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Enhancement of Heat Transfer Coefficient In Nucleate Pool Boiling on Vertical Cylindrical Stainless Steel Surface By Using Silica and Tungsten Oxide Nanofluids

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Abstract

The enhancement of heat transfer coefficient during pool boiling of two nanofluids i.e. silica and tungsten oxide has been carried out. Nanoparticles were tested at the different concentration of 0.01g/l to1.0g/l. The vertical cylindrical Stainless steel specimen having 12mm diameter and 17mm length formed test heater. The experiments have been performed to establish the influence of nanofluids concentration as well as surface material on heat transfer coefficient at atmospheric pressure. The results indicate that independent of concentration nanoparticle material (silica and tungsten oxide) has influence on heat transfer coefficient while boiling of water –silica or water- tungsten oxide on vertical surface of Stainless steel specimen. It seems that heater material did not affect the boiling heat transfer in 1.0 g/l water-silica or water-tungsten oxide nanofluid. The results are compared with different concentrations for both silica and tungsten oxide.

Keywords: silica nanofluid and tungsten oxide nanofluid, Pool boiling, vertical cylindrical surface of Stainless steel specimen

Introduction

In nanotechnology engineering field have allowed development of a new category of liquids termed nanofluids, which was first used by a group in Argonne National Laboratory USA to describe liquid suspensions containing nanoparticles with thermal conductivities, orders of magnitudes higher than the base liquids, and with sizes significantly smaller than 100 nm. The augment of thermal conductivity could provide a basis for an enormous innovation for heat transfer intensification, which is pertinent to a number of industrial sectors including transportation, power generation, micromanufacturing, chemical and metallurgical industries, as well as heating, cooling, ventilation, and air-conditioning industry.

The heat transfer processes and the reduction of energy losses are hence important tasks, particularly with regard to the prevailing energy crisis. In this regard, the heat transfer boiling has been used extensively to acquire good heat transfer performance. In terms of boiling regimes, nucleate boiling is an efficient heat transfer mechanism however, for the incorporation of nucleate boiling in most practical applications. For decades, researchers have been trying to develop more efficient heat transfer fluids. This would, in turn, improve process efficiency and reduce operational costs. This is where nanofluids could play a key role, nanofluids could potentially revolutionise heat transfer.

Accordingly, various techniques for enhancement of the boiling heat transfer have been proposed and studied. Typical approaches that have been considered to enhance pool boiling heat transfer in particular include oxidation or selective fouling of a heater surface to increase the wettability of the liquid, vibration of heaters to promote the departure of bubbles from a heater surface and extended heater surface to increase the heat transfer area. An interesting advantage of using nanofluids for heat transfer applications is the ability to alter their properties. That is the thermal conductivity and surface wettability, for example, can be adjusted by varying the particle concentration in the base fluid, and hence allowing nanofluids to be used for a variety of different applications. However, it is also important to note that addition of nanoparticles to a base fluid also changes the viscosity, density and even the effective specific heat these properties also have a direct effect on the heat transfer effectiveness.

With the modern technology available it is quite possible to produce ultra fine nanosized metallic non-metallic particles which will revolutionize heat transfer enhancement methods (Zeinali et al.2007). Considering very small particle size and their small volume fraction problems such as clogging ad increased pressure drop become insignificant if these particles are used along with base fluids. The relative large surface area of nanoparticles increases the stability and reduces the sedimentation in addition to dramatic improvement in heat transfer efficiency. This is possible due to decreased particle size in a suspension and increased surface area of the particles.

Improving the thermal properties of energy transmission fluids may become an effective means of augmenting heat transfer. Conventional heat transfer fluids such as water, ethylene glycol and oil have inherently low thermal conductivity relative to metals and even metal oxides. Therefore fluids with these suspended solid particles can offer better heat transfer properties compared to conventional heat transfer fluids.

Pool Boiling Experiments

Figure shows the schematic diagram of the experimental set up. It consists of a boiling vessel of 80 mm diameter and 200 mm long made up of stainless steel 316 fitted with flanges at top and bottom.

