

EXPERIMENTAL STUDIES ON POOL BOILING HEAT TRANSFER USING ALUMINA AND GRAPHENE OXIDE NANOFLUIDS

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Abstract - Energy crisis around world has triggered more attention to energy saving and efficient energy conversion devices. One of the effective methods for transferring thermal energy with large heat flux is liquid-vapour phase change process is called boiling. The aim is development of special surface geometry or texture for enhancing nucleate pool boiling heat transfer is to decrease the boiling incipience and to delay the critical heat flux (CHF). During pool boiling and subsequent inspection, formation of a porous layer of nanoparticles on the heating surface occurred during nucleate boiling. This layer significantly changes surface texture of the heater wire surfaces which could be the region for the improved in the CHF value. Common fluids with particles of the order of the nanometers in size are termed as a "nanofluid" which has created considerable interest in recent times for their improved heat transfer capabilities. With very small volume fraction of such particles the thermal conductivity and convective heat transfer capability of these suspension are significantly enhanced without the problems encountered in common slurries such as clogging, erosion, sedimentation and increase in pressure drop. In this work, experiments on Alumina and Graphene oxide nanofluids was used to study the effect on pool boiling heat transfer and its effect on heat transfer enhancement was studied on the horizontal test wire immersed in different concentration of nanofluid viz. 0.01g, 0.1g/l and 1g/l. The effect on heat transfer enhancement was investigated by flow visualization and by surface inspection of the heater surface by SEM images.

1. INTRODUCTION

Nanofluids are dilute liquid suspended of nanoparticles with at least one critical dimension smaller than 100 nm. Pool Boiling Heat Transfer using nanofluids (which are suspended of nanoparticles in a base fluid) has been a subject of investigations and incoherent results. In the past, experiments were conducted in nucleate pool boiling

with varying parameters such as particle size, concentration, surface roughness etc. Critical Heat Flux (CHF) is the heat flux at which a boiling crisis occurs accompanied by a sudden increase of the heat transfer surface or decrease of the heat transfer rate. The CHF imposes a limit in designing and operating boiling heat transfer equipments in power generations industries such as nuclear power plants and fossil fuel power plants. Thus, an increase in the critical heat flux can enhance the safety margins and allows for more economical design and operation at higher heat fluxes. As the capacity of nuclear power plants or fossil boilers increases, a higher heat load per unit heat transfer area is required. In fusion reactors, the maximum heat flux may be higher than 10 MW/m² for this special heat transfer measures are necessary. Among all the regimes of pool boiling the most effective heat transfer mechanism is nucleate boiling, the upper boundary of which is dictated by the CHF. Therefore, efforts have been exerted to expand the regime of nucleate boiling.

1.1 Boiling Heat Transfer (BHT)

Heat transfer is the process of transferring the heat from high temperature region to low temperature region at a certain rate without aid of any external agency. Hence it obeys the Second Law of Thermodynamics. There are three modes of heat transfer viz. conduction, convection and radiation.

Boiling is a convection process involving a change of phase from liquid to vapour. Boiling may occur when a liquid is in contact with a surface maintained at a temperature higher than the saturation temperature of the liquid. The transfer of heat takes place in the boiling according to the Newton's law of cooling, It states that the rate of heat transfer in convection process is directly proportional to the product of temperature difference and convective heat transfer coefficient (It is constant for the given fluid) per unit area.

$$\text{i.e. } q_s = h \Delta t_e$$

Where, $\Delta t_e = t_s - t_{sat}$ is called Excess temperature, And h = Convective or Boiling Heat Transfer Coefficient. If the heat is provided to a liquid from a submerged solid surface, the boiling process is called pool boiling. In this process the vapour produced may form bubbles, which

grow and subsequently detach themselves from the surface rising to the free surface due to buoyancy effect. BHT coefficient is the rate of heat transfer per unit area due to the change in the thermal forces (Δt_e). Finally the BHT coefficient is a measure of the heat transfer due to phase change of a liquid during boiling.

