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Boiling Heat Transfer Coefficient of Hybrid Nanofluids with and without Surfactant

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ABSTRACT

Experiments were carried out to investigate the effect of surfactants on the boiling heat transfer coefficient of hybrid water-based nanofluids. In the present work, both Al_2O_3-SiO_2 and Al_2O_3-TiO_2 hybrid nanofluids were prepared with a 75:25 composition ratio and concentration of 0.01 v/v%, mixed with SDS surfactant of 40 ppm and prepared using ultrasonic process. It was found that Al_2O_3-SiO_2 and Al_2O_3-TiO_2 hybrid nanofluid enhance BHTC performance compared with distilled water, however, its performance will deteriorate gradually after 5 minutes of the experiment. Additional SDS in both Al_2O_3-SiO_2-SDS/Water and Al_2O_3-TiO_2-SDS/Water hybrid nanofluid will increase its BHTC performances up to 112.27% and 127.03% respectively compared with distilled water. Al_2O_3-SDS has better BHTC performance compared with Al_2O_3-SiO_2 and Al_2O_3-TiO_2 hybrid nanofluid which is 327.15% compared with distilled water.

1. Introduction

There is a variety of techniques that can be used in the boiling process such as pool boiling, pool boiling, macro/mini/micro-channel flow boiling, jet-impingement and spray. This method also can be hybrid by combining more than one of these methods. However, pool boiling is the most popular in the industry because it is the simplest and most cost-effective method compared with other techniques.

Nucleate boiling is where the bubble starts to nucleate, grow and leave along with the surface heater [1]. At this phase, the nanoparticle is deposited on the heated surface to change the surface properties such as wettability, roughness and capillarity [2-9]. These changes may cause the heat transfer coefficient enhanced or deteriorated depending on the applications and method used [10].

The presence of surfactant is to reduce the surface tension of the water but does not affect its physical properties when a small concentration is applied. If the concentration of the surfactant

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increase, it will affect the dynamic surface tension concentration-induced Marangoni flow [11]. It also reduces the agglomeration of nanoparticles and improves the consistency of nanoparticle distribution in nanofluids. Most of the researchers proved that anionic surfactant has better enhancement boiling heat transfer performances in nanofluids [12-18].

The nanofluid application can save more energy and reduce the emissions in industrial cooling. The replacement of cooling and heating fluid with nanofluid could save about 10-30 trillion Btu of energy per year in the U.S electric power industry [19]. They reported that the reduction of emissions is approximately 5.6 million, 8600, and 21000 metric tons of carbon dioxide, nitrogen oxide and sulphur dioxide, respectively.

This study is to investigate the boiling heat transfer performances of Al_2O_3-SiO_2/Water and Al_2O_3-TiO_2/Water hybrid nanofluids with and without sodium dodecyl sulphate (SDS).

2. Methodology

2.1 Preparation of Nanofluids

The nanoparticle manufactured by Aerosil Corporation is:

i. Aeroxide Alu C (Aluminium Oxide, Al_2O_3) particles with d_p of 13 nm
ii. Aerosil 90 (Silicon Dioxide, SiO_2) particles with d_p of 20 nm
iii. Aeroxide TiO_2 P 25 (Titanium Dioxide, TiO_2), were used to prepare hybrid nanofluids with the 2-step method.

The nanoparticle particle was mixed with a ratio of 75:25 to produce hybrid nanofluids with a concentration of 0.01 vol.%. Sodium dodecyl sulphate (SDS) will be used as the surfactant with a concentration of 40 ppm. The nanoparticle will be weight-based in Table 1. Then the mixture was added with 75 ml distilled water as a based fluid. Then the sample will be dispersed with ultrasonic (Branson, CPXH Ultrasonic Bath with capacity of 1.8 litres and 40 kHz frequency) for two hours.

