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Research Paper

Influence of ultrasound to convectional heat transfer with fouling of cooling water

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HIGHLIGHTS

- A double-tube heat exchanger and an ultrasonic device were precisely combined.
- Effects of properties of cooling water to fouling were investigated with ultrasound.
- The parameters of ultrasound were studied to convective heat transfer and fouling.
- The cavitational effect to antifouling was analyzed for present results.

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ABSTRACT

Experimental study was conducted to investigate antifouling effect of ultrasound to convective heat transfer process with cooling water as working fluid in different hardness and temperature. An ultrasonic treatment device was preinstalled before a double-tube heat exchanger. The ultrasound was applied and controlled in the range of 28–40 kHz in frequency and 25–50 W in power. A remarkable effect of antifouling was observed from experimental results of heat transfer process with ultrasonic treatment. There was lower fouling resistance which means better antifouling effect in lower frequency of 20 kHz than that in higher frequency of 40 kHz. But a contrary result was observed for ultrasonic power, i.e. a higher antifouling rate was reached with the high power of 50 W ultrasound.

1. Introduction

Fouling usually exists in industrial heat exchangers when cooling water is used as working fluid, which not only decreases heat transfer performance and increases energy consumption seriously, but also reduces the life of heat transfer equipment. Therefore, it is extremely important to carry out water treatment in heat exchanger and restrain the mitigation of fouling.

The methods of water process are generally divided into chemical and physical ways, whereas the chemical treatment by using chemical inhibition agent may cause second pollution to cooling water though it is effective to antifouling application. Then the physical methods including electromagnetic and ultrasonic treatments attracted to the attention of scientific researcher and engineers in recent years. The ultrasonic treatments have been applied early in 1950s, especially in equipment cleaning with its small energy consumption, low cost and little environmental pollution. With requirement of energy conservation and environmental protection around the world the ultrasonic treatment has become the new focus to heat transfer enhancement and antifouling, recently.

Ultrasound is recognized as acoustic waves of which frequencies are higher than 20 kHz. When it propagates in liquid, some interesting phenomena can be observed including acoustic cavitations, streaming, heating and so forth, which may result in heat transfer enhancement [1]. Especially the ultrasonic cavitations are more important phenomena, which comprise the formation, growth, oscillations, and powerful collapse of gas bubbles into a liquid. During ultrasonic cavitations, extremely high pressure of thousands of atmospheric pressure and temperature up to thousands of Kelvin degree can be produced, thus subsequently affecting the liquid flow and heat transfer performance of equipment. Amount of research have been summarized comprehensively around heat transfer enhancement by ultrasound in Ref. [2], in which mechanism and effects of ultrasound to heat transfer have been surveyed in detail, but research on fouling treatments by ultrasound are far more deficient.

Luo et al. [3] verified experimentally the effect of ultrasound of 20 kHz/100 W to hard water and their results showed that fouling crystal changed in shape with fouling inhibition rate up to 91% within time up to 600 seconds. Fu et al. [4] conducted experiments in heat transfer process by 28 kHz ultrasound with different powers, and

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they confirmed the antifouling effect of ultrasound with the power less than 200 W, then the scale removal effect when the power is larger than 200 W. Experimental results by Ma et al. [5] for hard water treated by 100 W ultrasound showed that the concentration of calcium ion and alkalinity of solution may decrease gradually and the shape of crystal $CaCO_3$ changed with the ultrasound treatment. Zhang et al. [6] constructed mathematical and physical model of ultrasound transmission in liquid flow and showed their results that the transmission of ultrasound may attenuate faster in flow than in static fluid, and the viscidity of liquid has quite effect to attenuation of ultrasound. Gondrexon et al. [7]'s investigation showed that by ultrasound of 120 W/24 kHz overall heat transfer coefficient can increase up to 1.2 times of original value without treatment. Legay et al. [8] gave experimental results that the heat transfer enhancement factor increased about 1.2–2.3 for double-tube heat exchanger by 35 kHz ultrasound. Guo [9] concluded experimentally that the ultrasonic frequency may have better effect than flow velocity and ultrasonic power for cooling water, and got the best descaling effects in case of ultrasound 30 kHz and 400 W, and 0.6 m/s flow velocity. Li [10] showed experimental results for vapor condenser that the descaling rate increased with increasing power of ultrasound, and optimal value of power exist at certain running conditions. Zhang and Hu [11] studied experimentally the influence of water temperature to transmission of ultrasound and found a quadratic function between ultrasound attenuation and temperature in range of 25–75 °C. Legay et al. [12] simulated the descaling process of ultrasound by paint-spray experiment and got very good effect during a few tens of minutes of ultrasound treatment. Li et al. [13] investigated ultrasound cavitations effect on antifouling and descaling and found the different cavitational active temperature for liquids and reverse effect of acoustic intensity.

