Tests of a two-stage vortex device for homogenization of milk

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Abstract. The subject of the study is milk homogenization process in the original design two-stage vortex device consisting of two vortex tubes connected with each other in series at a right-angle. The aim of this work is to optimize the operational and geometrical parameters of the vortex tubes relative location, with tubes forming the homogenizing device. Experimental study of the vortex devices was conducted on the basis of an OGZM-1.6 plunger pump with a capacity of 1.6 m$^3$/h, using a milk with fat content of 2.5% at a temperature of 60ºC. To assess the quality of the homogenization process, the microscopic examination method was used employing BIOLAR high-resolution microscope with immersion lens (1000 x magnification). Process quality was assessed according to the average size of milk fat globules. Experimental studies have shown that the best result for two-stage homogenization is achieved with the installation of the second vortex tube at an angle of 20° to the horizon with the differential pressure of the first stage 14 MPa and in the second stage – 3 MPa.

1. Introduction
Homogenization has become a standard production process in the dairy industry to obtain a stable structure of viscous, liquid food products, various emulsions obtained from one or more components [1]. Homogenization prevents fat settling during storage of milk, inhibits oxidative processes [2] and increases the level of milk digestibility [3]. Vacuum, ultrasonic and rotary homogenizers can be used for homogenization. One of their advantages is low energy costs, but they do not provide high degree of dispersion. Homogenizers of ultrahigh pressure and microfluidizers, on the contrary, have an ultrahigh energy consumption and a high degree of dispersion of the emulsion [4].

Two-stage valve homogenizers have become widespread in the dairy industry; the second stage is used in these homogenizers for breaking up agglomerates of the milk fat globules produced after the first stage [5]. It is commonly known that vortex homogenization ensures obtaining the high quality finished product even when using one stage and completely eliminates the agglomeration process [6]. At the same time, repeated vortex homogenization leads to improved quality of the finished product: the average size of fat globules is decreased, and individual uncrushed globules remaining after the first stage are crushed [7].

Rehomogenization of the product with the aim of improving its quality is not economically feasible due to high energy consumption for carrying out the process. Therefore, one of the most effective methods of reducing the size of the milk fat globules may be the use of the second stage of homogenization [8].

The aim of this work is to optimize the operational and geometrical parameters of the relative location of vortex tubes forming the homogenizing device, from the point of view of the
homogenization process quality.

2. The design of the device
The device used for homogenizing milk involves two stages consisting of vortex pipes. They are connected so that their axes are at a right angle, and the output of the first stage is directly connected to the input nozzle of the second stage, which is the diaphragm of the first stage. Each stage length ratio to its diameter is (10÷14):1[9]. Figure 1 shows the structure of the vortex two-stage device.

![Design of the two-stage vortex device](image)

**Figure 1.** Design of the two-stage vortex device: 1 – body of the first vortex tube; 2, 5 – plugs; 3 – adapter; 4 – the body of the second vortex tube; 6 – discharge pipe; 7, 8 – inlet nozzles; 9, 10 – vortex chambers; 11 – a diaphragm with a hole; 12 – device mounting holes.

The device for milk homogenization consists of a body of the first vortex tube 1, in the butt end of which cover 2 is fixed by threaded connection. The body of the first vortex tube has four holes 12 for fastening to the plunger unit. There is an input nozzle 7, which is tangentially connected to the vortex chamber 9. The body of the first vortex tube is connected to the adapter 3 by threaded connection. The adapter 3 is in turn connected to the body of the second vortex tube 4. At the butt ends of the tube 4 body, there is a plug 5 and a discharge nozzle 6. In the body of the second vortex tube 4 there is also
an input nozzle 8 tangentially connected to the vortex chamber 10. The diameter of the input nozzles 7 and 8 holes of the vortex tubes is selected in such a way as to maintain the first stage homogenization pressure at 3, 6, 10, 14 MPa, and the second stage – at 3 MPa. Plugs 2 and 5 are used for vortex tubes maintenance and washing.

