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EXPERIMENTAL STUDY OF POOL BOILING OF NANO-FLUIDS

Dr. Amer Hameed Majeed [1*], Yasmin Hamed Abd [2]

1) Assistant Prof., Materials Engineering Department, Mustansiriyah University, Baghdad, Iraq.
2) Lecturer, Highway and Transportation Engineering Department, Mustansiriyah University, Baghdad, Iraq.

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Abstract: Pool boiling of Nano Al_2O_3, TiO_2, and ZrO_2 of concentrations 0.1, 0.4, 1.0, 2.5, 5.0 g/L in distilled water (which is taken as a base fluid) were experimentally studied in a test boiling chamber of stainless steel cylindrical vessel of 15 cm diameter and 30 cm length, provided with a 500 W heater. Results showed that the Nano-fluid heat transfer coefficients are higher than that for distilled water. The increments of heat transfer coefficient of Al_2O_3-H_2O Nano-fluid was more than that for TiO_2-H_2O Nano-fluid which is more than that for ZrO_2-H_2O Nano fluid. The increment beyond 1 g/L were slight for nanomaterials used.

Keywords: *boiling heat transfer, heat transfer coefficients, nanomaterials, Nano-fluids.*

دراسة تجريبية للغليان الحوضي لموائع نانوية

الخلاصة: تم اجراء دراسة تجريبية لغليان حوضي لماء مقطر يحتوي على كل من اوكسيد الالمنيوم النانوي، اوكسيد التيتانيوم النانوي، اوكسيد الزركونيوم النانوي وبتراكيز 0.1 ، 0.4 ، 1 ، 2.5 ، 5 غرام / لتر ماء . استخدمت منظومة تتكون من وعاء غليان اسطواني الشكل مصنوع من الصلب بارتفاع 30 سم وقطر 15 سم مزود بمسخن ذو قدرة 500 واط . تبين من النتائج التي تم الحصول عليها أن معاملات انتقال الحرارة للموائع النانوية تكون اكبر مما للماء النقي . حيث ان الزيادة تكون للماء الحاوي على اوكسيد الالمنيوم اكبر منها للماء الحاوي على اكسيد التيتانيوم وهذه بدورها اكبر منها للماء الحاوي على اوكسيد الزركونيوم. وقد لوحظ ايضا ان الزيادة التي طرأت على معاملات انتقال الحرارة كانت بوتيرة اقل بعد التركيز 1 غرام/لتر ولكل المواد النانوية المستعملة في البحث.

1. Introduction

Pool boiling is a form of boiling in which the fluid is constant with respect to the heating surface. Due to its effective and efficient method, boiling heat transfer have a wide range of applications, such as in oil and gas process industries, power generation, refrigeration, air conditioning, high power electronics component cooling, cooling of nuclear reactors, etc. [1].

To increase the rate of boiling heat transfer, particularly during nucleate boiling regime, additives of solid particles in form of Nano-sized to the boiling liquid is a

**Corresponding Author*: amer.h.m.altaee@gmail.com

common practice used, due to high surface area of nanoparticles and high thermal conductivity compared to base fluid. So the successful using of Nano-fluid will lead to smaller heat exchanger [2].

A Nano-fluid is a suspension with a nanosized solid particles in water or other base fluid. The nanoparticles used in Nano-fluids have an average size below 100 nm. Large surface area and high thermal conductivity of nanoparticles increases the stability of Nano-fluid and enhancing the effective thermal conductivity which increases the heat transfer rate.

However, several experimental works concerning boiling Nano-fluid, further, observations made so far to present a more knowledge, due to some controversies [3].

The results of Cieslinski and Kaczmarczyk [4] indicated that independent of nanomaterial concentration (Cu and Al_2O_3) often has no effect on boiling heat transfer coefficient on smooth copper tube, but there were lower heat transfer coefficient noticed for copper tube than for stainless steel tube for the same heat flux.

Das et.al.[5] noticed that boiling performance of 1, 2 and 4 % Al_2O_3 nanoparticle concentration in water deteriorate with increasing particle concentration. Their results showed a good agreement with Cornwell and Houston correlation [6] for determining heat transfer coefficient.