2. OBJECTIVES

This project focuses on the fundamental mechanisms in pool boiling responsible for heat transfer enhancement techniques using alumina and Graphene oxide nanofluid. The primary objectives of this research work are as follows:

- To study the **pool boiling phenomenon** till the Burnout point or Critical Heat Flux (CHF) using a **horizontal test surface** immersed in different concentrations of alumina and Graphene oxide nanofluid at atmospheric pressure.
- To investigate the reasons for increasing or decreasing in Critical Heat Flux by subjecting the test surface to different concentrations by using SEM Images.
- To study the **flow visualization** in pool boiling.

3. MATERIALS AND METHODOLOGY

3.1 Apparatus used: Glass beaker, electric heater, electrodes, condenser, thermocouple, voltmeter, ammeter, dimmer stat, test wire, distilled water and nanofluids.

3.2 Specifications:

- Capacity of heating coil - 250 W
- Distance between electrodes- 85 mm
- Diameter of the test wire-0.193 mm (SWG 36)
- Capacity of dimmer:
 - Single phase current Input - 240 V
 - Maximum load -15 A
 - Output - 0 to 270 V
 - Frequency - 50 HZ
- Nichrome wire:
 - Nickel 80%, Chromium 20% alloy
 - Density $\approx 8200 \text{ Kg/m}^3$
 - Resistance = $34 \Omega/\text{m}$
 - Melting temperature = 1400°C
 - Maximum continuous service temperature = 1200°C
 - Non magnetic
- Glass beaker:
 - Inner diameter = 125 mm
 - Height = 180 mm
- Electrode:
 - Copper alloy (Brass)
 - Diameter = 8 mm
 - Length = 100 mm

3.3 Formulae:

Heat supplied (Q):

$$Q = VI \text{ (Watts)}$$

Where,

V = Voltage in Volts (V)

I = Current in Amperes (A)

Critical heat flux (q):

$$q = Q/A \text{ (W/m}^2\text{)}$$

Where,

A = Surface area of wire (m^2)

$$= \pi dl \text{ (m}^2\text{)}$$

d = Diameter of wire (m)

l = Length of wire (m)

3.4 Properties of nanoparticles used

3.4.1 Graphene oxide

Graphene oxide is electrically insulated due to disruptive sp^2 bonding network but it can be converted conductive by restoring network.

| Parameters | Approximate Values |
|-------------------------|-----------------------------------|
| Thickness | 0.8 - 1.6 nm |
| Purity | 98% |
| Number of Layers | Average number of layers 1 - 2 |
| Surface Area | 350m ² /g |
| Bulk Density | 0.121g/cm ³ |
| Electrical Conductivity | Insulator [Tuneable to conductor] |
| Length | < 10 - 20 micron |

3.4.2 Aluminum oxide

| Parameters | Approximate Values |
|----------------------------|--------------------------------|
| Average nanoparticle size | 40 - 60 nm |
| Purity | 99% |
| Number of Layers | Average number of layers 1 - 2 |
| Surface Area | 200 m ² /g |
| Bulk Density | 3.7 g/cm ³ |
| Nanoparticle morphology | Spherical |
| Crystallographic structure | Cubic |

