

# Experimental Studies on Pool Boiling Heat Transfer using Titanium Oxide and Magnesium Oxide Nanofluids

Girish Sapre<sup>1</sup>, Dr. S. Kumarappa<sup>2</sup>

Assistant Professor, Dept. of Mechanical Engineering, CMRIT, Hyderabad, Telangana, India<sup>1</sup>

Professor and Head, Dept. of Mechanical Engineering, BIET, Davangere, Karnataka, India<sup>2</sup>

**ABSTRACT:** Boiling heat transfer is used in a variety of industrial process and applications such as cooling of nuclear reactors, cooling of high power electronics components, heat exchangers. However critical heat flux (CHF) imposes a limit in the designing and operating of the heat transfer equipment. Therefore Enhancement in critical heat flux is very important and that will make boiling heat transfer process for industrial applications more energy efficient and increases the safety margins. In a present days Nanofluid is considered as innovative technique to enhancement of critical heat flux. In our work, experiments on the Titanium oxide and Magnesium oxide nanofluids were conducted and studied the effect on the pool boiling heat transfer. The effect on heat transfer enhancement was investigated by characterization of the wire surface.

**KEYWORDS:** Critical Heat Flux (CHF), Nanofluids, Scanning Electron Microscope (SEM)

## I. INTRODUCTION

Fluids play an important role in a heat transfer, some of the fluids most likely used for heat transfer applications are water, propylene glycol, ethylene glycol etc. and these are considered as conventional fluids for heat transfer. These conventional fluids are having poor heat transfer properties. Because of the poor convection heat transfer characteristics, researchers are finding out the new kind of heat transfer fluids that will make higher heat transfer rate and that will enhance the efficiency of the complete system. These special kind of heat transfer fluids are called as “Nano fluids”.

Nanofluids can be considered as the next generation heat transfer fluids which contains ultrafine particles that are suspended in a liquid. “Nanofluid” refers to a fluid in which nano-meter size particles of present metal oxide substances such as aluminium oxide, titanium oxide are suspended in a liquid. These Nanofluid plays role of enhancing heat transfer due to the enhance in the thermal conductivity of it compared to conventional fluid.

Nucleate boiling is a highly efficient heat-transfer mode for removing large amounts of heat at a low temperature difference. However, a maximum value of the heat flux, known as a critical heat flux (CHF), exists at which nucleate boiling transitions to film boiling. Beyond a critical value of the heat flux (or CHF) a vapour layer develops between the liquid and the solid surface, thus severely deteriorates heat transfer due to poor thermal conductivity of the vapour film, and eventually damaging the heating surface. Therefore, the designs of heat transfer systems that operate in the nucleate boiling regime are limited by CHF. So Critical Heat Flux, or CHF, is an important condition that defines the upper limit of safe operation of heat transfer equipment employing boiling heat transfer in heat flux controlled systems.

## II. RELATED WORK

Nano-fluids, with their reduced thermal resistance and improved heat transfer properties, are a potential choice for these working fluids since late 90s. There are a large number of engineering systems like thermal application, cooling package in electronics as well as nuclear engineering that can take advantage of such fluid. “Nanofluid” refers to a fluid

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 3, March 2017

in which nanometer sized particles are suspended in a fluid, usually a liquid (Choi et al., 1995). Practical experimental tests with uniformly distributed nanoparticles for CHF measurements have been conducted by several researchers to validate the existence of pool boiling CHF prediction model.

You et al. [1] demonstrated that when nanofluids used instead of pure water as a coolant, CHF can be significantly enhanced. Their test results for pool boiling of alumina-water nanofluid showed that the CHF increased dramatically (approximately 200% increase) at low concentrations compared with pure water. Sudev Das et al [2] conducted experiment on pool boiling with nanofluid at different surface temperatures by increasing the TiO<sub>2</sub> nanoparticle concentration from 0.32 to 1.25 wt% show that the heat flux increases upto 69.88kW/m<sup>2</sup> approximately. M.Kim et al [4] were conducted pool boiling experiment and investigated the enhancement of CHF using various nanoparticles of TiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, and SiO<sub>2</sub> observed nanoparticle surface coating on the heating surface after the experiment and concluded that CHF enhancement using nanofluids is caused mainly by the heater surface modification caused by the nanoparticle surface coating during pool boiling of nanofluids. Characterization of nanoparticle coated surface showed that the surface wettability, surface roughness is the important parameters closely related to the significant CHF enhancement using nanofluids.