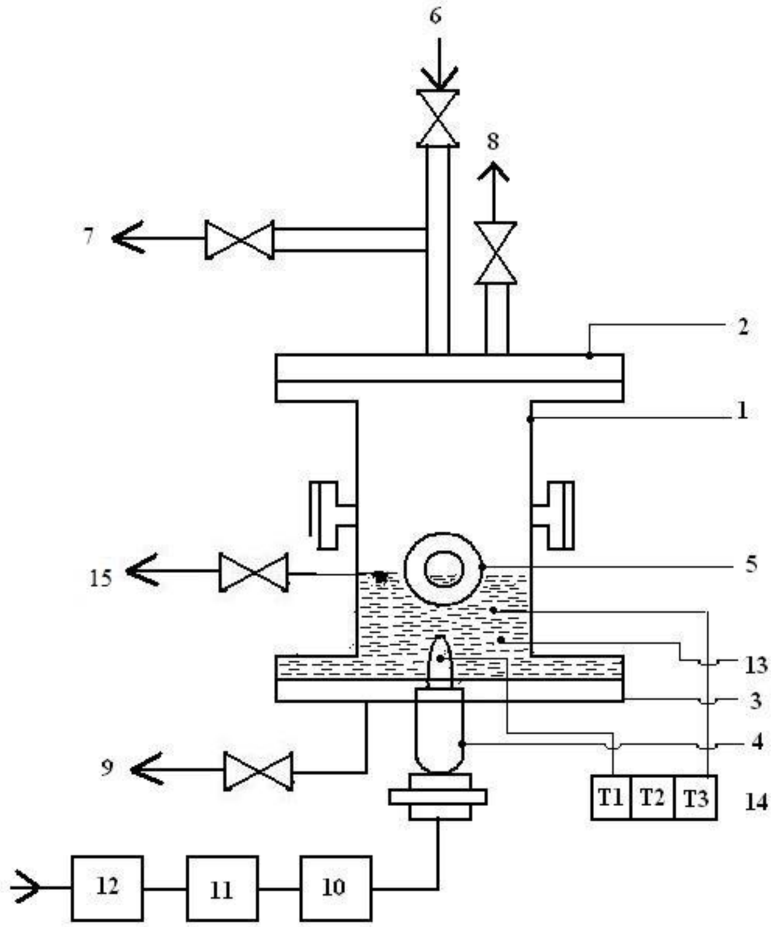

Figure 1: Schematic Diagram of Experimental Setup

1. Boiling vessel 10 Wattmeter
2. Top flange 11 Dimmer stat
3. Bottom flange 12 Stabiliser
4. Heater 13 Nanofluid
5. Watch glass 14 Temperature indicator
6. Liquid inlet (surface and liquid temperature)
7. To vaccum 15 Make up water
8. Pressure relief valve
9. Drain

Due provisions are made in these flanges for liquid charging inlet and outlet, vacum pump lines, thermocouples, test heater section and drain. The vessel is heavily insulated by asbestos rope and woollen ropes covered by packing material to reduce any heat transfer to surroundings. The test section is a cylindrical vertical surface of 12mm diameter and 17 mm length with two thermocouples fixed to the surface at opposite sides around at a depth of 1mm on the periphery. The test section is heated by an electrical heating element of 1000 w capacity. The heating element is connected to a wattmeter through a dimmer stat to vary the heat input during the experimentation.

Preparation of Nano fluids

In this work to prepare the nanofluids with desired concentration, nanoparticles were homogeneously dispersed into pure water. The characteristics of nanofluids are governed by not only the kind and size of the nanoparticles but also their dispersion status in the pure water. Due care was taken to ensure complete dispersion. After weighing equivalent weight of the solid nanoparticles were mixed with pure water in a flask, and then each time, vibrating machine was used to mix the nanoparticles uniformly for about 3 – 4 hrs. No considerable sedimentation was observed for the range of concentrations.

Experimental Procedure and Data Collection

First test setup is checked for its electrical consistency. The instrumentation thermocouples test vessel is cleaned by emery paper, dust, and other particles are cleared by using vacuum cleaner. The surfaces are cleaned by water splashing and draining off the test surface Pin is put in position into the heater necessary instrumentations (thermocouple) are arranged on the Pin and as well as in the liquid space. The vessel is charged with test liquid (water) and again the water is drained of twice to make sure that there are no sedimentation particles. Fresh charge of liquid is again filled. The auxiliary heater is switched on slowly and steadily the temperature of the liquid is brought to its saturation temperature. Once the steady state conditions are satisfactory maintained power is given to the test Pin heater slowly the heat is increased in steps to get to the desired condition. The make up water is expected to keep the concentration uniform.The readings are noted down. Then the heat is increased to the next position insteps and readings are noted down. The procedure is repeated till the last desired value of heat input (1kW).