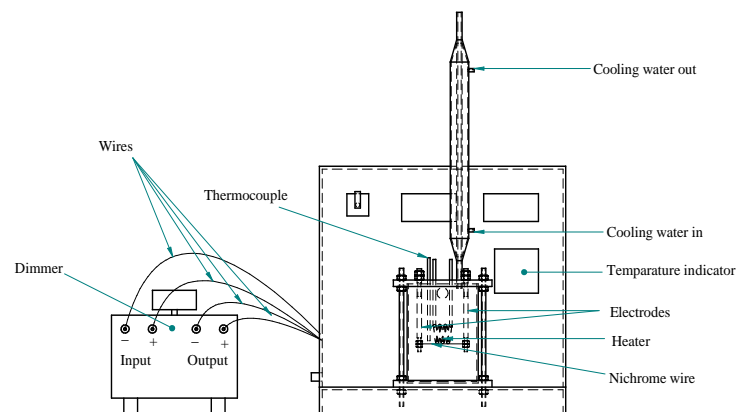


Fig -3.1: Line diagram of Experimental setup

3.5 Experimental Methodology

- Fill the beaker with 2 liters of distilled water.
- Hold the test wire between the two electrodes.
- Place the lid over the vessel such that heater, electrodes and thermocouple are immersed in the distilled water.
- Place the condenser firmly in the hole made in the lid and supply the cooling water through the condenser inlet.
- Switch on the experimental setup. Initially the distilled water in the beaker is heated by setting a temperature value (Saturation Temperature of distilled water) in the temperature controller.
- The temperature controller cuts off the power supply to the heating coil when the fluid reaches the preset temperature (saturation temperature of fluid).
- Then the power supplied through the electrodes by the dimmer creates a resistance in the nichrome wire which is held between electrodes causing to get heat supply.
- Meanwhile the voltmeter and ammeter readings are observed.
- When the supply of heat is increased gradually the formation of minute bubbles appears on the surface of the test wire indicating nucleate boiling.
- When the heat supply is further increased the rapid formation of bubbles occurs, indicating departure from nucleate boiling.
- When the heat supply is increased furthermore the film boiling regime attains and in the end the wire gets burnt out at the centre.
- The ammeter and voltmeter readings at the burn out point are noted.
- If the temperature of the fluid decreases less than the saturation temperature in the middle of the experimentation then stop supplying the heat. Wait for a while to attain the saturation temperature level and continue the process.
- The procedure is repeated for 8 to 10 times by mounting the fresh test wire each time.
- After that the distilled water is replaced by the nanofluid.
- The required nanofluid concentration say 0.1g/l is obtained by mixing 0.2 gram of Alumina nanoparticles in 2 liters of distilled water in a stirrer for 1 hour.
- The experiment is carried out at the various concentrations of Alumina and Graphene-Oxide nanoparticles.
- After each experimentation for distilled water as well as for all the concentration of Alumina and Graphene-oxide nanofluid. Collect the burnout test wire carefully without touching the surface in the air tight test-tube.

- The wire collected in the test tube is seen by the Scanning Electron Microscope (SEM) for the images captured at different magnification to investigate the reasons for why the critical heat flux increases or decreases.

3.6 Methodology for Flow visualization

- The experiments are conducted by the above procedure (Content 3.7) for 0.01g/l of aluminum oxide and 0.01g/l and 0.1g/l of graphene oxide. During the experimentation photographs of bobbles formation on the surface of the wire are captured for different Voltage variations (2V, 4V...up to burnout point).
- The photographs are taken for all the mentioned nanofluids at the same Voltage and Current variation.
- These photographs are analyzed and found out the number of bubbles and diameter of each bubble in the selected section (The section has constant dimensions for all the photographs) by manual zooming and interpolation method.
- The rate of retention of the nanofluid can be calculated by taking the photographs of the fluid sample in the test tube at the intervals of 0 hour, 1 hour and 2 hour after preparing the nanofluid.

