Centrifugal Pump Effect on Average Particle Diameter of Oil-Water Emulsion

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Abstract. In this paper we review the process of oil-water emulsion particles fragmentation in a turbulent flow created by a centrifugal pump. We examined the influence of time necessary for oil-water emulsion preparation on the particle size of oil products and the dependence of a centrifugal pump emulsifying capacity on the initial emulsion dispersion. The investigated emulsion contained the brand fuel oil M-100 and tap water; it was sprayed with a nozzle in a gas-water flare. After preparation of the emulsion, the centrifugal pump was turned on and the emulsion samples were taken before and after the pump passing in 15, 30 and 45 minutes of spraying. To determine the effect the centrifugal pump has on the dispersion of the oil-water emulsion, the mean particle diameter of the emulsion particles was determined by the optical and microscopic method before and after the pump passing. A dispersion analysis of the particles contained in the emulsion was carried out by a laser diffraction analyzer. By analyzing the pictures of the emulsion samples, it was determined that after the centrifugal pump operation a particle size of oil products decreases. This result is also confirmed by the distribution of the obtained analyzer where the content of fine particles with a diameter less than 10 μm increased from 12% to 23%. In case of increasing emulsion preparation time, a particle size of petroleum products also decreases.

1. Introduction

Nowadays the world production consumes for technological purposes significant amounts of water, nearly 5 trillion m³ annually. High consumption of water resources, and leads to an increase in sewage production. One of the most common pollutants of industrial wastewater is petroleum products.

A comparative analysis of existing methods for the purification of oily waters is presented in [1-3]. The choice of the technological scheme of purification is made on the basis of the composition of waste water, the initial and final concentration and particle size of petroleum products. Depending on the average particle diameter, coarse dispersed and finely dispersed emulsions are distinguished [4,5]. Coarse-dispersed emulsions contain particles of oil products with a diameter of more than 10 μm. Such emulsions are unstable and after a short settling are stratified. Secondary emulsions have a particle diameter of petroleum products of less than 10 μm and are not defended even with prolonged settling. Cleaning of fine emulsions requires the use of complex circuits consisting of several series-connected cleaning methods.

According to theoretical studies [6,7], the creation of finely dispersed emulsions is promoted by the increased turbulence of the liquid flow. An experimental study of petroleum product particles fragmentation in a turbulent flow created by various types of agitators was carried out in [8-11]. It is
examined that the larger the turbulence scale (flow velocity) acting on the particles, the smaller is the average diameter of the particles formed. Experimental studies [12-14] also established that the average particle diameter of the emulsion is significantly influenced by the surface tension at the oil-water interface, viscosity, temperature and time of preparation of the emulsion. In this study, the surface tension, temperature and viscosity are constant values and will not be taken into account.

Pumps are the main source of turbulent flows during the transportation of oil-water emulsions for cleaning. Dynamic pumps are mainly used for pumping emulsions, especially centrifugal ones, so a practical interest of the paper is the study of the centrifugal pumps influence on the particle size of an oil-water emulsion.

The aim of the experiment is to determine the emulsifying ability of a centrifugal pump, i.e. determination of the difference in the average particle diameter before and after the pump in case of different initial particle size, depending on the emulsification time.

2. Experiment

The experimental study was carried out on the installation shown in Figure 1.

In the tank (1), tap water was piped (B1) at a temperature of 15 °C. Using a graduated cylinder, 30 ml of M-100 fuel oil was measured, then poured into the surface of the tap water in the container (1). After that, a centrifugal pump (2) [15] was activated and transferred the liquid from the bottom of the tank (1) to the nozzle (8). A jet of liquid emitted from the nozzle created a funnel on the surface, into which large drops of fuel oil were drawn, while in the liquid volume a gas-liquid flare was created, in which large droplets of fuel oil were crushed into small ones (Figure 2).

During the experiment the pump operating time was recorded. After 15, 30 and 45 minutes of spraying, simultaneously sample the emulsion to the pump (2) through the elbow (9) and after the pump (2) through the elbow (10). The samples were subjected to a dispersion analysis. Thus, it is possible to estimate the emulsifying ability of a centrifugal pump at different initial particle diameters.

At the present time, the most common methods of dispersion analysis of emulsions are optical and microscopic ones [16-18].
The optical method is based on the property of substances to scatter light differently. In our study was used a laser particle size analyzer Fritsch Analysette 22 NanoTec, made for measurements in the range from 17 nm to 2500 μm [19].

For microscopic analysis, high-resolution microscopes are used, with a micrometer grid inserted into the eyepiece. The micrometric grid scale breaks the field into 100 squares, the size of which depends on the magnification of the eyepiece and the lens. In order to obtain the best increase in particle counting, consider a sample with different eyepieces and choose one that does not contain more than 30-40 particles within the micrometer grid. This method of investigation is very labor-intensive, since it is necessary to carry out many measurements of a single sample. Therefore, at this stage of the study, only the photographing of the emulsion was performed to estimate the particle size presented on the surface of the sample.

