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# Quasi steady state of nucleate boiling heat transfer in low concentration of single and hybrid $Al_2O_3$-$SiO_2$ water-based nanofluids

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**Abstract.** Experiment were carried out to clarify the steady state condition of heat transfer coefficient (HTC) for single and hybrid $Al_2O_3$-$SiO_2$ water-based nanofluids in low concentration of nucleate pool boiling. $Al_2O_3$ and $SiO_2$ were chosen and ultra-sonification for 1 hour after being diluted in distilled water. The total of 0.001 vol.% concentration was divided into composition ratio of 0:100, 25:72, 50:50, 75:25, 100:0 for hybrid nanofluids. Successively, all the HTC values were collected through experimental works. In the present work, it was found that the steady stated for single and hybrid nanofluids were achieved except for single $SiO_2$ nanofluid where even after 5 hours, the value of its $\Delta T_W$ keep on decreasing. The nanoparticles deposited on the surface heater were suspected as the main factor for the current experimental results.

**Keywords.** Nucleate pool boiling; Nanofluids; Hybrid nanofluids; Mixing ratio; Steady state condition; Surface heater condition.

## 1. Introduction

Nanofluids is the familiar parameter for the enhancement of heat/cooling transfer ability in current era involving big heavy industries such as boiler, chiller, cooler and many more. Effected from this, various of study were conducted to accurately identify the types of nanofluids and their ability to transfer heat [1]–[4]. Heat Transfer Coefficient (HTC) and Critical Heat Flux (CHF) are the two main important parameters on controlling the heat transfer in the system.

As reported by Zuhairi M. Sulaiman [5] in nucleate pool boiling study, the HTC was enhanced for $Al_2O_3$ but deteriorated for $SiO_2$ respect to 1 hour time. In connection with that, the study of HTC for single and hybrid $Al_2O_3$ and $SiO_2$ water based was done by M A H Aizzat [6] identified that in 1 hour time, the HTC for hybrid nanofluid $Al_2O_3$ and $SiO_2$ water-based was enhanced for first 30 minutes and then deteriorated slowly respect to time depends on the volume ratio of nanoparticles. For higher volume of $Al_2O_3$ nanoparticle, the value of $\Delta T_W$ is lower than reference line ($\Delta T_W$ distilled water) while for higher volume of $SiO_2$ nanoparticle, the value of $\Delta T_W$ is located on top of reference line.

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Study by Yagnem et al [7], the enhancement of hybrid $Al_2O_3$/CuO nanofluids was 7.1% in 1 hour time and identified the main factor was nanoparticle deposition on the heater surface[8]–[10].

As previously reported by several researcher on HTC deterioration and enhancement of nanofluids, there are no further explanation on the ability of nanofluid to maintain the value of HTC respect to time in order to achieve the steady state condition. In conjunction of this, the present work will be focus on the steady state of $\Delta T_W$ for single and hybrid nanofluid.

In this study, an experimental investigation was performed in nucleate pool boiling of water-based single and hybrid nanofluids. Thus, the paper aim to identify the steady state of single and hybrid nanofluids in nucleate pool boiling study respect to time and seeking for mechanism that responsible on the steady state factor of the nucleate pool boiling experiment.

## 2. Experimental methods

### *2.1. Preparation of nanofluids*

For this study, Aeroxide Alu C ($Al_2O_3$ (Alumina)) and Aerosil 90 ($SiO_2$ (Silica)) were selected. These two nanoparticles were white in colour, sized range between 10 nm - 20 nm and fully mass-produced by Aerosil Corporation. For the first step, these nanoparticles were diluted into distilled water as described in table 1 for single nanofluids and table 2 for hybrid nanofluids with various of volume ratio. Next, weight scale (Sartorius Practum213-1S) were used to weight the mass volume of nanoparticles and mixed directly with 75 ml of distilled water in a 100ml test tube. Vigorously shook the test tube to make sure the nanoparticles dispersed in the distilled water. Then, the test tube was put into the ultrasonic bath (CPX2800H, Branson) and perform 1 hour of ultrasonic excitation to get stable dispersion of nanoparticles [11].

