Intensification of heat exchange by an ultrasound source for milk pasteurization.

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Abstract. The goal of this article is to investigate the effect of ultrasonic vibrations on the process of milk pasteurization. Ultrasound can potentially intensify heat transfer and reduce the formation of thermal sediment (soot deposit) on the walls of heat-exchange devices. The paper presents the results of experimental studies demonstrating the growth rate of thermal sediment on the wall of the heat-exchange apparatus and its amount in the volume of milk under the influence of ultrasonic vibrations and without it.

1. Introduction

In the process of pasteurization of milk and dairy products thermal sediment – soot deposit is formed on the walls of heat exchangers. It is caused by protein and fat globules in the boundary layer. Due to the high temperature of the thermal medium (hot water or steam with temperature of up to 150 degrees) the particles stick to the wall and burn.

The formation of this sediment increases the hydraulic resistance of the system and the thermal resistance of the heat exchange surface. The latter, either increases the energy consumption for heating, or reduces the quality of the product. For this reason, depending on the operating modes, quality of the heat-exchange apparatus and raw material (milk), it is often required to stop the production line one to three times per shift and clean it with acid and alkaline solutions. With each stop the manufacturer incurs losses.

The impact of ultrasonic vibrations on the wall-adjacent liquid layer can not only reduce the rate of deposition of thermal sediment on the walls of the heat exchange apparatus, but also intensify the heat exchange.

Many papers on the intensification of heat transfer by means of ultrasound state that exposure to the sound field can increase the heat transfer coefficient. This is explained by the fact that the impact of acoustic vibrations, which are transmitted by the thermal medium, there are secondary vortex currents. They permeate the viscous sublayer and thus intensify the heat transfer. In [1] it was proved that the formation of vortices on the heat exchange surface when exposed to ultrasound, intensified the heat exchange by 20-280%. The work [2] considers the complex effect of the ultrasonic impact: both intensification of heat transfer and reduction of sediment formation on the walls of heat-exchange apparatuses. However, the cleaning of the heat exchange surface may be caused by acoustic cavitation, which absolutely rightly accompanies most ultrasonic treatment processes. This method of dealing with thermal sediment is not acceptable in the dairy industry. The question remains relevant: Is it
possible to intensify the heat exchange during pasteurization of milk with the help of ultrasound so that the thermal sediment is not formed on the heat exchange surface, or, on the contrary, ultrasound can detach the thermal sediment from the heat exchange surface in the volume of milk and thus makes it unfit for consumption. Vibrating heat exchangers are being actively developed and researched [3]. It is important to explore the possibility of using ultrasonic waves to improve the performance of heat exchangers, including in the dairy and food industries in general.

2. Experimental conditions
The experimental setup consists of a metal plate (140*140*2 mm, material – ST40 grade steel), piezoelectric source of ultrasound (22 kHz, 100 W), induction heater and measuring equipment (Figure 1). In the center of the metal plate there is a fixing element, to which the ultrasonic source is screwed – directly or through a spacer. The spacer is used for modeling of ultrasonic power reduction - for example, if there is no possibility to screw the ultrasonic source directly to the heat exchange surface. The spacer is made of D16T aluminium.

Three configurations of the experiment were considered:
• without the ultrasonic source
• with the ultrasonic source
• with the ultrasonic source fixed through a spacer

![Schematic diagram of the setup.](image)

In all configurations, the plate is placed through silicone supports on the bottom of the glass container, which is placed on the induction heater – thus, the heater heats the plate. The setup has 3 temperature measurement points: at the center of the plate (T1), at the edge of the plate (T2), and in the milk volume (T3). Thermocouples are installed to track the temperature of the milk and the heat exchange surface. The installation works in a semi-automatic mode: the heater operates for 10 minutes after heating the plate to 100 degrees. An example of temperature oscillograms is shown on Figure 2.
3. Results

The results of the control weights are presented in Table 1. Weighing was carried out on Acom JW-1 scales. Five series of experiments were conducted. Before the experiment, a clean plate was weighed, and then the plate with the sediment, previously dried with a cloth material, was weighed. Initially the plates were additionally dried in room conditions for a week, since the thermal sediment is a porous structure and contains a lot of moisture, but later this drying was abandoned due to its excessive time duration.

The table shows Plate 1 – without the ultrasonic source, Plate 2 – with the ultrasonic source, Plate 3 – with the ultrasonic source mounted through a spacer.

| № of measurement | Plate 1 before | Plate 1 after | Plate 2 before | Plate 2 after | Plate 3 before | Plate 3 after |
|------------------|----------------|--------------|----------------|---------------|----------------|--------------|
| Average value across 5 experiments | 398.92 | 408.18 | 402.26 | 402.43 | 412.31 | 414.49 |

According to the results of five series of experiments, the average mass of the thermal sediment was equal:
- for the plate without ultrasonic exposure – 9.26 g
- for the plate with the ultrasonic source – 0.17 g
- for the plate with the ultrasonic source fixed through a spacer – 2.18 g.

From the results of the experiment, it can be seen that the effect of ultrasonic vibrations significantly reduces the formation of thermal deposit on the heat-exchange surface. At the same time, the presence of the spacer naturally reduces the efficiency of the system, as it dampens the vibrations, reducing the impact of ultrasonic vibrations on the plate.
Product quality is an important issue in milk production. A potential risk when using ultrasound in the heat exchange equipment can be the presence of thermal sediment in the product itself. To control the quality of milk after the experiment, samples were taken and examined under a microscope (ERGAVAL CARL ZEISS JENA) to identify and differentiate sediment particles by size and quantity. The results of the study are shown on Figure 3.

The figure shows that the use of ultrasound without a spacer (red) decreased the number of particles of 48, 36, and 24 μm compared to their number without the ultrasound source (blue). However, the number of particles smaller than 24 μm in the presence of a spacerless ultrasonic source (red), on the contrary, increased compared to the absence of the spacer. A possible reason for these results is the occurrence of acoustic cavitation, which pulverized the milk particles. In the configuration of the experiment with the spacer, the increase in the number of particles can be explained by the fact that both the spacer and the ultrasonic source (ultrasonic waveguide) are made of D16T aluminium. A loose fit of these two parts of the setup could lead to crushing of their materials and, consequently, to an increase in the number of particles.

4. Conclusions

Ultrasonic influence appears to be an effective tool to combat the formation of thermal sediment on heat exchange surfaces and as an intensifier of heat exchange processes, which is relevant and beneficial for the process of pasteurization of dairy products.

The use of ultrasound in heat exchange equipment can potentially lead to vortices near the heat exchange surface, to fluid flow mixing in the thermal boundary layer and to acoustic cavitation, and in the presence of boiling, to the facilitation of bubble detachment from the heat exchange surface.
Continued experimental research in this area will reveal the potential of heat exchange intensification and methods of combating thermal precipitation using ultrasonic impact.

The study of the presence of thermal sediment particles in milk yielded positive results. The total number of particles in milk for the cases (plate with the ultrasonic source) and (plate without the ultrasonic source) remains the same. Therefore, it can be tentatively assumed that the thermal sediment does not get into the final product, but simply does not have time to form. According to the results of the work, it can be claimed that ultrasound significantly combats the formation of thermal sludge. Application of such technologies will reduce the cost of milk production and, as a consequence, its final price.

References
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