Suriyawong, and Wongwises [7] obtained higher nucleate pool boiling heat transfer coefficient at 0.0001 vol. % of TiO_2 Nano-fluid compared with the base fluid, and lower heat transfer coefficient for higher than 0.0001 vol. % . After that Suriyawong et.al. [8] gives a correlation for assessing nucleate pool boiling heat transfer coefficients of TiO_2-water Nano-fluids at several low concentrations.

Later Pal and Bhaumik [9] remarked that the heat transfer coefficient for pool boiling of TiO_2-water Nano-fluids at 0.32 – 0.72 wt. % increases with concentration of nanoparticles at high heat fluxes and develops a theoretical correlation to predict heat flux and heat transfer coefficient.

Chopkar et.al.[10] observed enhancement in heat transfer coefficient only at low concentration of ZrO_2 and find out that the rate of heat transfer drops with the increase in concentration.

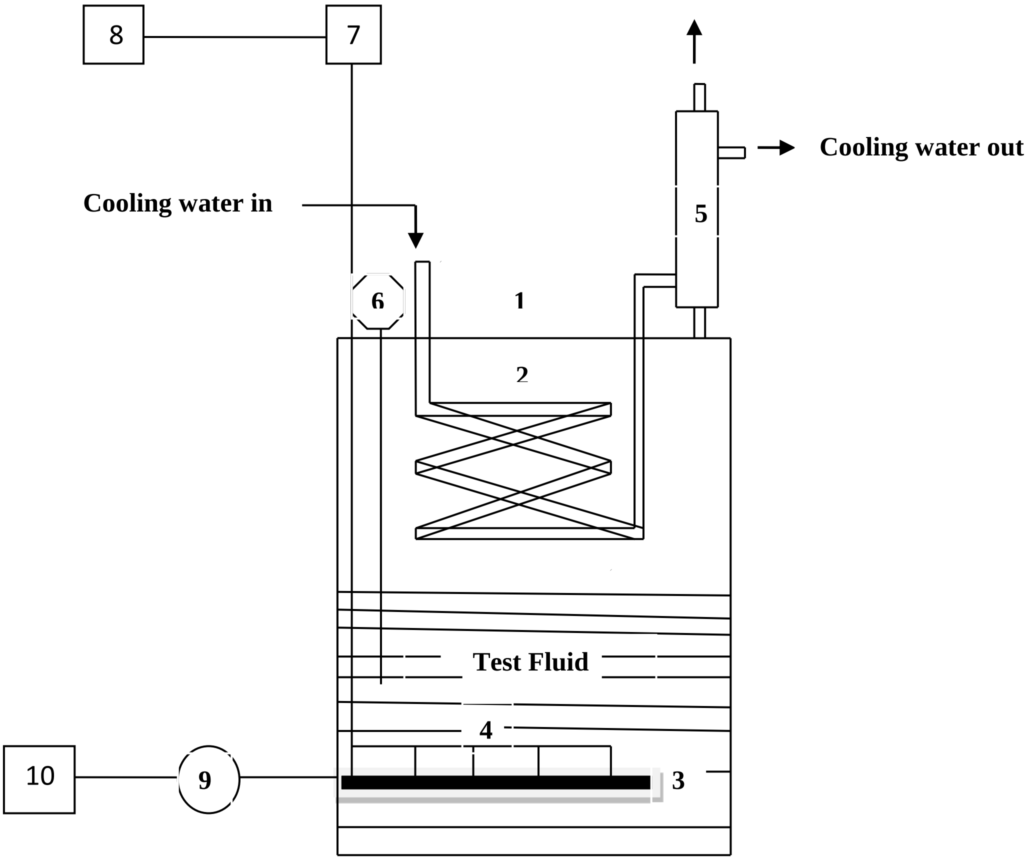
Fang et.al. [11] gives a comprehensive review included a summary tables for the experimental investigations of Nano-fluid for both flow and pool boiling heat transfer coefficient.