From the above work conducted by researchers, it is concluded that with the employment of the enhanced boiling techniques, the critical heat flux (CHF) can be increased, which ensures continuous cooling of the component. The reliable and effective cooling in nuclear power reactors is of highest priority, where transition to film boiling can have devastating consequences. Here the enhanced boiling technique increases the safety margin in a significant manner.

So in this paper, the work is presented over two different nanoparticles which are mostly available and having higher thermal conductivity. And investigate the reasons for increasing in critical heat flux by subjecting test surface of different concentrations in the Scanning Electronic Microscope & in EDS. Influence of the surface roughness over increasing critical heat flux using Profilometer device is evaluated.

## III. EXPERIMENTATION

### Experimental Setup

The experimental arrangement consists of a Borosil transparent glass vessel having size 130 mm diameter and 205 mm height. In the top the wooden block (Lid) of 30 mm is used to cover the glass vessel, so that vapour should not leave the vessel. It has a hole at the centre to fix the condenser which was used to condense the vapour that is escaping from the vessel to maintain constant nanofluid level inside the vessel. Small 5 holes are made top of the lid in one hole the thermocouple is inserted in other 2 holes the electrode made up of Brass of diameter 8mm and length 100 mm were inserted, which is connected with Positive and negative poles of wires from which current is supplied the electrodes. Remaining 2 holes is for inserting the Auxiliary heater, were an auxiliary heater was installed to maintain the temperature of the liquid at saturation temperature.

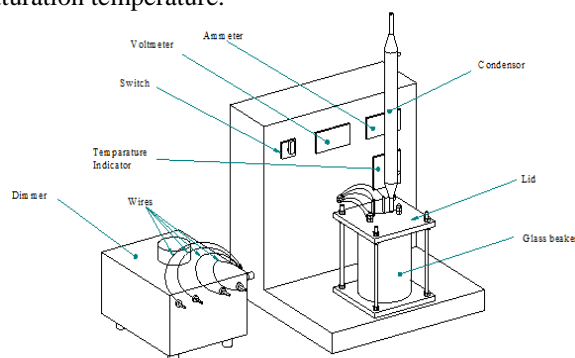


Fig 2.1 : Schematic diagram of Experimental setup

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 3, March 2017

The CHF of distilled water and Nanofluids ( $\text{TiO}_2$  &  $\text{MgO}$ ) were measured with a Nichrome (NiCr) wire of 36 SWG (0.193 mm diameter) horizontally submerged in the test fluid at atmospheric pressure. Length of the NiCr wire is 85 mm. Ends of the Nichrome wire is tightly secured to the electrodes with help of Nuts at each side of electrodes.

The Pool temperature was measured using a K-type of thermocouple. DC rectifier was used to supply DC Power to test heater. Through knob of the DC rectifier voltage and current is varied.

Nucleate boiling experiments for studying the CHF of nanofluids are normally conducted with thin wires or flat plates. Thin wires were used to simplify the measurement of average heat flux and surface temperature and the post inspection of the heater surface.

## 2.2 Experimental Methodology

1. Put sufficient water in water bath (2 lt).
2. Cut the sufficient length of nichrome wire i.e. 85mm.
3. Fix wire between electrodes and immerse it in water bath.
4. Switch on the experimental setup. Initially the distilled water in the beaker is heated upto saturation temperature of distilled water by setting a temperature value in the temperature controller.
5. The Temperature controller cuts off the power supply to the heating coil when the fluid reaches the saturation temperature of fluid.
6. With the help of auto transformer(Dimmer) increase the power supply to the electrodes and hence to the nichrome wire.
7. Observe and note the Voltmeter & Ammeter reading at the instance when the nichrome wire brakes or melt.
8. After that the distilled water is replaced by the nanofluid.
9. The required nanofluid concentration say 0.1 g/l is obtained by mixing 0.2 gram of Titanium oxide nanoparticles in 2 litres of distilled water and stirred for 2 hour.
10. Experiment is carried out at the various concentrations of Titanium oxide & Magnesium Oxide nanoparticles.

## 2.3 Properties of Nanoparticle Used

### 2.3.1 Properties of Titanium Oxide & Magnesium Oxide

Titanium Oxide ( $\text{TiO}_2$ ) & Magnesium Oxide( $\text{MgO}$ ) are the promising nanomaterial's for heat transfer enhancement purpose due to its excellent physical and chemical stability. In addition to this  $\text{TiO}_2$  &  $\text{MgO}$  particles are cheap and commercially available.