The operational principle of the vortex homogenizing device is as follows. Through the inlet nozzle 7 located at the butt end portion of the first vortex tube 1 body, the feed is supplied into the vortex chamber 9 having a cylindrical shape, where the flow acquires a rotary motion due to a tangential location of the nozzle relative to the chamber. At the same time, the product moves along the vortex chamber to the chamber butt end opposite to the entrance. As a result of these two movements, the flow becomes a spiral movement, which theoretically can be attributed to the helical motion. Studies conducted on the basis of the theory of screw flows have shown that in the central part of the screw flow within the radius of the smaller than some critical value, a near-axis area of low pressure is formed where the pressure is below the triple point ($\approx 600$ Pa). The formation of such an area is caused by the intense acceleration of the flow when approaching the axis and as a consequence – by the conversion of potential energy into kinetic one. This area has a cylindrical shape and is located along the entire axis of the chamber. That is, the low-temperature area is equal to the chamber length. The temperature of the product in this area is below 0°C, while the absolute pressure when approaching the chamber axis theoretically tends to zero. Reduction of pressure below the triple point, in particular, below 600 Pa causes the freezing of moisture droplets in the area. Intensive formation of droplets in the area of such low pressures is associated with the process of sublimation, accompanied by evaporation. Equally important for intensive formation of droplets is a high velocity of flow in this area. If we follow the theory of low-temperature cavitational homogenization, the milk fat globules that falls into this area, colliding with the frozen droplets of moisture, are intensely crushed [9]. In order for the entire product to pass through the cavitational area of low-temperature homogenization, the output diaphragm of the vortex chamber is designed so that it has a diameter smaller than the diameter of the cavitation area.

In case of the two-stage homogenization studied in this article, the first-stage diaphragm is transferred to the nozzle of the second stage, which is located tangentially to the second vortex chamber. To ensure the above conditions for the entire product passing the cavitation area and tangential location of the nozzle of the second stage relative to the second vortex chamber, a special adapter 3 is provided between the diaphragm of the first stage and the second stage nozzle (Figure 1). The diaphragm, the adapter and the nozzle of the second stage are on the same axis with the first vortex chamber. The principle of homogenization in the second vortex chamber is similar to the first chamber.

3. Method of research
Experimental study of the vortex device (Figure 2) was conducted on the basis of the OGZM-1.6 plunger pump (Figure 3) with a capacity of 1.6 m$^3$/h. The raw milk fat content was of 2.5%. The experiment was conducted at a constant flow of product equal to 1.6 m$^3$/h and at a temperature of $t=60$ °C.

To assess the quality of the homogenization process, a microscopic examination method was used employing a high-resolution BIOLAR microscope with immersion lens (1000 x magnification). Process quality was assessed according to the average size of milk fat globules.
4. Results of experimental studies

The position of the first vortex device depends on the location of the plunger pump outlet branch. In the OGZM-1.6 plunger pump used in the presented experiments, the outlet branch is positioned to ensure horizontal position of the first stage 1 (Figure 3). Therefore, the first vortex device remained unchanged during the experiment, being in a horizontal position. The position of the second vortex device was changed by an angle $\beta$ (Figure 4) from horizontal to a vertical one with an upward outlet. According to the results of previously conducted experiments it was determined that the slope of the second vortex device down below the horizontal leads to homogenization quality deterioration. Therefore, the inclination option of the second device by the outlet branch downwards, was not considered.

The first series of experiments on two-stage vortex device was held at a constant pressures of 14 MPa in the first stage and 3 MPa in the second one (Figure 5). The experiment showed that the optimum inclination angle of the second vortex device is 20° upwards relative to the horizontal position; it provides a good degree of homogenization (1.25 µm).
With increasing slope angle up to 45°, the average size of fat globules increases, reaching a size of 1.75 µm. A further increase in the inclination angle up to 90° (vertical position with the upper output) does not affect the quality of the product. The horizontal position of the second vortex device turned out to be the least effective. The average size of fat globules was 2 µm, which is the lowest result.

In the next series of experiments, the simultaneous impact of two parameters on the quality of homogenization was studied, namely, the inclination angle of the second vortex tube and the pressure in the first vortex chamber. A somewhat different trend is observed here, compared with the first series of experiments. Namely, the optimum inclination angle of the vortex tube depends on the pressure on the first stage. On the chart (Figure 6) a clear trend to reduced size of milk fat globules with increasing pressure is observed. Thus, when the pressure in the first stage is 3 MPa, the best result is achieved when the chamber of the second stage is in the horizontal position. The average size of a fat globule is relatively large and is 2.2 µm. Changing the inclination angle from the horizontal position leads to an increase in the average size of fat globules to 2.4-2.5 µm. Already starting with the pressure of 6 MPa, the optimum position is achieved when the position of the second chamber is at an inclination angle of 20°.

![Figure 4](image_url)

**Figure 4.** The scheme of two-stage vortex device: 1 – the first vortex device (first stage); 2 – the second vortex device (second stage); \( \beta \) – the inclination angle of the second vortex device.
5. Conclusion

Based on the experiments conducted, the following conclusions can be made. The best result for the two-stage vortex homogenization is achieved by installing the second vortex tube at an angle of 20° to the horizon and with a pressure drop of 14 MPa in the first stage and 3 MPa in the second stage.

The object of further research may be possibility for using a two-stage vortex homogenization not only for milk and dairy products, but also processes of emulsification and dispersion of other liquid...
food products. Two-stage vortex tube for complete dust collection [10] during the purification of used air in the production of milk powder will also be interesting.

References

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