3. The results of the experiment
As a result of the dispersion analysis, graphs with differential and integral curves of particle size distribution were obtained (Figure 3). Each graph shows 5 curves corresponding to 5 parallel measurements of one sample.

On all the graphs (Figure 3b, c) two peaks are clearly pronounced: on the left is a small peak with an average diameter of 15 μm, on the right is a large peak with an average diameter of 500 μm. The large peak has approximately the same vertex position, independent of the emulsion preparation time and sampling point, while the peak of the small peak shifts.

The average particle diameter of a stable oil-water emulsion is in the range of 10-15 μm [20]. From this it can be assumed that the small peak in the distribution curves corresponds to the oil contained in the emulsion and the large one to impurities contained in pure water. To confirm this, an analysis of the pure water samples was made (Figure 3a). The graph shows that in almost all dimensions the small peak is absent.

Figure 3. Sample: a - clean water; b - oil-water emulsion of the pump; c - oil-water emulsion after the pump operation.
The presence of two peaks does not allow to evaluate the effect of the pump on the average particle diameter of petroleum products. However, the emulsifying ability of the pump can be estimated from the integral distribution curves, the numerical values of which are presented in Table 1. After the passage of the centrifugal pump, the number of particles with a diameter less than 10 μm increases in the emulsion, for example, at a 15 minute spraying, the amount of particles increased from 19.8% to 24%, at 30 minutes - almost twice from 12.9% to 22.4%, at 45 minutes - from 12.7% to 23.4%.

From the graphs of the distribution it can be seen that before the pump operation all the curves coincide, and after the pump operation the individual measurement results differ significantly, this indicates that the emulsion has become more polydisperse, i.e. in the samples after the pump operation contains a large number of particles of different sizes, which means that the pump breaks up the particles of petroleum products.

Table 1. Particle size distribution in emulsion

| d, μm | water,% | up to 15min,% | after 15 min,% | up to 30 min,% | after 30 minutes,% | up to 45 min,% | after 45 min, % |
|-------|---------|--------------|---------------|---------------|-------------------|---------------|---------------|
| 1     | 0,5     | 1,6          | 2             | 1,2           | 1,7               | 1,5           | 0,6           |
| 10    | 4,2     | 19,8         | 24            | 12,9          | 22,4              | 12,7          | 23,4          |
| 50    | 5,1     | 50,3         | 49,4          | 34,5          | 44,6              | 40,6          | 54,3          |
| 100   | 5,1     | 50,3         | 49,4          | 34,5          | 44,6              | 40,6          | 54,3          |
| 400   | 11,5    | 55,4         | 55,2          | 46,2          | 51,4              | 42,9          | 54,4          |
| 700   | 51,8    | 85           | 86,2          | 88,7          | 86,7              | 82,2          | 65,6          |
| 2000  | 100     | 100          | 100           | 100           | 100               | 100           | 100           |

The photographs of the samples of the emulsion collected before the pump (Fig. 4a, c, e) shows that the reduction in the size of the petroleum product particles is noted with the increase in the emulsion preparation time.

From photographs of samples taken at the same emulsification time, it is evident that the particle size of petroleum products on the water surface after the pump operation (Fig. 4b, d, f) is much smaller than in the samples taken before the pump operation. At that, the smaller the initial particle size of the emulsion before the pump operation, the smaller the particle size centrifugal pump operation

The oil-water emulsion after the pump operation contains particles with size different by several orders of magnitude. Fine-emulsified particles with a diameter of less than 10 μm are stabilized in the emulsion, and their size can be determined by a laser analyzer. Since the collected samples were sent to the laboratory to determine the dispersed composition of the emulsion, it took approximately 1 hour from the time of sample collection to analysis. During this time, particles with a diameter greater than 10 μm coagulate and float to the water surface. Large particles from the surface of the water do not enter the analyzer, so their size should be determined using a microscope. For further research, it is necessary to use a microscopic method for measuring large particles with a diameter greater than 10 μm, and optical microscopy for small particles with a diameter of less than 10 μm.

4. Conclusion

Based on the results of the pilot study, the following conclusions can be drawn:

1. The centrifugal pump breaks up the oil particles in the water. When the centrifugal pump passes through the emulsion, the content of oil products particles with a diameter less than 10 μm is almost 2 times increases.

2. The optical method of investigation does not allow to determine reliably the average particle diameter of the oil-water emulsion, with the particles larger than 50 μm. These particles actively coagulate, float to the surface and do not enter to the sample fed into the laser analyzer.
3. It is necessary to develop a new technique for dispersion analysis of oil-water emulsion, combining an optical method measuring the particle size of stabilized emulsions, and improve microphotography method, which measures large particles that float to the surface.

![Figure 4. Samples of oil-water emulsion: a - before the pump after 15 minutes; b - after the pump operation after 15 minutes; c – before the pump after 30 minutes; d - after the pump operation after 30 minutes; e - before the pump after 45 minutes; f - after the pump operation after 45 minutes.](image)

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