**Table 1.** Volume % for single nanofluids.

| Nanoparticle | Volume % | Type |
|---|---|---|
| $Al_2O_3$ | 0.00025 vol.% | A25 |
| $Al_2O_3$ | 0.0005 vol.% | A50 |
| $Al_2O_3$ | 0.00075 vol.% | A75 |
| $Al_2O_3$ | 0.001 vol.% | A100 |
| $SiO_2$ | 0.00025 vol.% | S25 |
| $SiO_2$ | 0.0005 vol.% | S50 |
| $SiO_2$ | 0.00075 vol.% | S75 |
| $SiO_2$ | 0.001 vol.% | S100 |

**Table 2.** Volume % for hybrid nanofluids.

| Nanoparticle | Volume % | Type |
|---|---|---|
| $Al_2O_3 + SiO_2$ | 0.001 vol.%: 0 vol.% | 100S0 |
| $Al_2O_3 + SiO_2$ | 0.00075 vol.%: 0.00025 vol.% | A75S25 |
| $Al_2O_3 + SiO_2$ | 0.0005 vol.%: 0.0005 vol.% | A50S50 |
| $Al_2O_3 + SiO_2$ | 0.00025 vol.%: 0.00075 vol.% | A25S75 |
| $Al_2O_3 + SiO_2$ | 0 vol.%: 0.001 vol.% | A0S75 |

*2.2. Experimental apparatus*

In the present work, an experimental setup was fabricated, followed the requirement to succeed the nucleate pool boiling experiments. The setup consisted of stainless-steel cylindrical vessel, clear polycarbonate plate, cartridge heater attached inside solid modified copper block, four thermocouples, immersion heater, modified PTFE block and ceramic fiber insulation blanket. All these apparatuses were shown in the schematic diagram in figure 1. The stainless-steel vessel with 3 mm thickness has outer diameter of 145 mm and height of 185 mm, act as the main body of the experimental setup. The ceramic fiber insulation blanket covered all the vessel body to reduce the heat loss to the ambient atmosphere. Below part of the vessel is where the heating component was mounted concentrically. The copper block was modified where one of its ends shaped cylindrically and has 20 mm diameter. This part of copper block will act as surface heater and has direct contact with the fluid in the main vessel body. It has 3 holes at the central axis line starting from heater surface to bottom. The main reason for the existing holes is to insert three type-K thermocouples to measure heat flux, $q_w$ and wall temperature, $\Delta T_W$ of distilled water inside the main vessel. Then, the copper block was inserted into modified PTFE block where it holds the copper block from dislocate from its original position while run the experiment. The PTFE blocks were mounted permanently to the bottom part of the main vessel. Using the uncertainty analysis method described by Cooke et al. [12], the measurement uncertainties of $q_w$ and $\Delta T_W$ were estimated within less than 84 kW/m$^2$ and 2.4 K, respectively. 1kW immersion heater was attached to the polycarbonate plate where the plate was located on top of the main vessel and act as the top cover of the experimental setup. The immersion heater was inserted into the main vessel and submerge below the distilled water surface. It was used to maintain the bulk temperature in the vessel at the saturation temperature. On top of the cover, the Reflux condenser was equipped on the top cover to make sure the vapour was released and at the same time the volume of distilled water inside the main vessel maintain its volume. The last type-K thermocouple was attached to the top cover and its pointy end was submerge into the distilled water. This thermocouple was set to measure the distilled water temperature in main vessel. On the other side of top cover, drilled a hole with 5 mm diameter where it will be the path for nanofluids injection using syringe. The hole was closed with rubber plug if there were no nanofluids injections.