Table 1
Experimental matrix of boiling heat transfer experiment with 0.01 v/v% hybrid nanofluid with SDS and 1.5 ml-based fluid

Mixture	SDS concentration (ppm)	Ratio of hybrid nanofluid	Mass of Al_2O_3 (g)	Mass of SiO_2 (g)	Mass of TiO_2 (g)	Mass of SDS (g)
Distilled Water	0	0	0	0	0	0
Al_2O_3-SDS	40	0	0.4444	0	0	0.06
Al_2O_3-SiO_2	0	75:25	0.4444	0.0994	0	0
Al_2O_3-SiO_2-SDS	40	75:25	0.4444	0.0994	0	0.06
Al_2O_3-TiO_2	0	75:25	0.4444	0	0.1586	0
Al_2O_3-TiO_2-SDS	40	75:25	0.4444	0	0.1586	0.06

2.2 Experiments Apparatus

There are six main components which are the ultrasonic bath, digital weight scale, boiling vessel, condenser, copper block and power regulator that will be used in this experimental study.

The model ultrasonic bath used in this experimental study is Branson, CPXH Ultrasonic Bath as shown in Figure 1. The capacity of this ultrasonic is 1.8 litres with a frequency of 40 kHz. This ultrasonic bath will be used to disperse the nanoparticle. This will improve the stability of the hybrid nanofluid. The nanoparticle will weigh on the digital weight scale. This scale is in unit gram with 4 decimal places. This is to improve the accuracy concentration of the nanofluid in the experiment. The boiling vessel was made from stainless steel with a thickness of 3 mm and an outer diameter of 145 mm of inner cylindrical diameter and the height of the vessel was 185 mm. The outer vessel was wrapped using aluminium foil to reduce the heat loss during the experiment. At the bottom of the cylindrical vessel, a heating component was mounted concentrically.

Next, the copper block will be used as the heating element in this experiment. The bottom of the block consists of five holes that will be inserted with heating element-powered electricity. An additional immersion heater with 1 kW was attached to the top cover and located concentrically at the centre of the lower part of the vessel. The immersion heater is used to maintain the bulk liquid temperature in the vessel at the saturation condition. A Reflux condenser was equipped on the top cover to prevent the vapour from the test vessel and it cooled with tap water circulation. The pressure inside the vessel was assumed to equal the atmospheric pressure as the top condenser was open to the atmosphere. A Reflux condenser was equipped on the top cover to prevent the vapour from the test vessel and it cooled with tap water circulation. The pressure inside the vessel was assumed to equal the atmospheric pressure as the top condenser was open to the atmosphere.

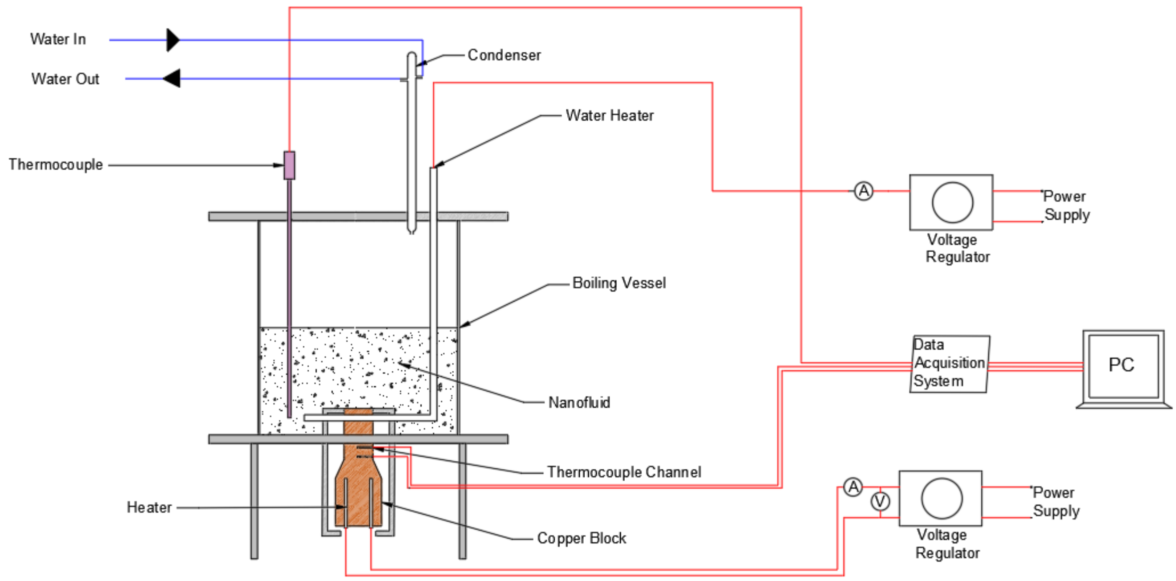

Fig. 1. Experiment schematic diagram

2.3 Experiment Procedure

The heated surface was polished by using metal polishing past and Acetone to remove oxidation and other material on the surface. Then the experiment device and apparatus were set up based on.