This wok aimed to explore the effect of addition of nanomaterials of aluminum oxide (alumina) Al_2O_3 , titanium oxide (titania) TiO_2 , and zirconium oxide (zirconia) ZrO_2 on the pool boiling heat transfer coefficients of water.

2. Experimental Work

2.1. Experimental Apparatus

The experimental apparatus is shown in Figure 1. It consist of stainless steel cylindrical vessel of 15 cm diameter and 30 cm length which represent a test pool boiling chamber (1). The test pool boiling chamber is provided with a controlled power supply 500 W heater (3) of 1 cm diameter and 12.5 cm length which is used to boil the test fluid, attached on it five thermocouples (4) of type k with additional thermocouple in the test fluid, these thermocouples are connected to temperature reader (7), then to computer (8). There was a thermometer (6) inserted into the test fluid also. The chamber also contains cooling coil (2). An exterior coil condenser (5) attached with the pool boiling chamber (1) joined with the inner cooling coil (2) to ensure no vapor escapes.



1. Test chamber 2. Cooling coil 3. Heater 4. Thermocouples 5. Condenser 6. Thermometer 7. Temperature reader 8.Computer 9. Power supply 10. Power regulator

Figure 1. Experimental apparatus

2.2. Materials and Experimentation

Aluminum oxide (Alumina) Al_2O_3, titanium oxide (titania) TiO_2, and zirconium oxide (zirconia) ZrO_2 were used in a nanoparticles as additives. Particles of less than 50 nm of Al_2O_3 , TiO_2 , and ZrO_2 were used in concentrations of 0.1, 0.4, 1.0, 2.5, 5.0 g per liter of distilled water as a base fluid (which is nearly equivalent to 0.01, 0.04, 0.1, 0.25, 0.5 wt %). The materials (Al_2O_3, TiO_2, and ZrO_2) chooses on the differences in the density and thermal conductivity. The required quantity of nanomaterial are weighed and added to a 1 L water firstly, then diluted to the required concentration. To obtain a good dispersion, the prepared suspension are stirred using magnetic stirrer. The experimental work was carried out in laboratory of chemistry, College of Engineering, Mustansiriyah University.

2.3. Calculations

The heat transfer coefficients were calculated from Newton's law of heating $q = hA\Delta T$, the heat load q were calculated using the relation $q = I \times V$, the heat flux Q which is equal to $Q = \frac{q}{A}$, was determined. Then the heat transfer coefficients are calculated after introducing the vales of measured wall superheats ΔT in Newton's law of heating (i.e., $h = \frac{Q}{\Delta T}$) .

3. Results and Discussion

Figures 2, 3, and 4 show the results of the boiling curves of distilled water and Nano-fluids used. It seems that the variation of wall super heat (ΔT) is linearly changed with heat flux, which is in agreement with the literature results [8]. This increasing are reduced with increasing the concentration for the same heat flux, which is then causing an increase in heat transfer coefficient, due to the increment in thermal conductivity of Nano-fluid and high surface area of the nanoparticles.