4. RESULTS AND DISCUSSION

4.1 Comparison of CHF with distilled water, Aluminum oxide Graphene oxide for various concentrations

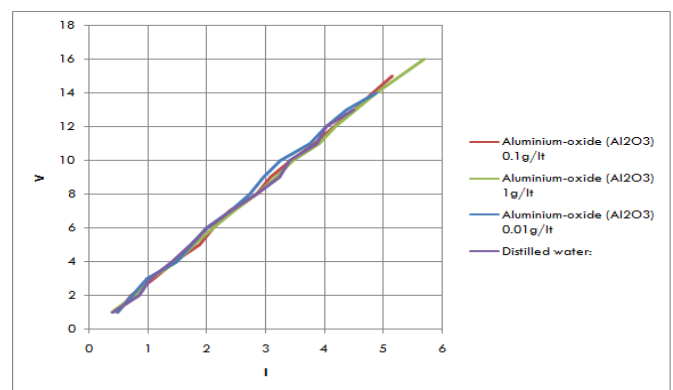


Fig -4.1: Variation of Voltage with Current for various concentrations of Alumina nanofluid with Distilled water

The above Fig -4.1 shows the Voltage v/s Current variations for the alumina nanofluid. It shows that the nanofluid at concentration of 0.01g/l, 0.1g/l and 1g/l are enhanced 17.3%, 32.6% and 56.27% of CHF compared to distilled water.

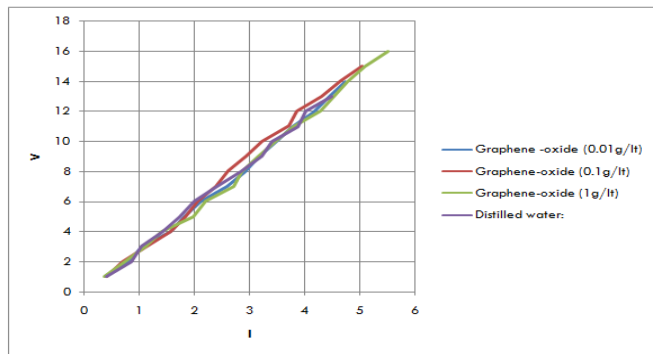


Fig -4.2: Variation of Voltage with Current for various concentration of Graphene oxide nanofluid with Distilled water

The above Fig. 4.2 shows the Voltage v/s Current variations for the Graphene oxide nanofluid. It shows that the nanofluid at concentration of 0.01g/l, 0.1g/l and 1g/l are enhanced 13.4%, 29.5% and 51% of CHF compared to distilled water.

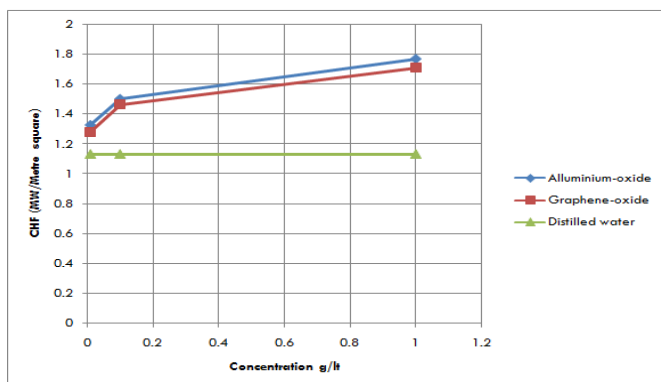


Fig -4.3: Variation of CHF with various concentrations of Alumina, Graphene-oxide, and Distilled water

The above Fig. 4.3 shows that the comparison of CHF v/s various concentration of alumina, Graphene oxide and CHF of distilled water. It clearly shown that at 0.01g/l concentration the alumina enhances the 17.3% whereas Graphene oxide enhances the 13.4%, at 0.1g/l concentration the alumina enhances the 32.6% whereas Graphene oxide enhances the 29.5% and at 1g/l concentration the alumina enhances the 56.27% whereas Graphene oxide enhances the 51% CHF.

