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Experimental Investigation of Flow Rate and Concentration Effects of Graphene-Water Nanofluid and Finding the Optimal Conditions Using Taguchi Method

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ABSTRACT: In this paper, graphene nanoplate was stabilized in a water-based fluid by sodium dodecyl sulfate as a surfactant. The prepared nanofluid in weight percentages of 0.01 -0.145 was placed in a gasket plate heat exchanger in the presence of cold fluid (deionized water). All experiments were performed for laminar flow in the range of Reynolds numbers of 500-1500. The effect of flow rate and concentration of nanofluid was investigated on the overall coefficient of heat transfer and pressure drop. The concentration increase causes both to increase at the same time. As a result, heat exchange efficiency and thermal effectiveness of the nanofluid were also analyzed. The highest thermal effectiveness (89%) and efficiency (1.244) occur at a minimum flow rate (2 liters per minute) and maximum weight percentage (0.145) Taguchi method was used to find the optimal conditions and confirm the validity of the experiments. It was also found that the decrease in the flow rate (98.56%) has a greater effect on the results of thermal effectiveness than the increase in concentration (0.404%). The error rate was 0.018%, which shows the accuracy of the results.

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1- Introduction

Low thermal conductivity of fluids is a major problem in engineering industries and the subject of heat transfer. One way is to add solid particles, which due to their higher conductivity than the base fluid, improves the thermophysical property of the fluid, but adding solid particles to the base fluid sediments after a short time [1]. By stability methods such as covalent and non-covalent functionalization methods, this problem can also be solved [2]. The production of graphene and carbon nanotubes is rapidly developing. Thus, research has been done on stability methods and thermophysical properties. For example, Agromayor et al. [3] stabilized graphene nanoplates in the base fluid. Another way is to use a plate heat exchanger, which due to the shape of the plates and the chevrons on them, increases the heat transfer surfaces and makes the fluid flow turbulent. So, researchers have studied different fluids for further cooling or heating in order to find the optimal conditions [4]. Researchers have tried to achieve the appropriate heat transfer rate by new methods so that the ratio of heat transfer to pressure drop is optimal.

This paper aims to fabricate nanofluids containing graphene nanoplates in a water-based fluid by a non-covalent method and study it in a plate heat exchanger. So graphene nanoplates were stabilized in a water-based fluid at a ratio of 1-1 by Sodium Dodecyl Sulfate (SDS) as a surfactant. Due to the importance of effectiveness and efficiency in optimal conditions, by the Taguchi method, the optimal conditions were analyzed.

2- Methodology

2- 1- Methods and materials

To prepare graphene nanofluids, graphene nanoplates (diameter 20-30 µm and thickness about 40 nm, 5 g, VCN Company), deionized water (200 lit, Iran), and SDS as a surfactant (50 g, Azmiran Company) were prepared. First, 1 g of surfactant was gently added to deionized water (neutral pH) placed on a sonicator, and stirred well for 25 minutes in the Erlenmeyer flask by a magnet. A gram of graphene nanoplates was added to them. Using an 800-Watt ultrasonic probe, the Erlenmeyer was stirred well for 40 minutes to finally produce a stable nanofluid at 0.1 wt.%. Other weight percentages of 0.01, 0.055, and 0.145 were obtained in the same way. The results of zeta potential analysis showed that the lower the weight percentage, the higher the fluid stability. For the mentioned concentrations, the zeta potentials were -32.61, -23.68, -19.27 and -16.85, respectively. It should be noted that the ratio of SDS to nanoparticles was 1-1. The ratios of 0.5-1 and 1-2 were also examined by zeta potential analysis (the zeta potential results were 27.43 - and -15.33). The highest stability was obtained for the ratio of

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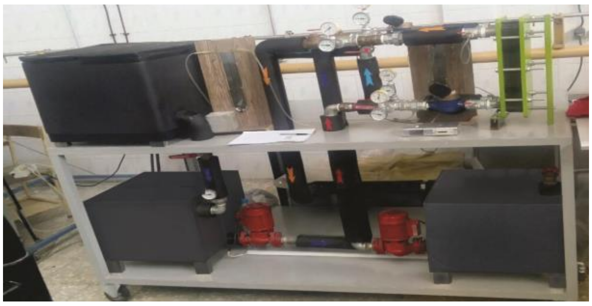

Fig. 1. Laboratory setup

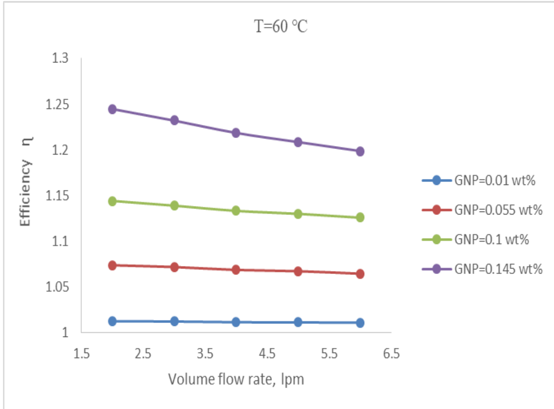

Fig. 2. Effect of nanofluid flow rate on efficiency at different concentrations

1-1). Shanbedi et al. [5] reached a similar result for carbon nanotubes and some surfactants such as Arabic gum and SDS, which showed the best stability ratio of 1-1.