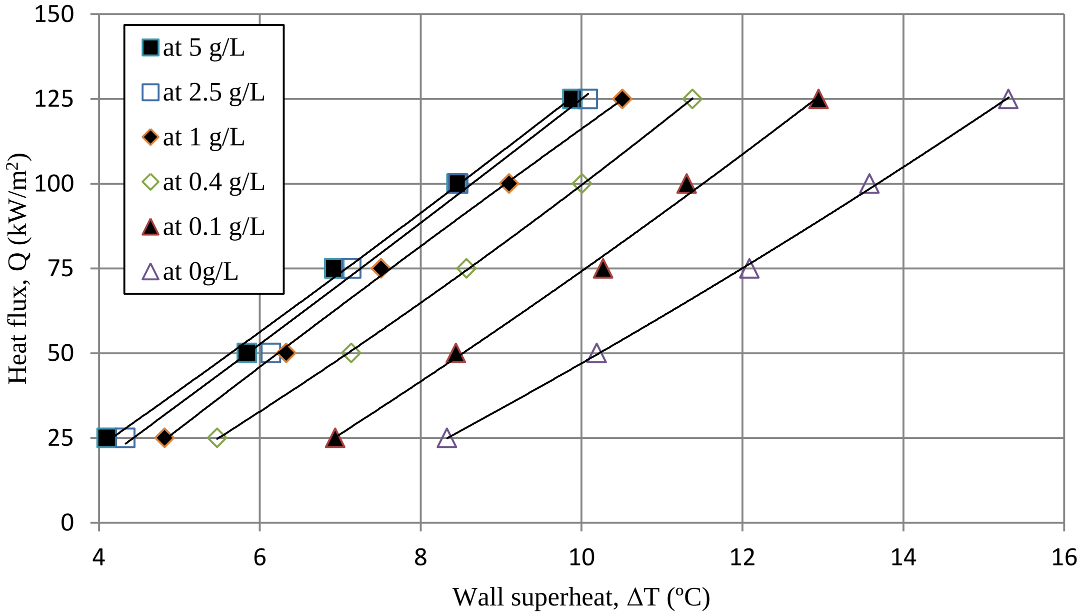


Figure 2. Boiling curves of nano Al_2O_3 concentrations

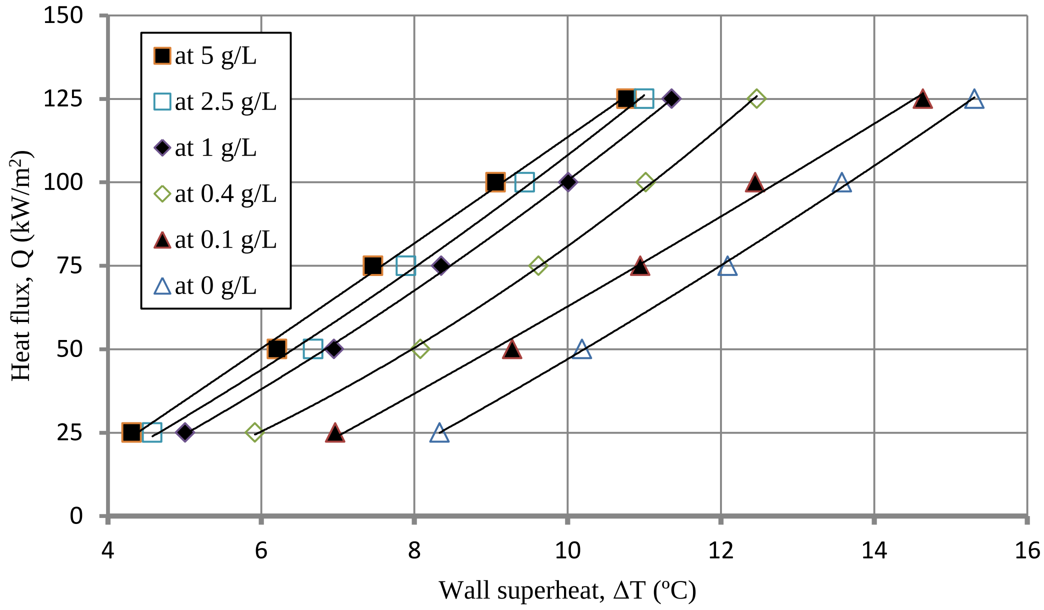


Figure 3. Boiling curves of nano TiO_2 concentrations

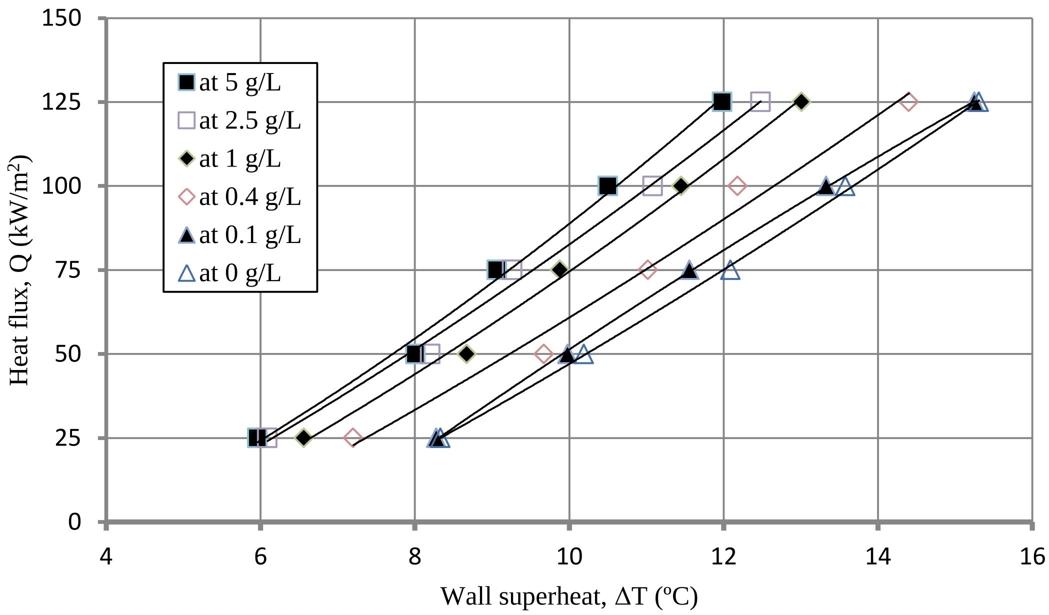


Figure 4. Boiling curves of nano ZrO_2 concentrations

Figures 5, 6, and 7 depicts the variation of heat transfer coefficients with heat flux. It indicates that the heat transfer coefficients is