4.2 SEM Images

4.2.1 Aluminum oxide 1g/l:

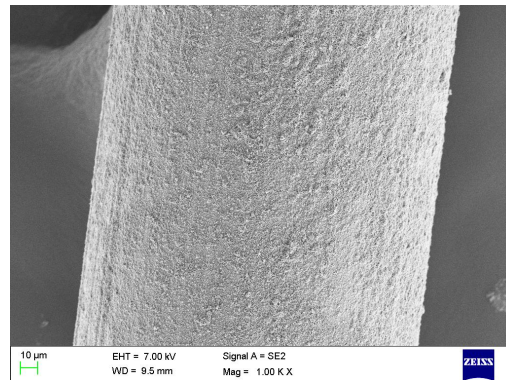


Fig -4.4: Al₂O₃ (1g/l) nichrome wire at 1000X magnification

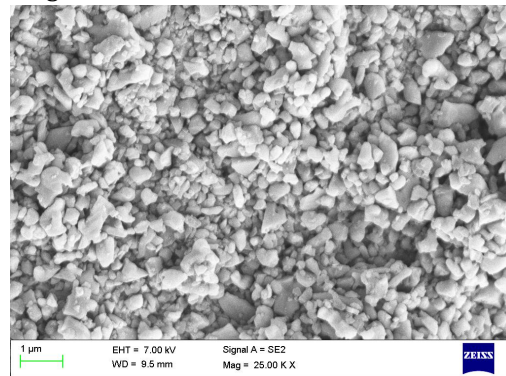


Fig -4.5: Al₂O₃ (1g/l) nichrome wire at 25000X magnification

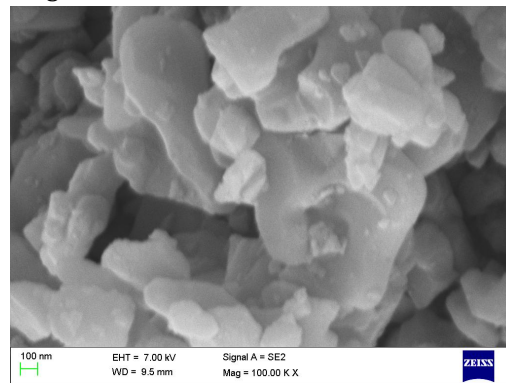


Fig -4.6: Al₂O₃ (1g/l) nichrome wire at 100000X magnification

The burnout wire is taken at a concentration of aluminum oxide 1g/l and it is observed in the SEM shown in the figure at different magnification. At this concentration the CHF is obtained **1.769 MW/m²**. The CHF of the Distilled is 1.132 MW/m² under atmospheric pressure. 56.27% of CHF is enhanced at this concentration.