The above procedure is followed with nanofluids.

The heat flux q is calculated using the following relation.

$q = Q/A$ W/m^2 or kW/m^2 1

Where Q is the heat input in W or kW

A is the surface area in mm^2 or m^2

Heat transfer coefficient h between the surface and the liquid is calculated by applying Newton's law of cooling.

$h = q / T_s - T_l$ W/m^2 K or kW/m^2 K........... 2

Where Ts is the average of surface temperatures recorded by thermocouples

T_l is the liquid temperature recorded by thermocouple

Experimental Procedure

Before starting the experiments the boiling chamber was cleaned to remove any dirt or other particles and evacuated by using a vacuum pump. The boiling vessel was filled with distilled water up to the mark in the vessel such that heating surface is completely immersed in the liquid. The vessel is closed. The auxiliary heater was switched on and it will give more heat . The system is run for 2 to 3 hours so as to ensure thermal steady state conditions. The liquid temperature were noted down the heating is continued till the liquid reached about 95^{0}C and the test section was given heat input through variac slowly and in steps the test heater power is increased to observe bubble formation and detachment. In every steps half an hour was allowed to get satisfactory steady state conditions the readings are noted down. The experiment is repeated for higher heat inputs. The readings are tabulated.

Results and Discussion

The results of water and different concentrations of silica nanofluids on stainless steel surface is shown fig 2. At the same heat flux the heat transfer coefficient at higher concentration of nanofluid is higher than that at lower concentrations across the range of heat flux. Heat transfer coefficients decreasing and increasing at higher heat flux more than 500kW/m^2 for 0.5g/l and 1.0g/l silica nanofluids

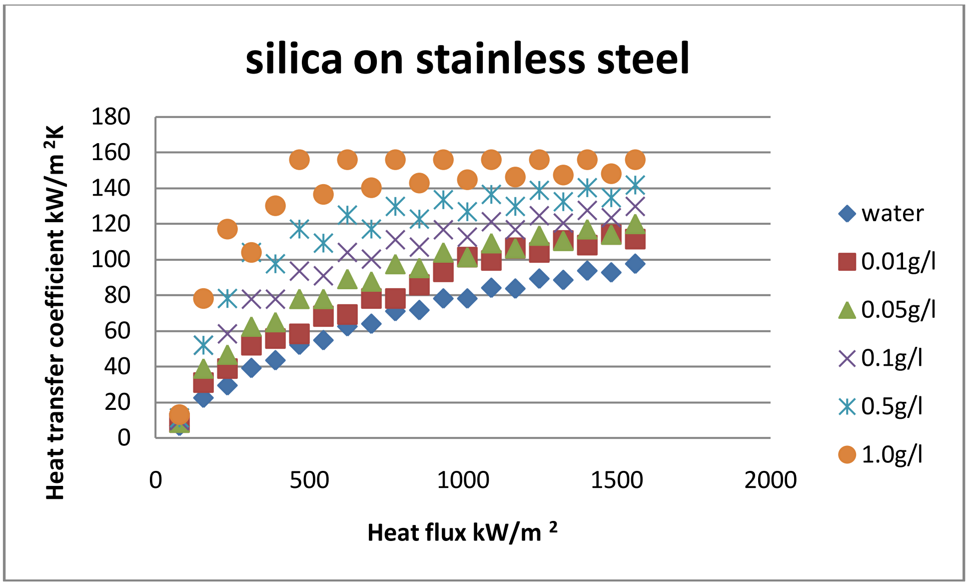

Figure 2: Comparison of Heat Transfer Coefficients For Silica

Nano fluid Different Concentrations on Steel Vertical Surface

Heat transfer coefficient enhancement is about 14.28% with 0.01g/l, 23.08% with 0.05g/l, 33.33% with 0.1g/l, 45.45% with 0.5g/l, 60% with 1.0g/l of silica nanofluids compared with those of pure water.

