of pollution of 4-5 g / l or more.

The use of pressure flotation in technological schemes at a certain stage of treatment is determined mainly by the quantitative and qualitative characteristics of the wastewater, requirements for purified water, as well as by economic indicators (capital and operating costs) [20].

3. Materials and methods

To determine the effectiveness of flotation industrial wastewater treatment, a laboratory flotation equipment LFM–001 was developed (figure 1) by the staff of department “Water Supply and Water Treatment” (Kalashnikov Izhevsk State Technical University). A laboratory flotation equipment LFM–001 consists of:
• compressor "Patriot euro 24–240";
• devices for regulating pressure (gearboxes);
• devices for supplying and consuming air, working fluid;
• instrumentation;
• non-return and safety valve (set to 7 bar);
• 50 liter aeration chambers made of stainless steel 1 mm thick, designed for pressure up to 7 bar (maximum);
• a desktop flotation chamber with a volume of 38 l and a height of 700 mm made of transparent organic glass;
• connecting pipelines and high pressure hoses (up to 8 bar);
• diffusers for pouring prepared liquid into the lower central part of the flotation chamber;
• sampling devices for treated wastewater;
• filling and drain taps and valves.

A fluid in the aeration chamber is a tap water (volume 35–40 dm³ depending on the test tasks), and a mixture of wastewater and air–saturated tap water is located in the flotation chamber. Air consumption is up to 3–5% of the water flow and is intended to produce a working fluid (water saturated with fine air bubbles with a diameter from 60 to 100 microns). The size of the resulting bubbles is determined by the pressure established in the aeration chamber before the tests and the flow rate of the air–water mixture in the flotation chamber.

**Figure 1.** Overall structure of the laboratory flotation unit LFM–001: 1, 5, 10, 12, 22 – ball valve; 2 – wing counter SVU–15; 3, 8, 19 – shutoff valve; 4 – aeration chamber; 6.7 – thermometers; 9 – pressure regulator (gear); 11 – flotation chamber; 13, 14, 15 – sampler; 16 – compressor; 16.1 – pressure gauge; 16.2 – pressure regulator; 17, 21 – pressure gauge; 18 – check valve; 20 – safety valve; 23 – diffuser.

4. Results
To improve the working method of the laboratory unit LFM–001, studies about possibility of treating contaminated wastewater after washing railway locomotives with surfactants were carried out.

Following parameters were selected to obtain a water–air mixture for the tests:
• volume of water for air saturation – 15 liters;
• pressure, at which saturation was occurred – 0.5 MPa;
• the time of saturation of water with air in the aeration chamber of the laboratory flotation machine – 10 minutes;
• average water temperature during saturation with air – 19 °C.
Typical solution of contaminated runoff was prepared in five laboratory containers with a volume of 1000 ml, for every test. To prepare a typical runoff solution after washing railway locomotives, we used fuel oil and an anionic surfactant – sodium dodecyl sulfate \( \text{CH}_3(\text{CH}_2)_{11}\text{OSO}_3\text{Na} \) (amphiphilic substance used in industry as a strong cleaning and wetting agent) with a concentration of 0.1 g / dm³ (hereinafter – anionic surfactants).

Following reagents were used in experimental studies:
- coagulant Aqua-Aurat 30 (aluminum polyoxychloride \( \text{Al}_2(\text{OH})_n\text{Cl}_{6-n} \)) in the form of a working solution with a mass fraction \( \text{Al}_2\text{O}_3 \) from 1% to 9 %;
- sodium hydroxide \( \text{NaOH} \) – to activate coagulation processes, the pH of the liquid solution was adjusted to 7;
- powdered activated carbon (hereinafter – PAC).