logarithmically increasing with heat flux but the span between the curve of water and that for nano Al_2O_3 is more than that between water and TiO_2 which in turn more than that between water and ZrO_2. This may be attributed to the density difference between the three materials used.

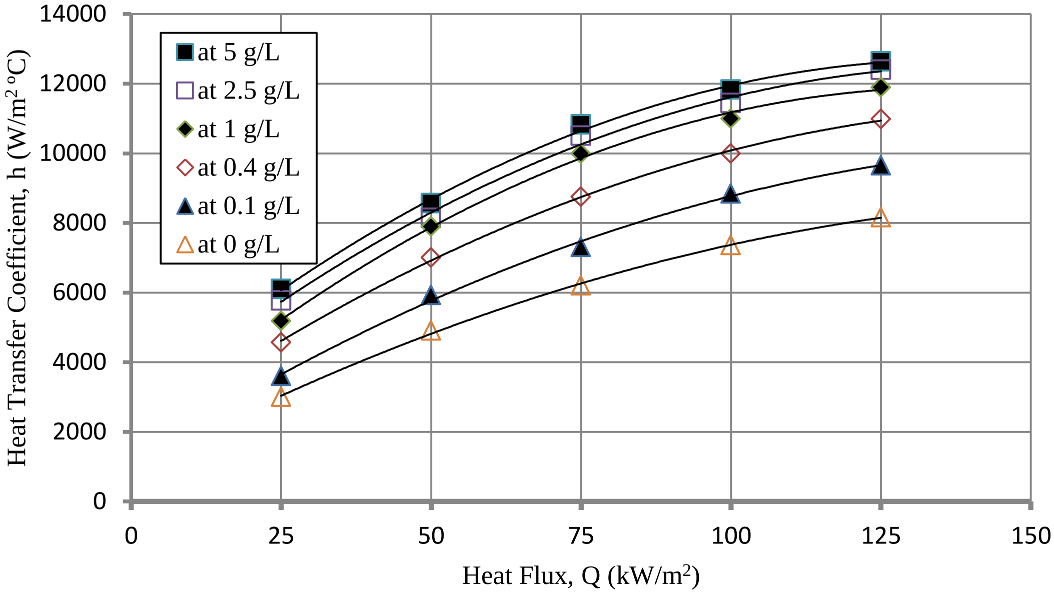


Figure 5. Varying of boiling heat transfer coefficients with heat flux as a function of nano Al_2O_3 concentrations