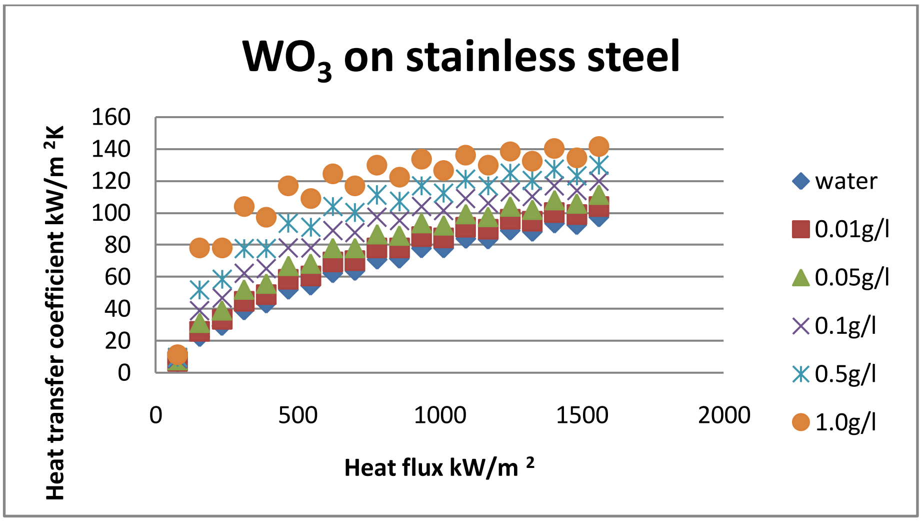

Figure 3: Comparison of heat transfer coefficients for WO_3

Nano fluid Different Concentrations on Stainless Steel Vertical Surface

These results of water and different concentrations of WO_3 nanofluids on stainless steel surface is shown fig 3. At the same heat flux the heat transfer coefficient at higher concentration of nanofluid is higher than that at lower concentrations across the range of heat flux. From this graph heat transfer coefficient of a pure water, 0.01g/l,0.05g/l increased from lower level to higher level, and remaining concentrations of heat transfer coefficient is increased from about 250kW/m^2 to higher range.

Heat transfer coefficient enhancement is about 6.66% is increased with 0.01g/l, 14.28% is increased with 0.05g/l, 23.07% is increased with 0.1g/l, 33.33% is increased with 0.5g/l, 45.45% is increased with 1.0g/l of tungsten oxide nanofluids compare with pure water.

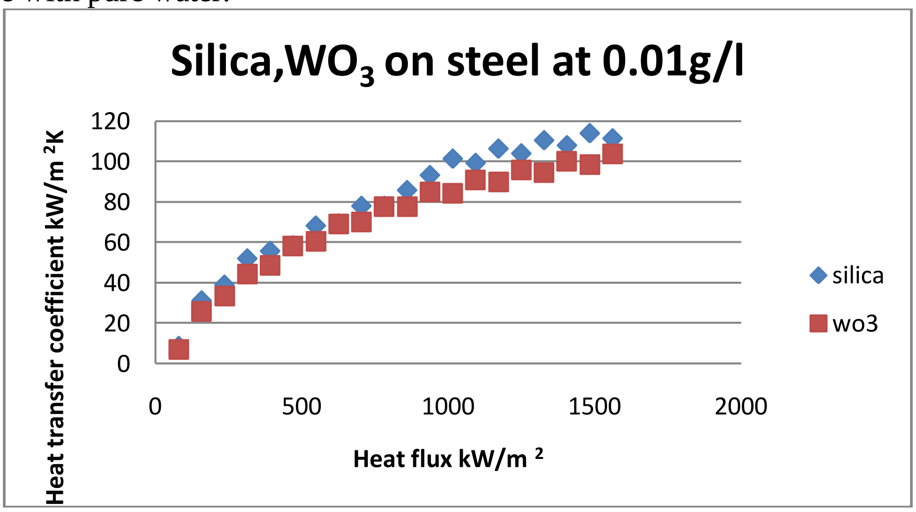

Figure 4: Comparison of silica and WO_3 nanofluids on stainless steel surface at 0.01g/l

Fig 4. shows that the results of silica and tungsten oxide nanofluids on steel vertical surface at 0.01g/l. Heat transfer coefficient for silica nanofluid higher than those of tungsten oxide nanofluid.