After that, 1425 ml of distilled water were poured into the vessel and the vessel was closed using a Polycarbonate sheet cover attached on the top and degas and boiled by using an immersion heater. A Reflux condenser was used to keep the water in saturated condition and avoid evaporated vapour during the experiment. The degassing process was set to be 20 minutes for each experimental work and the voltage output from the variable transformer for the immersion heater was reduced to the appropriate level enough to keep the water at the saturated condition. At the same time, another power regulator was switched on and regulated to 600 kW or 1.14 A to copper block.

The temperature in the copper block and fluids were measured and monitored by using a temperature module data logger from National Instrument and DASY LAB software, respectively. Then, these temperatures were used to calculate the value of wall superheat ΔT_w. The experiment was ready for the next step after the ΔT_W in steady-state conditions.

Separately, the prepared mixture of hybrid nanofluids was heated in a test tube in boiling water which was approximately 100 °C. This is to ensure that the temperature of the nanofluid did not affect the saturated temperature of the distilled water in the vessel. Then, this mixture was poured into the boiling vessel once the ΔT_w was in steady-state conditions. The experiments were run for one hour and temperatures were recorded every second. Then time variation of wall superheat, ΔT_w was analysed.

3. Results and Discussion

3.1 Time Variation of Wall Superheat

Figure 2 shows the graph of the time variation of wall superheat (ΔT_w) after being injected with distilled water, 40 ppm of SDS and 0.01 v/v% Al_2O_3-SiO_2 and Al_2O_3-TiO_2 hybrid nanofluid. The T_w is in steady-state condition before the mixture is injected. The additional 75ml of distilled water did not affect the ΔT_w since there were no significant changes observed in one hour.

Both Al_2O_3-SiO_2/Water and Al_2O_3-TiO_2/Water hybrid nanofluid will cause the sharp reduction of ΔT_w which is approximately 2 K after being injected into the boiling vessel. However, the ΔT_w value starts to increase gradually after four minutes of the experiment and keeps increasing even after sixty minutes experiment. The increment of ΔT_w value, when injected with Al_2O_3-TiO_2/Water hybrid nanofluid, is higher compared with Al_2O_3-SiO_2 hybrid nanofluid. As shown in the graph, the value of ΔT_w after sixty minutes injected with Al_2O_3-TiO_2 is approximate with the value at t = 0 s. While after being injected with Al_2O_3-SiO_2 hybrid nanofluid, the ΔT_w is increased monotonically.

The reduction of ΔT_w value after 40 ppm SDS is injected into the boiling vessel is higher compared with both hybrid nanofluids. The value ΔT_w plunged 4 K after being injected into the boiling vessel. Then, the value of ΔT_w continued to reduce monotonically in sixty minutes of experiments.