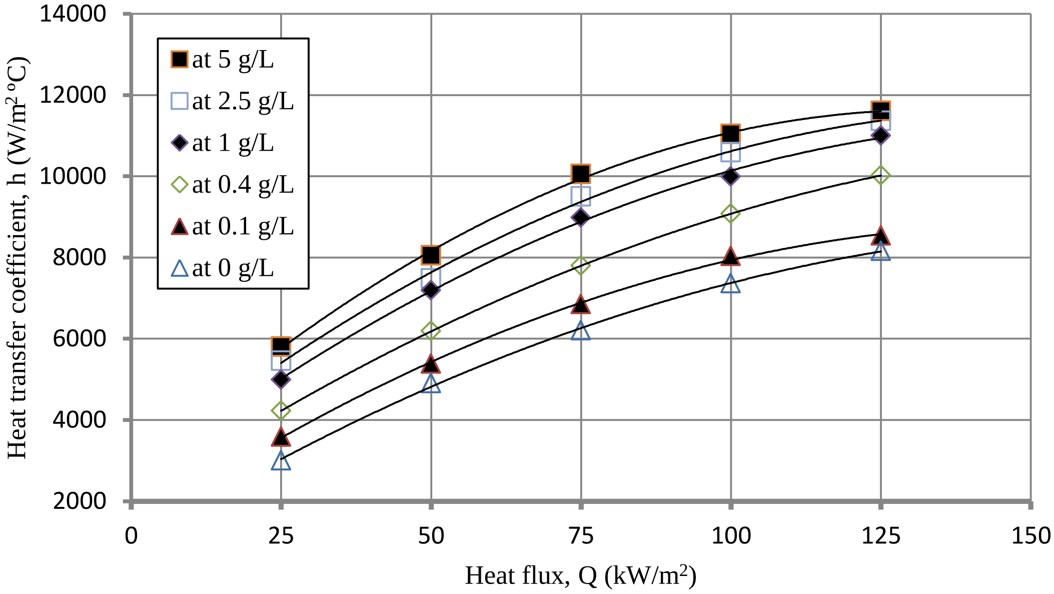


Figure 6. Varying of boiling heat transfer coefficients with heat flux as a function of nano TiO_2 concentrations

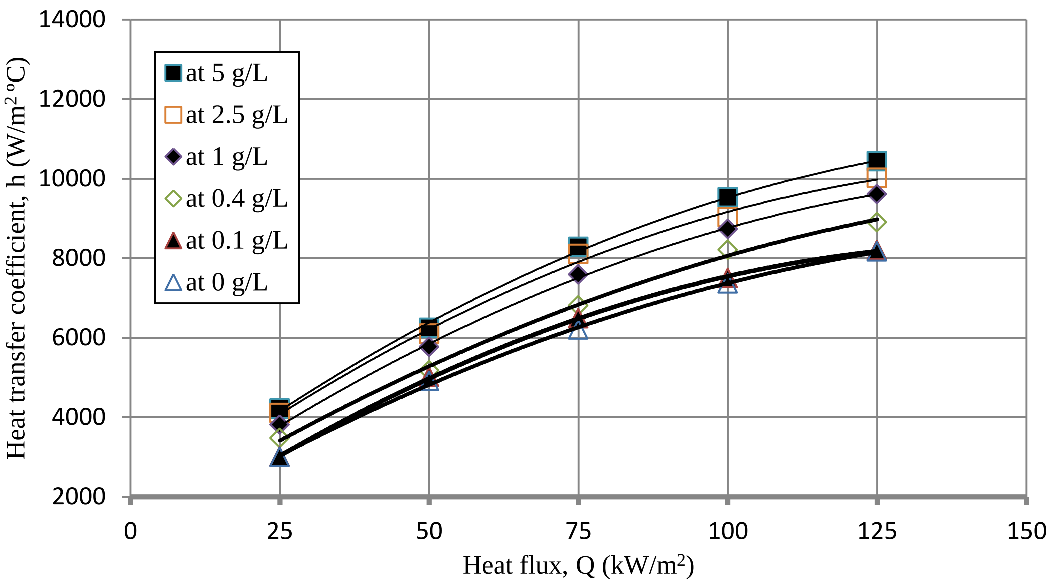


Figure 7. Varying of boiling heat transfer coefficients with heat flux as a function of nano ZrO_2 concentrations

Figures 8, 9, and 10 gives the relation between heat transfer coefficients and concentrations of nanomaterials. As appear the effect of concentrations of nanomaterials on the increment of heat transfer coefficients diminishes after 1 g/L for the three materials used, these findings are in agreement with the results of Chopkar et.al. [9]. This may be attributed to the sedimentation which may be took place on the heater which in turn rise the temperature difference between the temperature of heater surface and the Nano-fluid used.