At the initial stage, 500 ml of tap water was added to each of the 5 containers, and fuel oil, anionic surfactants, Aqua-Aurat, \( \text{NaOH} \) and water–air mixture obtained using the LFM–001 were added to each container, depending on the conditions of the test. The ratio of the volumes of substances added to the containers are shown in table 1. The experimental results are shown in figure 2.

| № container | Tap water, ml | anionic surfactants, ml | fuel oil, cm³ | Aqua-Aurat 30, ml | NaOH, ml | PAC, ml | Water–air mixture, ml |
|-------------|---------------|-------------------------|--------------|------------------|----------|--------|---------------------|
| 1           | 1000          |                         | 1            |                  |          |        |                     |
| 2           | 1000          | 0.5                     | 1            |                  |          |        |                     |
| 3           | 500           | 0.5                     | 1            | 2                | 1.8      | 2      | 500                 |
| 4           | 500           | 0.5                     | 1            | 2                | 1.8      | 2      | 500                 |
| 5           | 500           | 0.5                     | 1            | 2                | 1.8      | 2      | 500                 |

In the first laboratory vessel, fuel oil surfaced in the upper part of the beaker and formed an oily film with a thickness from 1 to 2 mm. It should also be noted that part of the fuel oil remained in the water and the water became cloudy compared to its initial state (figure 2, № 1).

In the second laboratory vessel, with the addition of anionic surfactants, most of the fuel oil dissolved in water, which led to increasing turbidity of water. The same oily film was formed with a thickness from 1 to 2 mm on the surface of water in the glass. The fuel oil particles were smaller compared to the water from the first glass, due to the reaction with anionic surfactants (figure 2, № 2).

Flocculation occurred in the third laboratory vessel. Dark flakes from 1 to 4 mm in size were visible with the naked eye, which after some time partially rose to the surface or fell to the bottom of the glass, some flakes remained in liquid. After 10 minutes of observations, stratification was occurred – there was a liquid with a small concentration of flakes in the middle part of the container, and a layer of foam was formed in the upper part, consisting of flakes, fuel oil particles and air bubbles, at the bottom of the container a thin layer of small flocculent particles could be seen (figure 2, № 3).

In the fourth laboratory container, everything was much more interesting, since a water–air mixture was added to it, particles of fuel oil located in the water column, and the coagulant formed flakes. These flakes, together with air bubbles of the air–water mixture, floated to the surface of the container, forming a foamed, oily layer 5 mm thick. Water was visually more transparent than water in other laboratory containers, however, a small content of small particles could be observed in the water (figure 2, № 4).

In the fifth laboratory vessel, the separation of liquid into layers was faster. The third and fifth vessels are noticeably different from each other. In the fifth container, the layer of flakes became much denser, fewer flakes precipitated, the water became more transparent compared to the 3rd vessel. The flakes of the upper and lower layers became smaller, their structure became more loosened (figure 2, № 5).
5. Conclusions
Laboratory flotation unit LFM–001 made it possible to carry out a number of visual experiments of treating simulated wastewater and assess the possibility of using this equipment for the treatment of wastes obtained from washing railway locomotives with surface–active substances, in case of given parameters of the installation. In tests where a water–air mixture was added to the container, fuel oil particles formed flakes in the presence of a coagulant. These flakes, together with air bubbles of the air–water mixture, floated to the surface of the container, forming a foamed, oily layer 5 mm thick. At the same time, the water in the container was visually more transparent than water in other laboratory containers.

Acknowledgments
The authors would like to express their sincere gratitude the head of the training laboratory, German Svalov, for organizing and assisting in the development and installation of the laboratory flotation equipment LFM–001.

The work was carried out at the financial support by Kalashnikov Izhevsk State Technical University within the framework of the grant no. DMY/20-70-24 and supported by the DAAD (German Academic Exchange Service) and by the Ministry of Science and Higher Education of the Russian Federation under “Mikhail Lomonosov – B 20” – Programme.