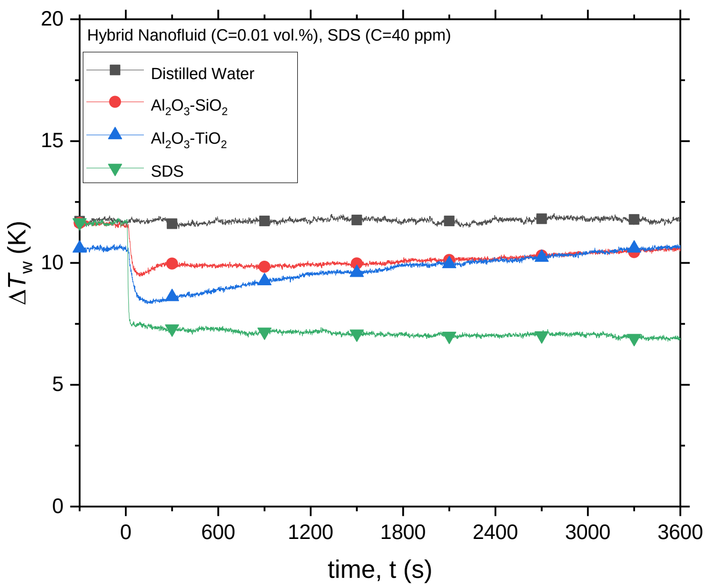

Fig. 1. Time variation of wall superheat after adding 75:25 ratio of 0.01 v/v% hybrid nanofluid and 40 ppm SDS

Figure 3 shows the graph of the effect additional 40 ppm SDS in Al_2O_3-SiO_2 hybrid nanofluid boiling heat transfer. As can be seen in the graph, the additional SDS in Al_2O_3-SiO_2/Water hybrid nanofluid will improve the boiling heat transfer up to four times compared to without SDS in the mixture. The first five minutes after injecting Al_2O_3-SiO_2/Water hybrid nanofluid into the boiling vessel, the ΔT_w dropped drastically before it bounced until 5 K. Then it increased gradually before it achieved steady-state conditions.

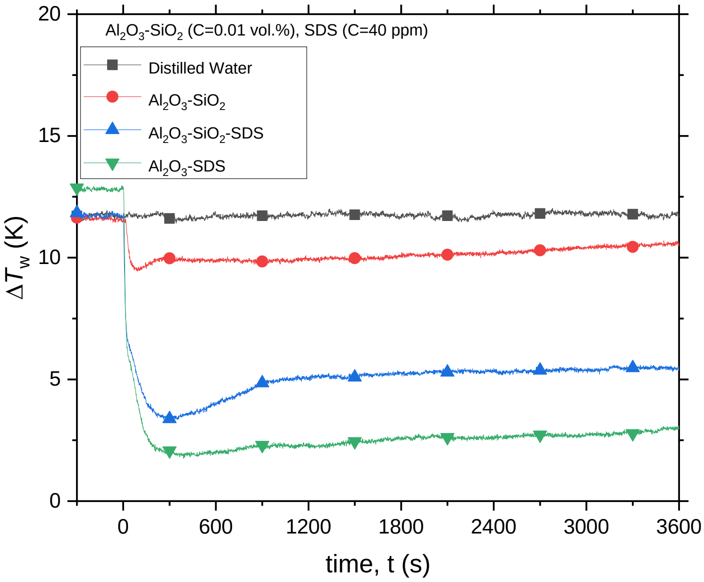

Fig. 3. Time variation of wall superheat after adding 75:25 ratio of Al_2O_3-SiO_2/Water hybrid nanofluid with 40 ppm SDS

The effect of SDS in Al_2O_3-TiO_2/Water hybrid nanofluid boiling heat transfer as shown in Figure 4 is almost similar in Al_2O_3-SiO_2/Water hybrid nanofluid. The ΔT_w value drops immediately after being injected with Al_2O_3-TiO_2/Water hybrid nanofluid and SDS in the first five minutes. Then the value of ΔT_w bounces back rapidly to 5 K. However, this increment process is slow compared with Al_2O_3-SiO_2-SDS/Water hybrid nanofluid. The ΔT_w keeps increasing monotonically until it achieves a steady-state condition at t = 2500 s.