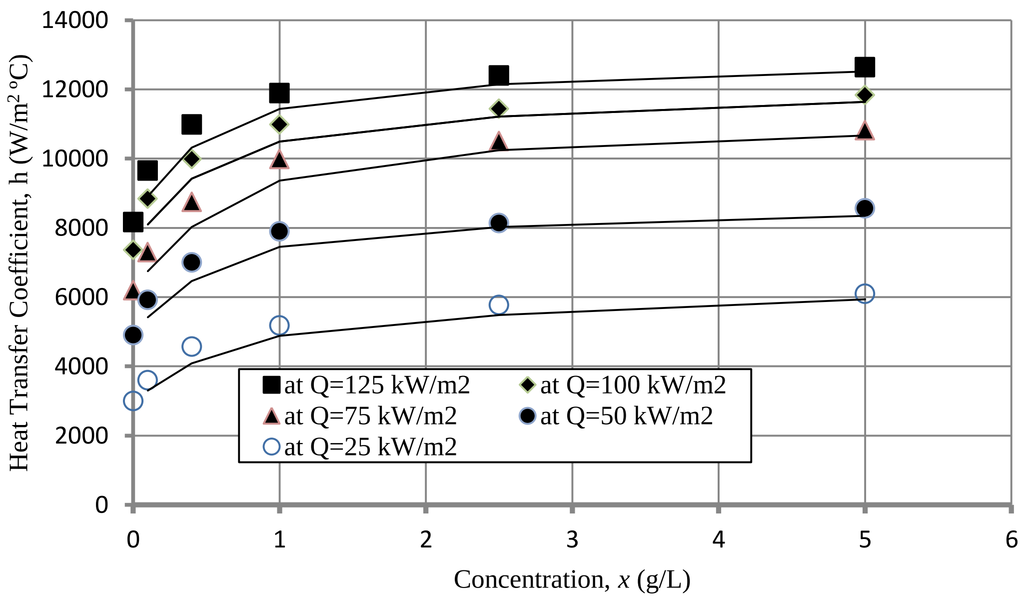


Figure 8. Boiling heat transfer coefficients versus nano Al_2O_3 concentrations as a function of heat flux