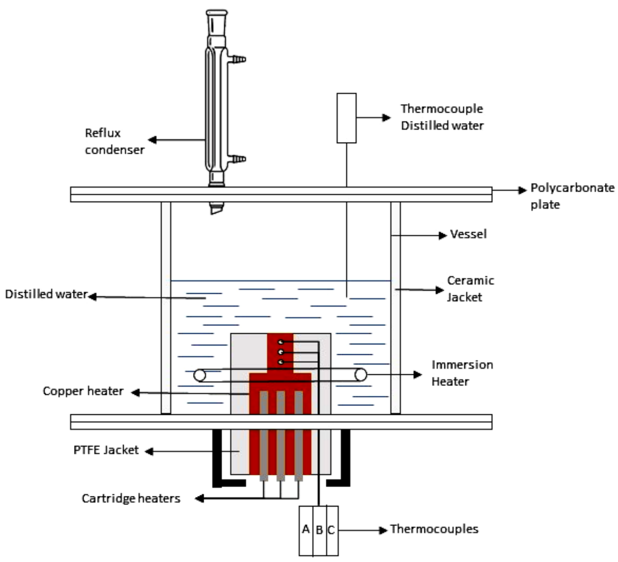


**Figure 1.** Schematic diagram of experimental setup.

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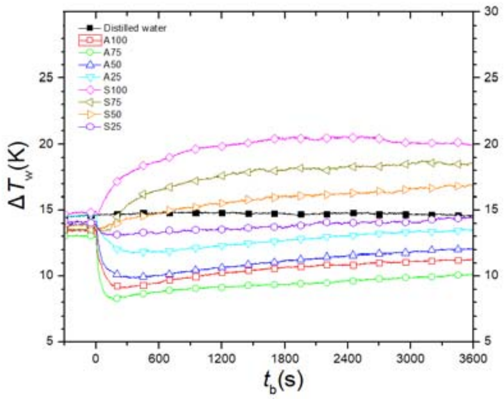
*2.3. Experimental procedure*

The experiment started with polishing the heater surface. Using metal polishing paste and Kim Wipes tissue, polished the heater surface and make sure that the surface was smooth and has no scratch on it. Then clean the surface using the acetone to remove the unnecessary excess which stick on the surface. Next, insert the copper heater into the PTFE jacket block and mount it at the bottom part of the main vessel. 4 cartridge heaters were insert inside the heater copper block and was regulated to supply a 600 kW/m2 of heat flux. After that, poured 1425ml of degassing distilled water inside the main vessel and closed it using polycarbonate top cover. The immersion heater, which already submerged inside the distilled water supplied continuous heat to make sure that there was no heat loss and the temperature inside the main vessel maintain saturated. In the experimental stage, a temperature module datalogger from National Instrument and DASY Lab were used to measure the surface heater and fluids temperature. The collected data were used to calculate the value of wall superheat, $\Delta T_W$. Then, the scattering value of $\Delta T_W$ were observed in the experimental run was about less than 0.3 degrees C for the approximate duration of 10 minutes. The experiment was ready for next step after the copper heater achieved the steady state. For the experiment, the acceptable mean $\Delta T_W$ was in range of $14 \pm 1$ $^OK$ and at this state, the nanofluid injection was conducted. This step was important in this experiment because it reduced the influence of the scattering of the initial wall superheat. In the same time, the test tube contain nanofluids were heated separately. This step was to make sure that the saturated temperature of the distilled water in the vessel did not affected by the temperature of nanofluids. Measured temperature of nanofluids using multi-meter (Fluke True-rms Clamp Meter 324) and wait until it reached 95$^o$C. Once reached, the nanofluids were injected into the main vessel through the small hole at the top cover. The experiment was run for 5 hours, and temperatures were recorded for every second and the time variation of wall superheat, was analysed.