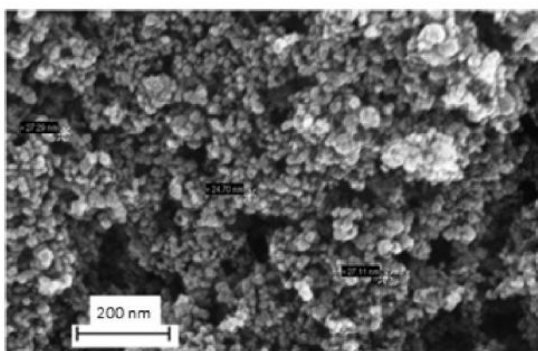


Fig 2.2- SEM Image of  $\text{TiO}_2$  Nanoparticle

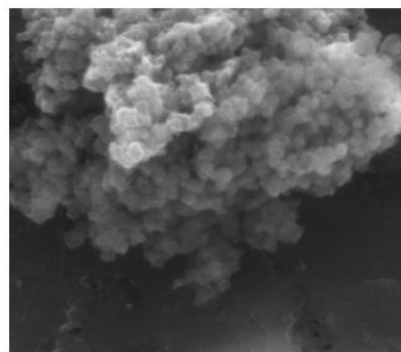


Fig 2.4- SEM Image of  $\text{MgO}$  Nanoparticle

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 3, March 2017

Parameters	Approximate Values	Parameters	Approximate Values
Crystalline Size	6 nm	Crystalline Size	7 nm
Surface Area	>50 m <sup>2</sup> /g	Surface Area	204 m <sup>2</sup> /g
Density	3580 kg/m <sup>3</sup>	Density	3780 kg/m <sup>3</sup>
Thermal Conductivity	45 W/mK	Thermal Conductivity	11.8 W/mK

## III. EXPERIMENTAL RESULTS

### 3.1 Performance variation of Distilled Water and Titanium oxide for various concentration

The Fig 3.1 shows the variation of current with voltage for the Titanium Oxide nanofluid. It shows that the nanofluid at concentration of 0.01g/lt, 0.1g/lt, 1g/lt are enhanced by 10.51%, 24.81%, 52.42% of CHF compared to Distilled Water.

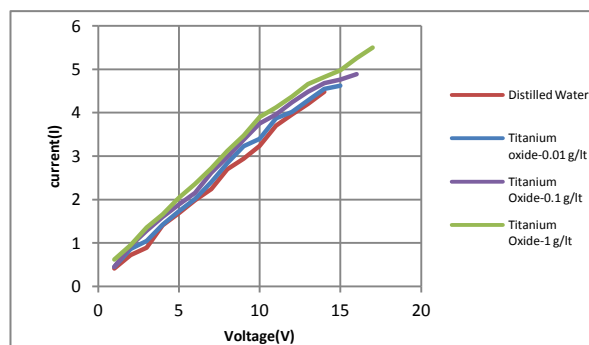


Fig 3.1- Variation of current with Voltage for various concentration of Titanium Oxide nanofluid with Distilled water

### 3.2 Performance variation of Distilled Water and Magnesium oxide for various concentration

The Fig 3.2 shows the variation of current with voltage for the Magnesium Oxide nanofluid. It shows that the nanofluid at concentration of 0.01g/lt, 0.1g/lt, 1g/lt are enhanced by 23%, 43.80%, 60.88% of CHF compared to Distilled Water.

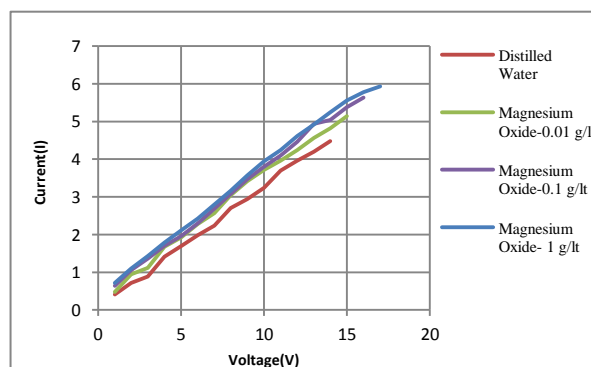


Fig 3.2- Variation of current with Voltage for various concentration of Magnesium Oxide nanofluid with Distilled water

### 3.3 Comparison of CHF with Distilled Water, Titanium Oxide, Magnesium Oxide for various concentration

Both the Nanofluids exhibit enhanced Critical Heat flux than that of Distilled Water and for increased value of nanoparticles volume fraction, CHF also start to increase. Fig 8 demonstrates the Critical heat flux variation for TiO<sub>2</sub> and MgO nanofluid with increased volume concentration. The result shows that CHF improves in the range of 10.51% to 52.42% in case of TiO<sub>2</sub> and 23% to 60.88% in case of MgO nanofluid with increase in volume fraction. The increase in CHF is due to the increase in thermal conductivity of nanofluid by the diffusion effect of nanoparticles in the Distilled water and particle migration.