For the morphology of the obtained powder, X-ray energy diffraction spectrometer, Raman spectrometer, and transmission electron microscope were performed. The results of the X-ray diffraction spectrometer show that the graphene is purified and free of contamination. Also, the Raman results of three peaks for graphene nanoplate were found that the first peak was observed around 1500 cm^{-1} (D band), the second peak around 1580 cm^{-1} (G band), and the third peak around 2670 cm^{-1} (2D band). The transmission electron microscope indicated that the graphene nanoplate diameter was 20 nm.

2- 2- Laboratory setup

Fig. 1 shows the prepared setup which consists of two hot and cold loops with a fluid storage tank, a pump, a section for measuring pressure and temperature (before and after the exchanger), and a section for measuring fluid flow rate. A U-shaped manometer is also installed in the setup to measure the pressure drop. Also in the hot section, there are two heating elements equipped with a thermostat, and a cooling system has been used in the path of the cold fluid and before the cold fluid storage source. The thermophysical properties can be calculated according to the bulk temperatures of the two fluids at the inlet and outlet of the heat exchanger. By recorded flow rates and thermophysical properties, the heat transfer rate and the total heat transfer coefficient are calculated. By obtaining the friction factors, the pressure drop for the path and inlets (ports) is achieved. The total pressure drop is two paths of inlet and outlet pressure [6]. Thermal effectiveness or the ratio of actual heat transfer to the maximum was calculated [7]. Efficiency was also calculated Eq. (1). In order for the use of nanofluids to be economically viable, the ratio of heat transfer coefficient to the pumping power in both nanofluids and water must be more than one [8].

$$\eta = \frac{\left(\frac{h_{nf}}{h_b}\right)}{\left(\frac{W_{nf}}{W_b}\right)} \tag{1}$$

3- Results and Discussion

To determine the effect of concentration on heat transfer coefficient and pressure drop, nanofluids of 0.01, 0.05, 0.1, and 0.145 wt.% were used. The results showed that increasing the concentration from 0.01 wt.% to 0.145 wt.% increases the overall heat transfer coefficient (At 2 lpm, increasing the weight percentage causes an overall heat transfer coefficient of 8.51% and at 6 lpm is 5.53%). The use of nanofluids in higher concentrations also increases the pressure drop. This increase in low flow rates is very close to the base fluid (at 0.01 wt.% and 2 lpm, the pressure drop for nanofluid and base fluid is 0.1322 and 0.1312 kPa, respectively). In all the mentioned concentrations, the pressure drop is more than the base fluid, however, in 0.01 wt.%, this difference is insignificant. For example, in the flow rate of 2 lpm, this difference is 0.76%. The lowest pressure drop is observed at 2 lpm and 0.01 wt.% (0.1312 kPa). Increasing the concentration increases the overall heat transfer coefficient (positive effect) and decreases the pressure drop (negative effect). Therefore, to find the optimal conditions, effectiveness and efficiency were examined. Increasing the concentration improves the effectiveness of the nanofluid (5.94% at a constant flow rate of 2 lpm). At a constant temperature (60°C) and a certain flow rate, increasing the concentration compared to the base fluid reduces the specific heat capacity of the fluid (At a constant flow rate of 2 lpm, the specific heat capacity of the nanofluid for 0.01 and 0.145 wt.% were 4139 and 3612 J/kg.K, respectively). The highest efficiency (89%) was related to nanofluids in 0.145 wt.% and minimum flow rate (2 lpm). Fig. 2 shows the effect of nanofluid flow rate on efficiency at different concentrations. Increasing the concentration leads to increasing efficiency (Increasing the flow rate from 2 to 6 lpm at of 0.01 wt% reduces the efficiency by 0.14%, but this rate is 3.84% at 0.145 wt.%). The highest efficiency is when the nanofluid flow rate is the lowest and the concentration is maximum (2 lpm and 0.145 wt.%, maximum efficiency is 1.244). It is also observed that in all concentrations this amount is more than one, which indicates that the use of nanofluids is appropriate and economically justifiable.

To evaluate the effectiveness in optimal conditions (increasing the thermal efficiency), the Qualitek-4 software that uses the Taguchi method was used [9]. In this study, the effect of weight percentage and the nanofluid flow rate was selected as two factors for statistical analysis of the Taguchi method. For each of the factors, 3 levels of change were selected (for example, for the concentration factor, levels of 0.01, 0.1, and 0.145 were selected).To find the effect of each factor under optimal conditions, the analysis was performed. The results show that the effect of nanofluid flow rate (contribution=98.566%) is much greater than its weight percentage (0.404%) on the effectiveness. It means that it is easier to achieve optimal effectiveness by changing the nanofluid flow rate.

4- Conclusions

The results showed that the use of nanofluids compared to water-based fluid (at 2 lpm) increases both the overall heat transfer coefficient (9.17%, favorable result) and pressure drop (13.1%, unfavorable result). As a result, the use of nanofluids, especially in high concentrations, increases both effectiveness factors (5.95% in volume flow rate of 2 lpm, and 0.8% in 6 lpm) and the efficiency of the heat exchanger (3.84% at the least flow rate of 2 lpm). Also, it was found by the Taguchi method that the decrease in nanofluid flow rate is more effective than nanofluid concentration to reach the optimal conditions. Under optimal conditions (2 lpm and 0.145 wt.%), the total heat transfer coefficient of 1262 W/m^2.K and pressure drop of 0.148 kPa, the effectiveness and efficiency were found to be 89% and 1.244, respectively.

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