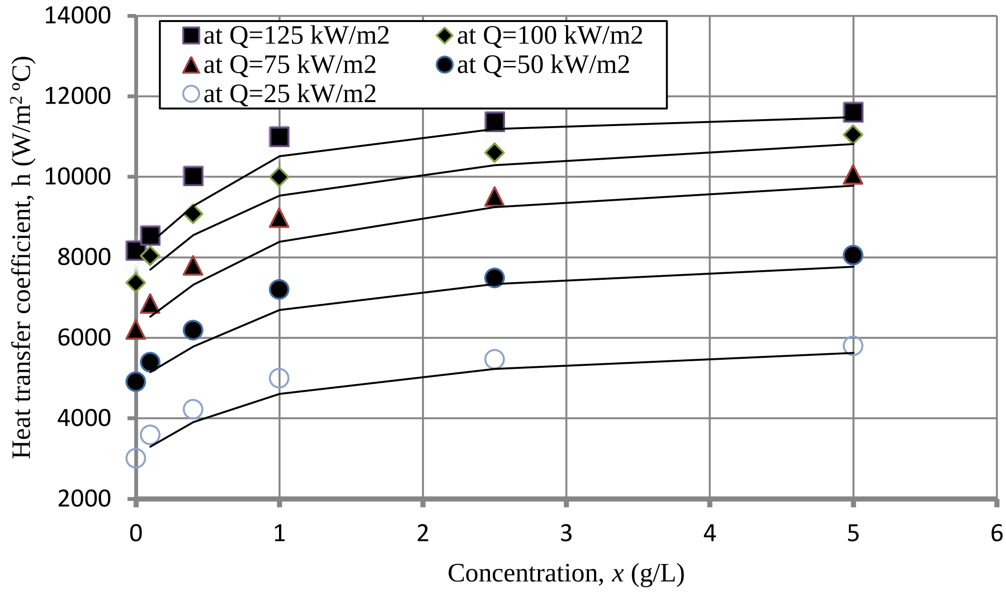


Figure 9. Boiling heat transfer coefficients versus nano TiO_2 concentrations as a function of heat flux

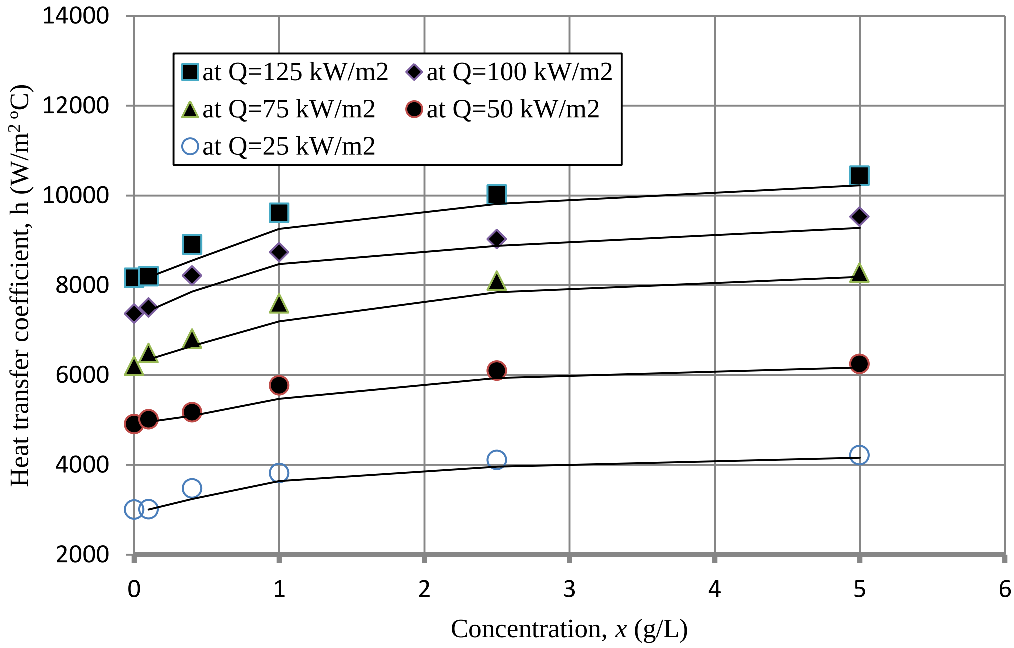


Figure 10. Boiling heat transfer coefficients versus nano ZrO_2 concentrations as a function of heat flux

4. Conclusions

Pool boiling heat transfer coefficients of Nano-fluids studied (Al_2O_3-H_2O, TiO_2-H_2O, and ZrO_2-H_2O) is higher than that for distilled water. It is found that the heat transfer coefficients increases with increasing of the concentrations of nanomaterials up to 1 g/L, then diminishes. And the increments of heat transfer coefficient of Al_2O_3-H_2O Nano-fluid was more than that for TiO_2-H_2O Nano-fluid which is more than that for ZrO_2-H_2O Nano-fluid.

5. Nomenclatures

A	Area of heating surface	(m^2)
h	Heat transfer coefficient	(W/m^2 ºC)
I	Electrical current	(amp)
q	Heat load	(W)
Q	Heat flux	(kW/m^2)
T	Temperature	(ºC)
V	Electrical voltage	(volt)
x	Concentration of nanomaterials	(g/L)

5.1. *Subscripts*

sat Saturation
w Wall

5.2. *Greek letters*

Δ Difference

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