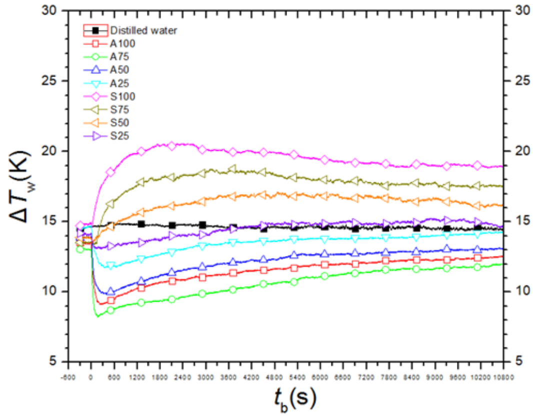
## 3. Results and discussion

*3.1. Steady state conditions for single nanofluid of 1 hour, 3 hours and 5 hours.*

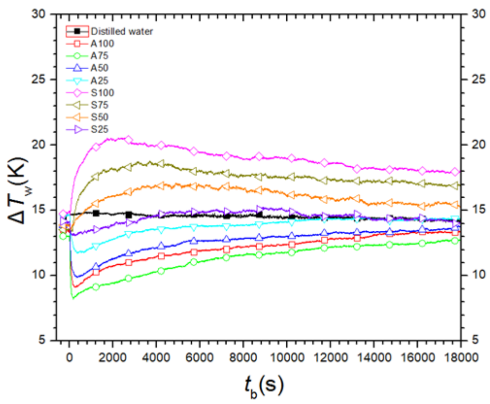
Figure 2 showed the time variation of wall super heat, $\Delta T_W$ for $Al_2O_3$/water and $SiO_2$/water. These two nanofluids were categorized in few levels of concentration between 0.000025 and 0.001 volume %. They were termed as A25, A50, A100, S25, S50 and S100 as coded by M A H Aizzat et al [6] in the previous study. The detail of the ratio can be referred in the previous section (see table 1). The time duration after the injection of nanofluids into the vessel were labelled as boiling time $t_b$ with 3 durations time of 1 hour, 3 hours and 5 hours present experimental setup. The first experiment was on the distilled water where same methods were used for nanofluids. After the steady state achieved, 75ml of distilled water from the heated test tube were injected into the main vessel. Resulted from this, the $\Delta T_w$ of distilled water were set as a reference line for next nanofluids experiments. Contradict to $\Delta T_w$ of distilled water, the $\Delta T_w$ for nanofluids experiments were drastically change after the presences of nanofluids as shown in figure 2.




(a) $\Delta T_W$ for single nanofluids ($Al_2O_3$ and $SiO_2$-$H_2O$) 1-hour time




(b) $\Delta T_W$ for single nanofluids ($Al_2O_3$ and $SiO_2$-$H_2O$) 3-hour time




(c) $\Delta T_W$ for single nanofluids ($Al_2O_3$ and $SiO_2$-$H_2O$) 5-hour time