Although the ultrasonic technology has been recognized as an effective method to heat transfer enhancement, which has been studied and applied widely, the detailed research with ultrasound to water treatment, especially in antifouling and descaling of heat exchanger, are far from enough and mechanism of ultrasonic treatment has not been comprehensively understood, either. Thus, this study was conducted based on experimental investigation in an on-line monitor setup of heat transfer for ultrasonic treatment. An ultrasonic treatment device was made and preinstalled in the convective heat transfer system simulated to industrial heat exchanger. The objective of this study focused on the influence of water temperature, hardness and frequency, power of ultrasound in fouling process of double-tube heat exchanger with cooling water as working fluid.

2. Experimental apparatus

Fig. 1 shows the schematic diagram of the online fouling monitor system of heat transfer, which included heat transfer test section, cooling water circle, hot water circle, refrigerating loop, measuring & controlling device, and microscopic-imaging system.

The heat transfer test section is composed of two concentric tubes: the inner one is a copper tube, and the outer one is a stainless steel tube with a short glass (for optical observation). The hot water (deionized water) flows inside the inner tube, whereas the cooling water (test liquid) flows in the annular gap between the two tubes in the opposite direction of the hot water, thus forming a counter-flow double-tube heat exchanger. The scales deposit on the outside surface of the inner tube. To simulate actual cooling system of industry the ultrasonic treatment device is installed on the outside wall of tube just before the heat transfer test section in the cooling water circulating loop. After passing the test section, the cooling water is sent first to the shell-and-tube heat exchanger for emitting heat and then returns to the cooling water tank. There are three electric heaters of 5 kW power at the bottom of the hot water tank, and one electric heater of 3 kW power at the bottom of the cooling water tank. The volumes of the two tanks are both 200 liters. The refrigerant water is supplied by a set of ground-source heat pump and absorbs heat from the cooling water in the shell-and-tube heat exchanger, and then returns to the heat pump to be refrigerated. A data acquisition system is used to measure temperatures, flow rates,

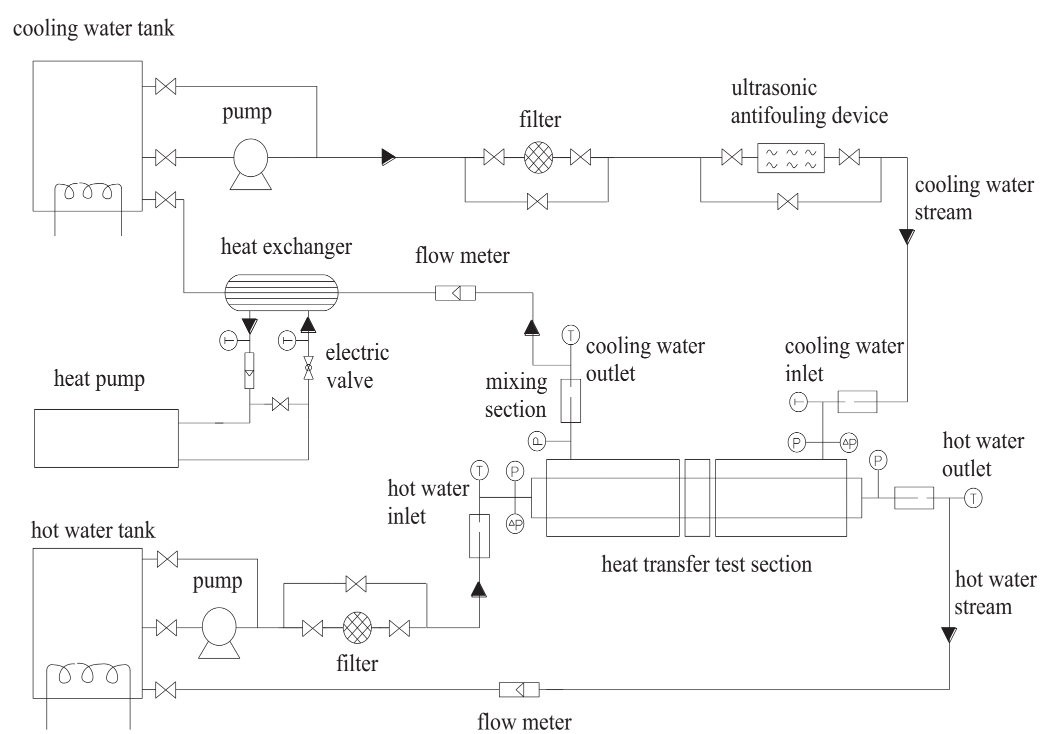

Fig. 1. Schematic diagram of fouling monitor system of heat transfer.