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Research Article

Heat Transfer Augmentation: Experimental Study with Nanobubbles Technology

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The experimental research on heat transfer characteristics is an ever-ending scheme since the life of all thermoelectronic devices relies on the effective management of thermal energy. In some cases, the gradient of temperature for heat transfer is to be minimum to avoid energy loss, but also there are numerous applications where the requirement of heat transfer to be maximum and could be achieved with a higher temperature difference between the heat transfer medium. In our current research, distilled water-ethylene glycol heat transfer fluid (HTF) was tested with different inlet mass flow rates and temperature as the hot fluid. Atmospheric air was chosen as the cold fluid. The natural convection heat transfer rate between hot and cold fluid streams was analyzed with and without the generation of micronanobubbles in the hot fluid. It was observed that compared to the base heat transfer fluid, the nanobubbles heat transfer fluid resulted in a 10–12% increase in heat transfer rate at hot fluid inlet temperatures of 28°C, 30°C, 32°C, 34°C, and 36°C. The method of generation of nanobubbles in HTF and their behavior are also highlighted.

1. Introduction

The demand for more effective and less complex techniques for accurate heat transfer analysis is the need for waste heat recovery in many process industries [1]. The gas-filled entities are called nanobubbles and their research was initiated in the 1990s [2]. Though it is a newer technology, due to its scope in all science, engineering, and medical fields, research is still growing in nature [3]. Agriculture [4], aquaculture [5], germination of seeds [6], drug delivery [7], heat transfer [8], tissue engineering [9], and treatment of polluted water are some of the noteworthy contributions of this unique nanobubbles technology in the abovementioned fields. The ion exchange, temperature change, pressure change, and hydrodynamics are the commonly employed methods for generating nanobubbles in any liquid medium [10]. As per the YoungLaplace theory, the gas that forms the bubble posed about 30×10^5 Pascal internal pressure which was in a 30 : 1 ratio compared to any surrounding liquid which was at ambient pressure of 1×10^5 Pascal [11]. Due to this very high-pressure gradient, the bursting of the bubble happens in microseconds, resulting in the formation of still lower size nanobubbles [12]. The motion of nanobubbles in liquid is in all x, y, and z directions, but till now no technology is available to analyze these 3D motions [19, 20]. Nanoparticles Tracking Analyzer (NTA) and dynamic light scattering (DLS) are the presently used methods for analyzing the nanobubble movement in 2D [13]. The negligible buoyancy of nanobubbles is attributed to the lateral movement rather than movement towards the free surface. The surface area per unit volume, stability, zeta potential, pH, size, and number density are the most important characteristics that need to be understood prior to nanobubbles research in any specific application [14]. Based on the previous studies, it was concluded that the nanobubbles research on heat transfer is a wide area to be focused on to arrive at the most significant conclusions considering the life of many thermoelectronic devices.

Figure 1: Equipment for nanobubble generation.

Table 1: Temperature difference between hot and cold fluids.

Parameters	Hot fluid mass flow rate (kg/s)	Hot fluid inlet temperature (°C)	Hot fluid outlet temperature (°C)	Cold fluid inlet temperature (°C)	Cold fluid outlet temperature (°C)
Before nanobubbles generation	0.1	28	26.5	22	23.2
		30	27.2	22	23.9
		32	28.1	22	24.5
		34	29.5	22	25.1
		36	29.9	22	26.4
After nanobubbles generation	0.1	28	26.8	22	23.4
		30	27.9	22	24.2
		32	28.7	22	25.3
		34	30.5	22	26.4
		36	32.6	22	27.4

2. Generation of Nanobubbles

The hydrodynamic method works on the principle of cavitation; this causes the formation of bubbles as shown in Figure 1. An orifice plate or a venturi tube is mostly used in the method of generation. The microbubbles (MBs) generator of the orifice type has an aperture in a flowing water tube via which water is pressurized to enter the generator. A little distance downstream of the orifice, the difference in water velocity between the orifice and generator outlet causes negative pressure. The air is sucked via a stainless steel perforated pipe inserted in the running water tube, which, because of intense shear force, splits the air into numerous MB. The venturi type generator mainly consists of three main components, those are, a diverging part, a converging part and a throat. According to F. Haung, simple structure, durability, and more efficiency are the benefits of this generator. Due to the shape of the venturi tube, it has more impact on the local pressure and the cavitation and hence thereby controlling the bubble size and efficiency.