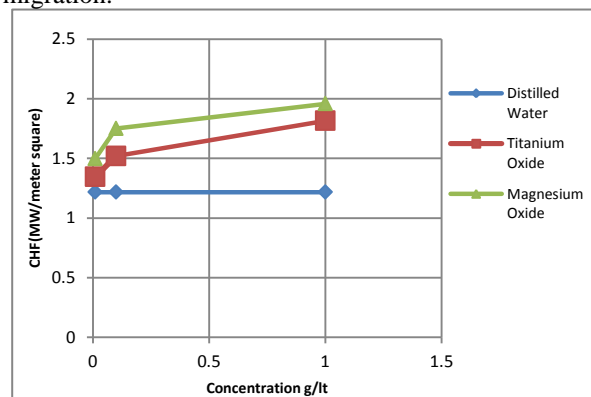


Fig 3.3- Variation of CHF with various concentrations of Titanium Oxide, Magnesium Oxide, and Distilled Water

### 3.4 SEM Analysis

During nanofluid boiling heat transfer, the nanoparticles deposited on the heating surface can increase the active cavities of nucleate boiling, thereby enhancing boiling heat transfer. This can be practically examined by, carrying a burnout wires after experimental conduction to the SEM analyser.

#### 3.4.1 SEM Analysis of TiO<sub>2</sub> 1 g/l

The burnout wire is collected in the test tube and taken to the Scanning Electron Microscope(SEM) for characterization of test wire at a different magnification (shown in Fig 3.4.1). From the Fig 3.4.1(a) it is clear that the after pool boiling experiment there small layer will be formed over the wire Fig 3.4.1(b) & Fig 3.4.1(c) are the magnified images of SEM micrograph which indicates the nanoparticle morphology of TiO<sub>2</sub> nanoparticle presented over the test wire.

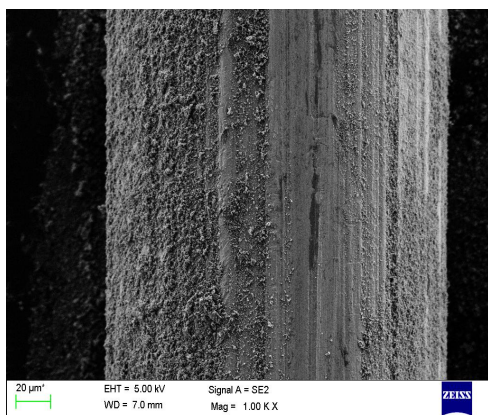


Fig 3.4.1(a)- SEM micrograph of nichrome wire after used in TiO<sub>2</sub> (1 g/l) (1000×)

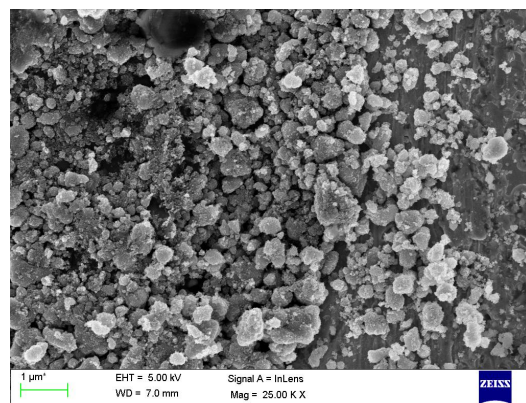


Fig 3.4.1(b)- SEM micrograph of nichrome wire after used in TiO<sub>2</sub> (1 g/l) (25000×)



## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 3, March 2017

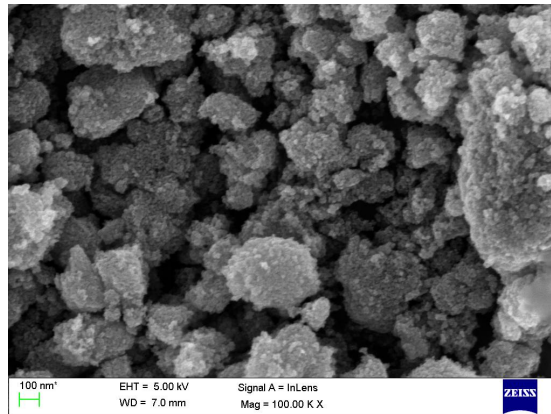


Fig 3.4.1(c)- SEM micrograph of nichrome wire after used in  $\text{TiO}_2$  (1 g/l) (100000 $\times$ )

### 3.4.2 SEM Analysis of MgO 1 g/l

The burnout wire is collected in the test tube and taken to the Scanning Electron Microscope (SEM) for characterization of test wire at a different magnification (shown in Fig 3.4.2). From the Fig 3.4.2(a) it is clear that the after pool boiling experiment there small layer will be formed over the wire Fig 3.4.2(b) & Fig 3.4.2(c) are the magnified images of SEM micrograph which indicates the nanoparticle morphology of MgO nanoparticle.