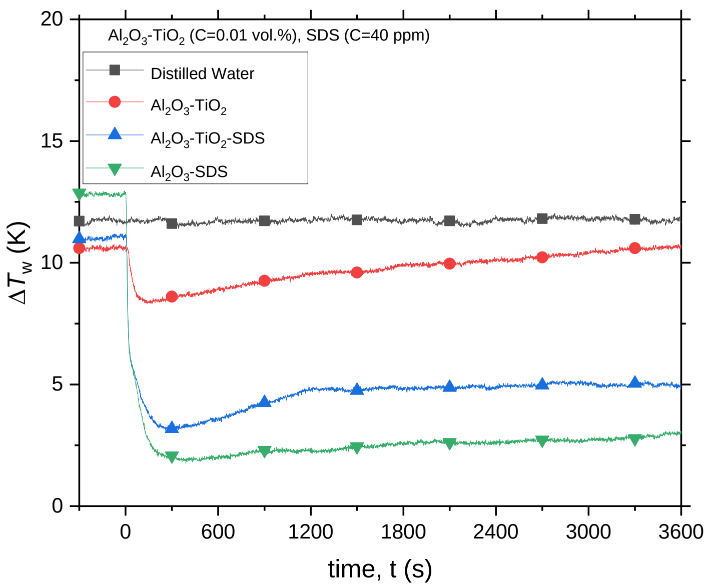

Fig. 4. Time variation of wall superheat after adding 75:25 ratio of Al_2O_3-TiO_2/Water hybrid nanofluid with 40 ppm SDS

However, the reduction of ΔT_w for both hybrid nanofluids is lower compared with Al_2O_3-SDS/Water nanofluid. The reduction value of ΔT_w after being injected with Al_2O_3-SDS/Water nanofluid is approximately 11 K. Then, the value of ΔT_w starts to increase after two minutes of experiments. This shows that Al_2O_3-SDS/Water nanofluid has better boiling heat transfer which is up to 1,8 and 3.5 times compared with hybrid nanofluid with and without SDS, respectively.

3.2 Heat Transfer Coefficient Performances

The heat transfer coefficient (HTC) in the pool boiling experiment was calculated by using an equation.

Figure 5 shows the graph performance of HTC of hybrid nanofluid and SDS in a minute experiment. The graph shows that both hybrid nanofluids will enhance HTC after being injected into a boiling vessel compared with distilled water. However, its performance gradually deteriorated during the experiment conducted. After sixty minutes, the enhancement HTC of Al_2O_3-SiO_2/Water and Al_2O_3-TiO_2/Water hybrid nanofluid compared with distilled water is 9.44% and 0.19%, respectively. This shows that the Al_2O_3-SiO_2 hybrid nanofluid has better HTC performance compared with the Al_2O_3-TiO_2 /Water hybrid nanofluid after 60 minutes of the experiment. However, 40 ppm of SDS has better performance in HTC compared with both hybrid nanofluids. It can increase the HTC up to 71.99 % compared with distilled after sixty minutes of the experiment.

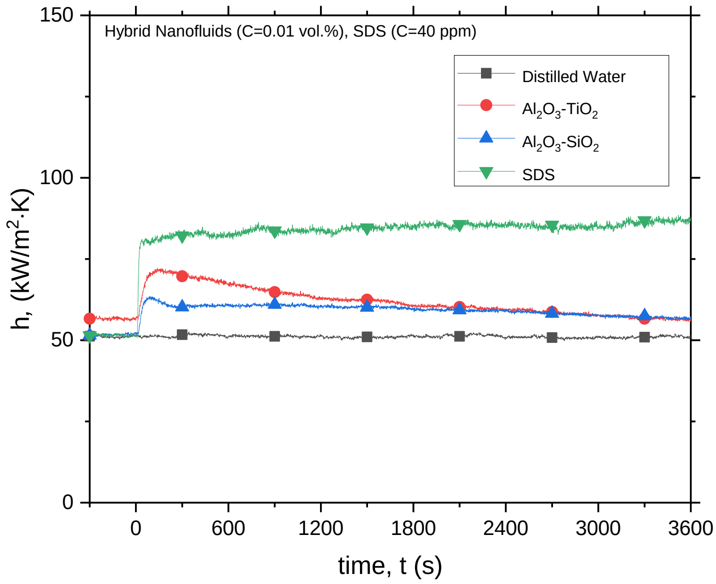

Fig. 5. Performance of heat transfer coefficient after adding hybrid nanofluid

Figure 6 shows the graph performance of HTC after being injected with Al_2O_3-SiO_2-SDS hybrid nanofluid. The addition of 40 ppm SDS in Al_2O_3-SiO_2-SDS/Water hybrid nanofluid will increase up to 250% of HTC performance compared with distilled water.