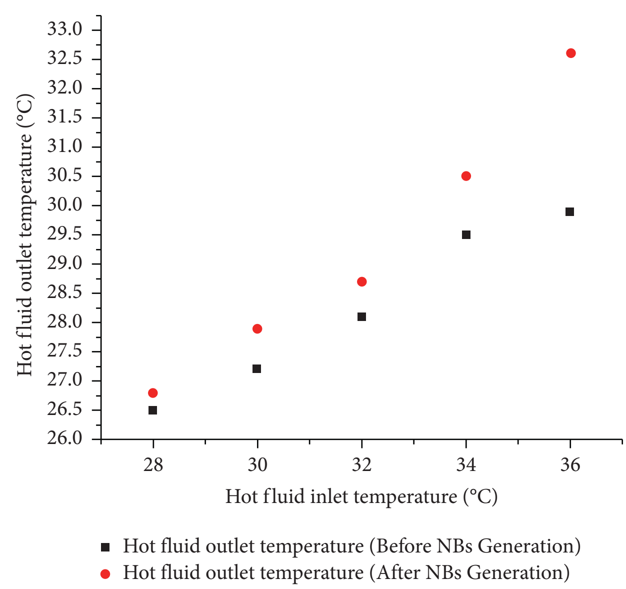

Figure 2: Influence of nanobubbles on hot fluid (water-ethylene glycol) outlet temperature.

3. Results and Discussion

Table 1 showed the variation in hot and cold fluid outlet temperatures. Figure 2 indicates the difference in hot water-ethylene glycol heat transfer fluid before and after the influence of nanobubbles generation. As compared with the inlet temperature, the hot fluid outlet temperature with nanobubbles generation was found to be higher. At higher hot fluid inlet temperatures of 34°C and 36°C, the % variation of hot fluid outlet temperature was very high and found to be 10–12% as compared with 28°C, 30°C, and 32°C.

Figure 3 indicates the difference in the cold air as heat transfer fluid before and after the influence of nanobubbles generation. As compared with the inlet temperature, the cold fluid outlet temperature with nanobubbles generation was found to be higher. At higher cold fluid inlet temperatures of

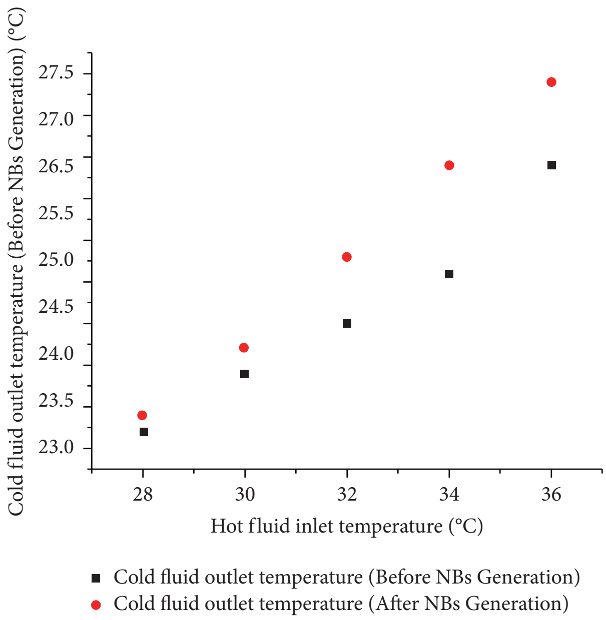

Figure 3: Influence of nanobubbles on cold fluid (air) temperature.

34°C and 36°C, the % variation of hot fluid outlet temperature was very high and found to be 9.5–11.4% as compared with 28°C, 30°C, and 32°C.

4. Conclusion

The experimental result outcome was that both the hot and cold fluid outlet temperatures attained a marginal increase in temperature when nanobubbles are produced in water-ethylene glycol heat transfer fluid as compared to the same fluid without nanobubbles generation. The exponential variation in both streams was found to be 10–12%. Hence, it is suggested that for any heat transfer applications, the heat transfer fluids can be used with nanobubbles to enhance the convective heat transfer rate. In the future study, most of the heat transfer fluids and phase change materials may be tested with nanobubbles prior to specific applications.

Data Availability

The data used to support the findings of this study are included in the article. Should further data or information be required, these are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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