**Figure 2.** Time variation of wall superheat after adding single nanofluids ($q_w$ = 600 kW/m$^2$).

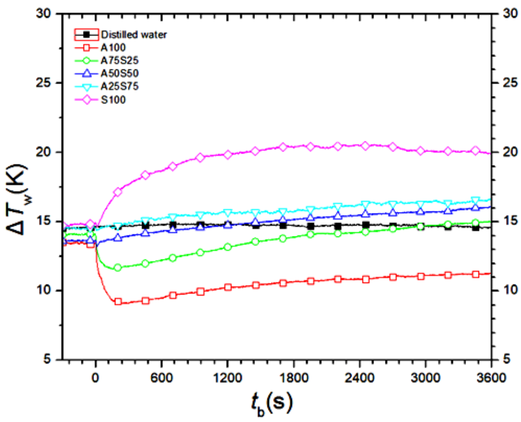
After the injection of $Al_2O_3$/water and $SiO_2$/water nanofluids into the main vessel, the results for time variation of wall superheat were plotted in figure 2(a). The time taken for the single experiments was 1 hour. As clearly to be seen, the $\Delta T_w$ for $Al_2O_3$/water was instantaneously and sharply reduced after the nanofluids injections for all low-level concentration. A100, A75 and A50 showed the similar pattern where at the early stage, there were sharp reduction of $\Delta T_w$ value. After 10 minutes of experiment, the trends slowly increased respect to time. As for A25 which the lowest concentration of $Al_2O_3$/water is, the $\Delta T_w$ slowly reduced but still not as much as other higher concentrations. However, after 1 hour of experiment, the values for A100, A75, A50 and A25 increased nearly same to the reference line. Differently for $SiO_2$/water where after the nanofluids injection, the $\Delta T_w$ increased as the concentration were increasing, located higher that the reference line as shown in the figure 2(a). Coded as S25, S50, S75 and S100, addition of $SiO_2$/water increased the value of $\Delta T_w$ depends on the concentration. It has same patterns to all reaction for $SiO_2$ nanofluids where if the concentration is increasing then the $\Delta T_w$ also increasing. S100 which was the highest concentration for single SiO2 experiment, the value increased monastically after the injection of nanofluids and maintain in the range of +/-120 $^oC$. After 30 minutes, it can be said it achieved the steady state condition where there were no changes of the value for $\Delta T_w$. For S50 and S75, the plotted graph showed same as S100 where slowly increase respect to time and located higher than reference line. However, differently for S25 where after the injection of lowest concentration for $SiO_2$ nanofluids, the values of $\Delta T_w$ were lower than reference line. However, it slowly increased respect to time. Nearly 1 hour of experiment, the line for S25 clearly approaching the reference line. The experiment was let to run until 3 hours and the results were plotted in the figure 2(b). After 3 hours of experimental works for single nanofluids, the value of $\Delta T_w$ for $Al_2O_3$/water keep on increasing and did not achieved steady state yet where all the lines slowly approaching the reference line. For the lines pattern, they still followed the same pattern from the previous 1-hour time. However, for A25, it already touched the reference line meaning the value of $\Delta T_w$ was same with the reference line hence there are no enhancement of HTC at that moment. For higher concentration than A25, the HTC was still happened during the experimental works. Differently for $SiO_2$/water cases where there were not so much changing for $SiO_2$/water. For 1-hour experimental work, the HTC since to have deterioration and the value for $\Delta T_w$ as much as +/-120 $^oC$. However, after 1.5 hours, the value for $\Delta T_w$ seems decrease for all the line plotted in figure 2(b). From 1.5 hours to 3 hours, the $SiO_2$/water did not achieve steady state condition yet where the value for $\Delta T_w$ have a little different from previous values. For S100, S75 and S50, the plotted lines in the graph had the same line patterns. Interestingly for S25, for the early experimental stage, the line located below the reference line and after 1.5 hours, it slowly increased respect to time. It achieved the steady state where the value for $\Delta T_w$ did not have a lot of changes during the 3 hours' time experiment.

To understand more on the steady state of each single nanofluids, the experiments continued to run until 5 hours. After 5 hours of experiments as plotted in the figure 2(c), there were changes in the patterns for $Al_2O_3$/water where all the values for $\Delta T_w$ approached the reference line. For A25, the line was located on the reference line means the HTC at that time was neither increase nor decrease. For A50, A75 and A100, it still located below the reference line however there are not so much different in the term of value $\Delta T_w$. It can be said that the single nanofluids for $Al_2O_3$/water in this nucleate pool boiling experiments were achieved the steady state condition. For $SiO_2$/water experimental, after 4 hours, there were not so much different in value of $\Delta T_w$ and it maintained even until 5 hours of experiment. These trends were same for S25, S50, S75 and S100 therefore the steady state conditions were already achieved after 4 hours for $SiO_2$/water.