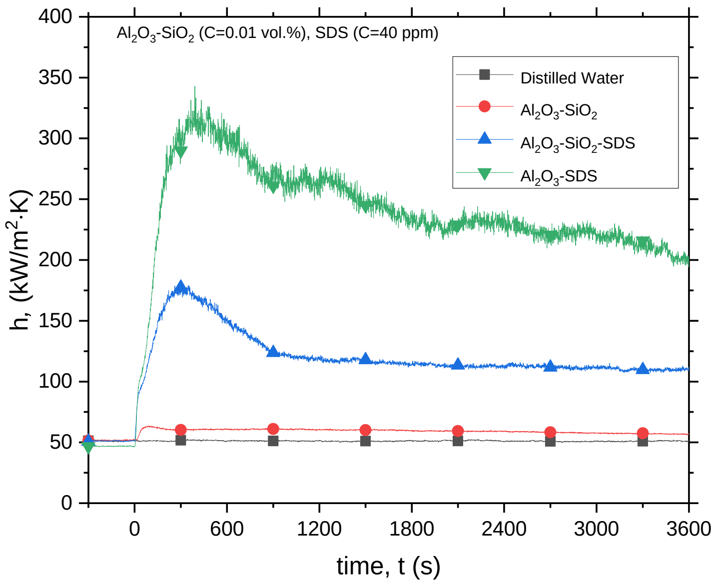

Fig. 6. Performance of heat transfer coefficient after adding with Al_2O_3-SiO_2-SDS/Water hybrid nanofluid

While additional 40 ppm SDS in Al_2O_3-TiO_2-SDS/Water hybrid nanofluid will enhance up to 253% of HTC performance compared with distilled water as shown in Figure 7. However, the performance for both hybrid nanofluids will deteriorate after 5 minutes of the experiment. The enhancement of Al_2O_3-SiO_2-SDS/Water and Al_2O_3-TiO_2-SDS/Water hybrid nanofluid after sixty minutes of experiments is 112.27% and 127.03% compared with distilled water.

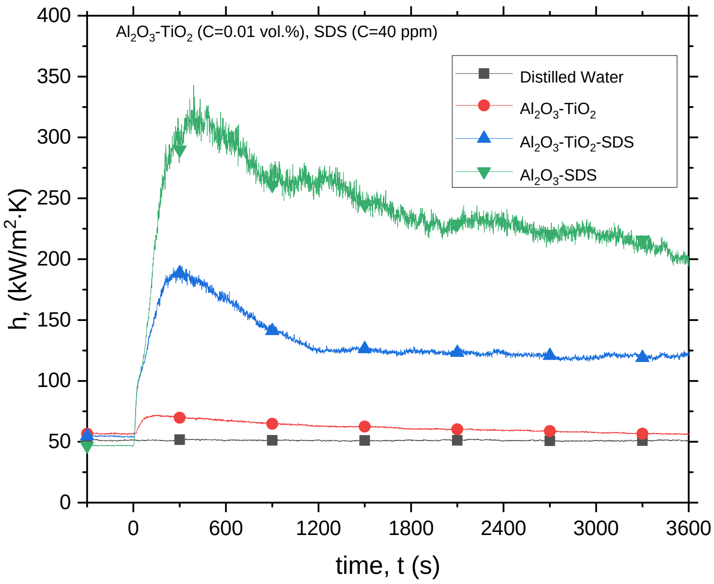

Fig. 7. Performance of heat transfer coefficient after adding with Al_2O_3-TiO_2-SDS/Water hybrid nanofluid

The HTC of Al_2O_3-SDS is highest compared with both hybrid nanofluids (Figure 8). It can enhance up to 580% of HTC compared with distilled water. Al_2O_3-SDS/Water nanofluid also shows the same behaviour as hybrid nanofluid with and without SDS/Water and its HTC performance will deteriorate after 5 minutes of experiments. The enhancement of Al_2O_3-SDS/Water nanofluid after sixty minutes of the experiment is 327.15% compared with distilled water.