4.2.2 Graphene oxide 1g/l:

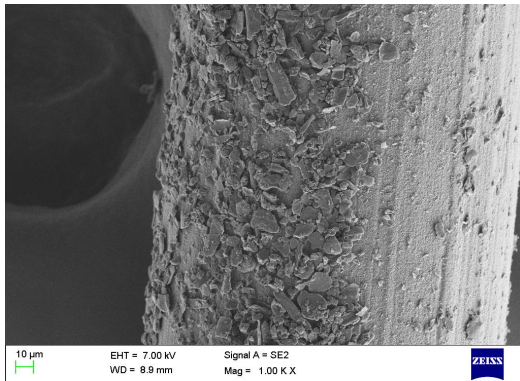


Fig -4.7: GO (1g/l) nichrome wire at 1000X magnification

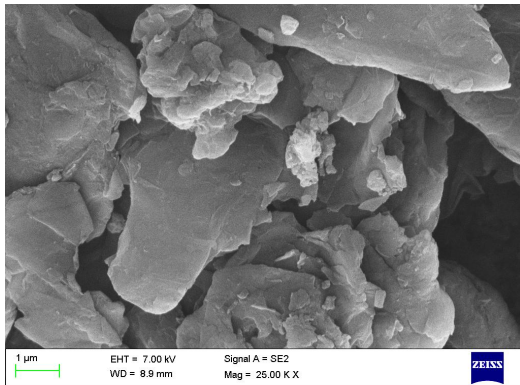


Fig -4.8: GO (1g/l) nichrome wire at 25000X magnification

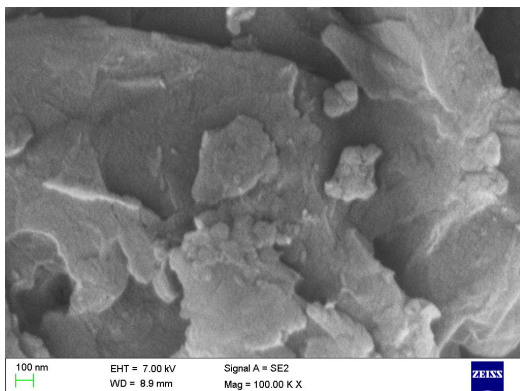


Fig -4.9: GO (1g/l) nichrome wire at 100000X magnification

At the Graphene oxide nanofluid concentration of 1g/l SEM Images are shown in figure at different magnification. At this concentration CHF is obtained **1.71 MW/m²** and 51% of CHF is increased compared to the distilled water.

4.3 Rate of retention

By comparing the photographs (photographs were taken at 0hr, 1hr, 2hr after preparing the nanofluid) the rate of

retention is found more in the Graphene oxide nanofluids than the alumina nanofluids due to the inhomogeneous solution.

The rate of retention is found less in case of high concentration range and it is noticed high in case of low concentration range. The nanoparticles have the high intermolecular forces (cohesive forces) so it is difficult to break the particles at low concentration range of solution. But in case of high concentration range, more numbers of particles are involved in the mixing, the rate of collision of the particle is more hence the mixing is well and rate of retention is less in high concentration range due to proper mixing. This is more in case of graphene oxide compared to the alumina.

4.4 Flow visualization

The wetted surface is increases by increasing the concentration of nanofluid and also increased creating the porous layer over the surface of heating wire.

5. CONCLUSIONS

Pool boiling CHF characteristics in nanofluids are investigated with different concentrations of Alumina and graphene oxide nanofluid ranging from 0.01g/l, 0.1g/l and 1g/l and the effect of nanoparticles in pool boiling CHF for each concentration is studied experimentally and the effect on heat transfer enhancement are investigated by flow visualization and by surface inspection of the heater surface.

- It is observed that with low concentration of Al₂O₃ (0.01g/l) the dispersion is homogeneous while higher concentration of Al₂O₃ (1g/l) resulted in the formation of coating over the heater surface and fouling of the vessel inner surface. Whereas in case of the GO the dispersion is not much homogenous in all the concentrations compared to Al₂O₃ but in 1g/l concentration of GO is better homogeneous compared to 0.01g/l concentration of GO. In mid range concentrations (0.1g/l) characteristics of both the fluids place in between higher and lower concentrations characteristics of corresponding fluid.
- While Al₂O₃ shows an increase in CHF by 17.3%, at 0.01g/l concentration (Fig -4.3) and 56.27% increase (Fig -4.3) in CHF at 1g/l concentration. The maximum CHF was recorded at 1.769 MW/m² for Al₂O₃ at 1g/l concentrations against 1.132 MW/m² of DI water.

- In GO the CHF is increase 13.4% at 0.01g/l concentration (Fig -4.3) and 51.5% increase (Fig -4.3) in CHF at 1g/l concentration. The CHF values are obtained slightly less than the Al_2O_3 . It can be observed by the Graph (Fig -4.3).
- Though GO has more good qualities than Al_2O_3 due to lack of molecular level mixing (Fig -4.7, 4.8, 4.9 molecules in bulk form) with the distilled water and high rate of retention the CHF is obtained slightly less than the Al_2O_3 .
- The nanoparticle coating layer over the heating surface is improved surface wettability and enhanced the CHF is also supported by the SEM and EDOX observations and flow visualisation.
- Nanofluids can be considered as a potential candidate for heat transfer enhancement and are highly suitable for applications in practical heat transfer processes.

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