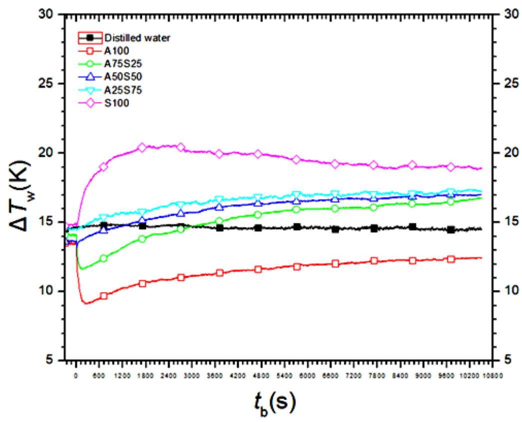
In the present study, it was obvious that the wall temperature, $\Delta T_w$ changed drastically after the present of $Al_2O_3$ and $SiO_2$ due to low concentration of nanofluids as supported by the previous study [13]–[20]. In that situation, the HTC was enhanced for $Al_2O_3$/water and deteriorated for $SiO_2$/water as shown in the figure 2, same as reported by M A H Aizzat et al [6]. It was proven that even a very low amount as much as 0.001 vol% of concentration, it did affect the HTC performance of the experiment. The experiments were proceeded until 5 hours to identify the steady state condition for the $Al_2O_3$ and $SiO_2$. The $\Delta T_w$ seems slowly changed respect to time for all ratios of nanofluids and after 3 hours, there were low changes of $\Delta T_w$ and the value remain maintained. It can be said all the nanofluids were achieved the steady state for low concentration of single nanofluids.

### *3.2. Steady state condition for 1 hour, 3 hours and 5 hours of hybrid nanofluid experiments.*

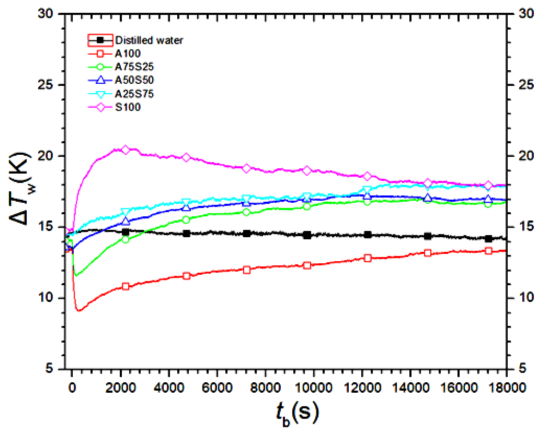
Due to contradicting results in HTC and steady state condition for single nanofluids as discussed in section 3.1, current experimental work focus on the mixing two types of nanoparticles and named hybrid nanofluids. Using certain ratio of amount as stated in table 2, mixing of $Al_2O_3$ and $SiO_2$ were diluted into 75ml of distilled water inside the test tube and were ultrasonification for 1 hour. The methods were repeated same as the single nanofluids experiment because all the hybrid nanofluids used same experimental apparatus. For the hybrid nanofluids, it should be noted that the similar trends will be obtained in the previous study by MAH Aizzat et al [6].