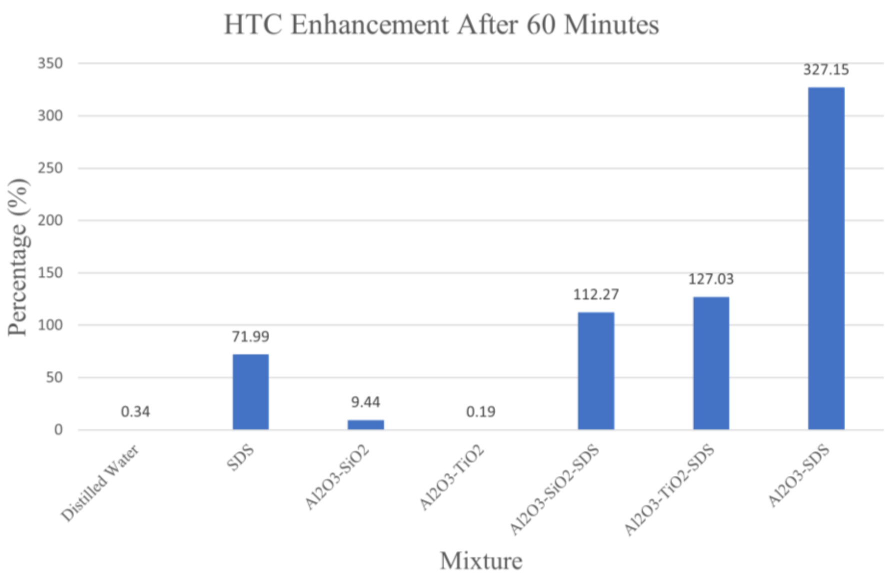

Fig. 8. Percentage of enhancement boiling heat transfer performance of various mixtures after 60 minutes of experiments

The result obtains shows that both Al_2O_3-SiO_2/Water and Al_2O_3-TiO_2/Water hybrid nanofluid with a ratio of 75:25 and concentration of 0.01 v/v% will enhance boiling heat transfer. However, its performance will gradually deteriorate with respect to time. This behaviour of hybrid nanofluid was also reported in the previous study by Aizzat *et al.,* [20]. The changes of ΔT_w in boiling heat transfer may be because of the deposition of nanoparticles on the heater surface. This active nucleation site will enhance boiling heat transfer [9,21].

An additional 40 ppm SDS will increase its HTC performance. The presence of SDS in hybrid nanofluid will reduce surface tension in the mixture. This will reduce the bubble departure diameter and promote the separation frequency of bubbles from the heater surface. Thus, this will increase the number of nucleation sites in boiling heat transfer and increase its HTC performance [22,23].

The deterioration of HTC performance to time in Al_2O_3-SiO_2/Water and Al_2O_3-TiO_2/Water hybrid nanofluid may be because of the increased nanoparticle deposition on the heater surface. In addition, SiO_2 and TiO_2 nanoparticles have low thermal conductivity compared with Al_2O_3. Low thermal conductivity will increase bubble nucleation duration on the heater surface. The increase of the deposition layer with SiO_2 and TiO_2 nanoparticles on the heater surface will increase its thermal resistance and reduce the performance of HTC [24,25].

4. Conclusions

The experiment was conducted to investigate the boiling heat transfer coefficient (BHTC) of Al_2O_3-SiO_2/Water and Al_2O_3-TiO_2/Water hybrid nanofluid with a ratio of 75:25 and 0.025 v/v% concentration. The effect of SDS in hybrid nanofluids also was investigated in these experiments. The main conclusions of this work were summarised as follows:

i. Al_2O_3-SiO_2/Water and Al_2O_3-TiO_2/Water hybrid nanofluid will enhance its BHTC performance compared with distilled water. This can be observed when the value of T_w drops drastically for the first 5 minutes experiment, then its performance starts to deteriorate gradually.
ii. Additional SDS will increase its HTC performances up to 112.27% and 127.03% for both Al_2O_3-SiO_2/Water and Al_2O_3-TiO_2/Water hybrid nanofluid respectively. However, Al_2O_3-SDS/Water has better BHTC performance compared with Al_2O_3-SiO_2/Water and Al_2O_3-TiO_2/Water hybrid nanofluid. Its enhancement is up to 327.15% compared with BHTC distilled water. This may be because SiO_2 and TiO_2 nanoparticles are insulators that have low thermal conductivity. The deposition of this nanoparticle showed a deterioration of its HTC performance.

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