At lower range both fluids are similar up to 200kW/m^2 and then silica nanofluid is slightly increased than tungsten oxide nanofluid. At higher level more difference than the lower level.

Heat transfer coefficient enhancement is about 7.14% is increased with 0.01g/l compare with tungsten oxide nanofluid.

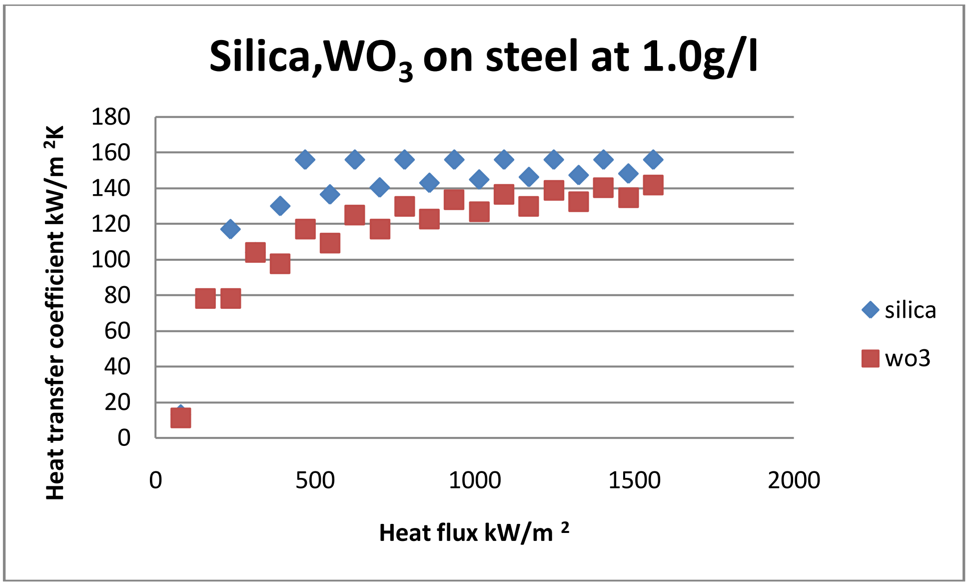

Figure 5: Comparison of silica and WO_3 nanofluids on stainless steel surface at 1.0g/l

Fig 5. Shows that the results of silica and tungsten oxide nanofluids on steel vertical surface at 1.0g/l. Heat transfer coefficient for silica nanofluid higher than those of tungsten oxide nanofluid.

From above graph the heat transfer coefficient of both fluids increased up to 1000kW/m^2 after that constant with heat flux, because at this range more bubbles are produced rapidly from the surface due to temperature of the surface is very high.

Heat transfer coefficient enhancement is about 10% is increased with 1.0g/l compare with tungsten oxide nanofluid.

Conclusions

The enhancement of heat transfer coefficient of pool boiling heat transfer has been conducted on Stainless steel cylindrical specimen for different concentrations of silica and tungsten oxide nanofluids. For Stainless steel cylindrical specimen, Furthermore based on the experimental results it is recommended to use nanofluids for enhancing the heat transfer coefficient around the Stainless steel cylindrical surfaces. In conclusion in terms of quantity for silica and WO_3 nanoparticles, The experiments on boiling of nanofluids on stainless steel surface with varying concentrations gave (i) with silica nanofluid the heat transfer enhancement is found gradually increasing with concentration of the silica from about 14.28% for 0.01g/l concentration to about 60% with 1.0g/l concentration when compared with heat transfer coefficient values for pure water.

(ii) With tungsten oxide nanofluids the heat transfer coefficient is found gradually increasing with concentration of tungsten oxide from about 6.66% for 0.01g/l concentration to about 45.45% with 1.0g/l concentration when compared with heat transfer coefficient values for pure water. The enhancement of heat transfer coefficient of silica is about 7.14% is higher than tungsten oxide at 0.01g/l same concentration. Heat transfer coefficient enhancement is about 10% is increased with 1.0g/l compare with tungsten oxide nanofluid.

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