(a) $\Delta T_W$ for hybrid nanofluids ($Al_2O_3/SiO_2$-$H_2O$) 1-hour time




(b) $\Delta T_W$ for hybrid nanofluids ($Al_2O_3/SiO_2$-$H_2O$) 3-hour time




(c) $\Delta T_W$ for hybrid nanofluids ($Al_2O_3/SiO_2$-$H_2O$) 5-hour time

**Figure 3**. Time variation of wall superheat after adding single nanofluids ($q_w$ = 600 kW/m$^2$).

Figure 3 shows the wall super heat $\Delta T_w$ for 100% ratio of single nanofluids $Al_2O_3$/water and $SiO_2$/water. Between these two data, there were plotted data for hybrid nanofluids which use the mixing ratio as shown in the table 2; A75S25, A50S50 and A25S75. It was proven by the graph plotted in the figure 3(a) where it has the increment pattern where it followed the reaction of the proven single nanofluid experiment from the previous section. If there were more amount of $Al_2O_3$, the starting of the experiment will decrease drastically and if there were more amount of $SiO_2$, the early $\Delta T_w$ increased so much. For A75S25, the reaction was first dropped then monotonically increased, slowly respect to time. After 1 hour, the line for A75S25 situated higher than reference line and slowly approach A50S50's line. For A50S50 where the nanofluids amount half from $Al_2O_3$ and half from $SiO_2$, the $\Delta T_w$ seemed dropped a little bit at the early experiment and increased monotonically until it located higher than reference line after 1 hour. For higher amount of $SiO_2$ in hybrid nanofluids experiment, A25S75 the $\Delta T_w$ did not drop at the earlier stage but immediately increase drastically after the nanofluids injection. After 1 hour of experiment, all three hybrid nanofluids seemed did not achieved the steady stated yet where all the lines were still increase time by time. The experiments were proceeded until 5 hours. For the first 3 hours, all the hybrid nanofluids still increased however slowly time by time. All the three-line located on the reference line. By this time, the hybrid nanofluids did not achieved steady state yet where the $\Delta T_w$ seems no stable yet. However, after 4 hours, A75S25 and A50S50 approached to each other and stable at the range of 17°C. For A25S75, it situated higher than those two lines and achieved the steady state at the same time with the other 2 hybrid nanofluids. A25S75 seemed achieved steady state and had nearly same value of $\Delta T_w$ with S100 after 5 hours. Therefore, after 5 hours of experiment, it can be said that A100, A72S25, A50S50, A25S75 and S100 achieved the steady state condition. In term of HTC performance, the HTC was enhanced if there were presence of $Al_2O_3$ and deteriorated if there were presence of $SiO_2$.

There were many explanations of the peculiar trends of the $\Delta T_w$ graph line plotted in the figure 2 and 3. It was clearly to be seen where right away after the injection of the nanofluids into the main vessel, the $\Delta T_w$ firstly dropped drastically and slowly took the effect of the nanofluids, depends on the type of nanofluids or the mixed ratio of the hybrid nanofluids. The main reason for these reactions was suspected due to the nanoparticles deposited on the heater surface. This will lead to the increasing of active nucleation site on the heater surface [21]. Consequently, the enhancement of the HTC due to the condition heater surface was discussed by several researcher. According to Lin et al [22], deposited nanoparticle on the heater surface affect the bubble departure from the heater surface and increase the disturbance of the heat flow between the heater surface and the liquid inside the main vessel. This will affect the performance of the HTC. However study by Li et all [23], the increment of HTC until 19% water based nanofluids in their study revealed that the diameter of the deposited nanoparticle on the heater surface also play a big role in the nucleate pool boiling nanofluid experiment. In deterioration of HTC for $SiO_2$, Hu et al [24] discovered that the deposition of the silica nanoparticle in the heater surface was thick and once all the heater surface area covered, the thermal resistance of the silica coating in higher and immediately increase the value of $\Delta T_w$. For the steady state condition, it need 5 hours to stable due to the deposited nanoparticles on the surface heater.

## 4. Conclusions

Nucleate pool boiling studies were conducted using low concentration, 0.001 vol.% of single and hybrid nanofluids ($Al_2O_3$ and $SiO_2$) water based. The resulted conclusions were:

- For single $Al_2O_3$ experiments, the $\Delta T_w$ was lower than the reference line hence the HTC was enhanced for all results. However differently for $SiO_2$ where after the addition of the nanofluids, the $\Delta T_w$ located higher than reference line and slowly decrease respect to time. This resulted the HTC were deteriorated for all $SiO_2$ cases. The value for $\Delta T_w$ depends on the concentration of the nanoparticles.
- For hybrid experiments, $\Delta T_w$ were decrease drastically after the injection of nanofluids. Higher amount of $Al_2O_3$ in the hybrid nanofluids resulted the line plotted started from below reference line and slowly approach the reference line. However, for high volume of $SiO_2$ nanoparticles, the line started to increase until range of 120°C. Respect to time, the value of $\Delta T_w$ for $SiO_2$ slowly decreased.
- The study was let to run until 5 hours and identified that for single nanofluids, A100, A75, A50, A25, S100, S75, S50 and S25 achieved the steady state where the lines plotted in the graph were stable. For hybrid nanofluids, they also need 5 hours to achieve the stable condition. This was because due to deposition of the nanoparticle on the heater surface take place at the first place. Then, depends on the type of nanoparticles and the HTC performance were obtained. After all the deposition nanoparticles process complete, the stable lines in the graph were also obtained and shown in the figure 2 and 3.

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