References
[1] Isakov V G, Vologdin S V, Ponomarev D S and Dyagelev M Y 2019 Modeling and system analysis of drinking water parameters in urban water supply systems IOP Conference Series: Materials Science and Engineering 537. DOI:10.1088/1757-899X/537/6/062045
[2] Zubareva G I 2019 Flotation in technological schemes of industrial wastewater treatment Bulletin of PNRPU. Construction and Architecture 10(4) 67–77
[3] Dyagelev M Y, Khvorenkov D A, Nepogodin A M, Bazhenov G K and Aleksandrov A I 2019 Content analysis of salts and suspended substances in snow and thawed water Journal of Physics: Conference Series 1399. DOI:10.1088/1742-6596/1399/5/055023
[4] Dyagelev M Y, Isakov V G and Grakhova E V 2019 α-factor experimental determination of aeration system in aeration tanks IOP Conference Series: Materials Science and Engineering 687. DOI:10.1088/1757-899X/687/6/066071
[5] Bensadok K, Belkacem M and Nezzal G 2007 Treatment of cutting oil/water emulsion by coupling coagulation and dissolved air flotation Desalination 206 440–448
[6] Alekseev E V 2015 *Wastewater treatment by flotation. Basic technology and application* (Moscow: ACB) p 160
[7] Chenga C, Phipps D and Alkhaddar R M 2005 Treatment of spent metalworking fluids *Water Research* **39**(17) 4051–4063
[8] Xing Y, Gui X, Pan L *et al* 2017 Recent experimental advances for understanding bubble-particle attachment in flotation *Advances in Colloid and Interface Science* **246** 105–132
[9] Ksenofontov B S 2003 Flotation treatment of waste water (Moscow: New technology) p 160
[10] Ksenofontov B S 2011 Problems of industrial wastewater treatment *Appendix to the journal "Life Safety"* **3** 1–24
[11] Chen G 2004 Electrochemical technologies in waste water treatment *Separation and Purification Technology* **38** 11–41
[12] Radzuan Aliff M R, Abia-Biteo Belope M A and Thorpea R B 2016 Removal of fine oil droplets from oil-in-water mixtures by dissolved air flotation *Chemical Engineering Research and Design* **155** 19–33
[13] Isakov V G, Dyagelev M Y, Varfolomeeva O I, Abramova A A and Chvorenkov D A 2019 Experience in industrial wastewater treatment of woodworking enterprise system *IOP Conference Series: Materials Science and Engineering* **537**. DOI:10.1088/1757-899X/537/6/062042
[14] Khouni I, Louhichi G, Ghrabi A and Moulin P 2020 Efficiency of a coagulation/flocculation–membrane filtration hybrid process for the treatment of vegetable oil refinery wastewater for safe reuse and recovery *Process Safety and Environmental Protection* **135** 323–341
[15] Matin A, Baig U and Gondal M A 2020 Facile preparation of superwetting surfaces by dip-coating of silane for efficient separation of different types of oils from water *Process Safety and Environmental Protection* **134** 226–238
[16] Pereira M dos S, Borges A C, Heleno F F *et al* 2018 Treatment of synthetic milk industry wastewater using batch dissolved air flotation *Journal of Cleaner Production* **189** 729–737
[17] Kochetkov L M, Sazhin B S, Sazhin V B *et al* 2010 Application of pressure flotation for wastewater treatment *Advances in chemistry and chemical technology* **3**(108) 113–116
[18] Zubareva G I and Chernikova M N 2011 The technological scheme of deep purification of oily waste water using the method of pressure head flotation *Ecology and industry in Russia* **10** 15–17
[19] An Ch, Huang G, Yao Y and Zhao Sh 2017 Emerging usage of electrocoagulation technology for oil removal from wastewater: A review *Science of The Total Environment* **579** 537–556
[20] Pintor Ariana M A, Vilar Vítor J P, Botelho Cidália M S and Boaventura Rui A R 2016 Oil and grease removal from wastewaters: Sorption treatment as an alternative to state-of-the-art technologies. A critical review *Chemical Engineering Journal* **297** 229–255