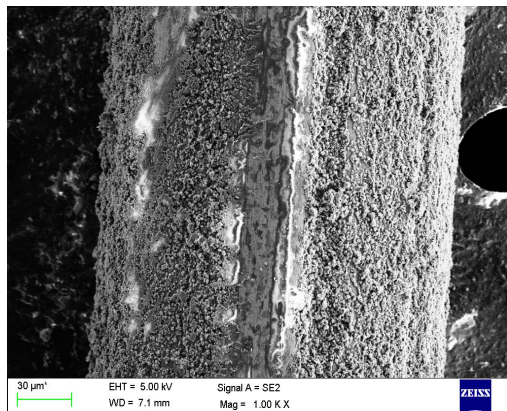


Fig 3.4.2(a)- SEM micrograph of nichrome wire after used in MgO (1 g/l) (1000 $\times$ )

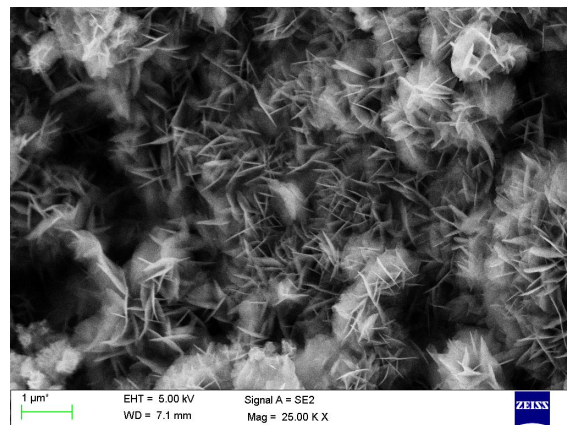


Fig 3.4.2(b)- SEM micrograph of nichrome wire after used in MgO (1 g/l) (25000 $\times$ )

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 3, March 2017

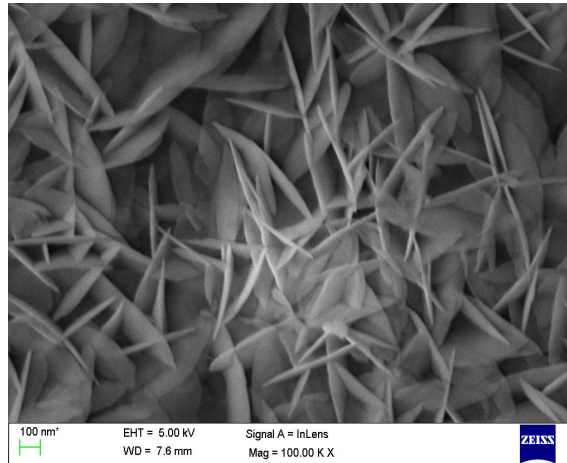


Fig 3.4.2(c)- SEM micrograph of nichrome wire after used in MgO (1 g/l) (100000×)

## IV. SURFACE ROUGHNESS

The surface roughness measurement is taken after the test surface exposed to different volume concentration of nanofluid after pool boiling critical heat flux tests made, known that critical heat flux enhancement of nanofluid is closely related with the surface microstructure and enhanced surroundings from the deposition of nanoparticles.

Since Nanofluid is a suspended nano sized particles in a distilled water, during the experiment the nanoparticles will adhere to the surface of the heater nichrome wire, this can be observed through SEM analysis. This adherence effect the heater wire surface roughness. nanofluid forms a layer over heater wire surface, thus surface roughness also changes. Rougher surface increase the nucleation site i.e physical location from which boiling process begins.



Fig 4.1- Optical Profilometer equipment for measuring Surface Roughness

Influence of surface roughness over critical heat flux can be studied by measuring the layer of nanoparticle coated over heater surface through optical profilometer device. From initial measurement of Bare wire to wire used in different concentration were measured and compared. The parameter, which is taken for investigation is  $R_a$  value. The  $R_a$  value can be defined as the Arithmetic mean deviation of the roughness profile from the line established while a surface

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 3, March 2017

roughness measurement. Millimeter( $\mu\text{m}$ ) is used as a unit for defining the surface roughness of measured nichrome wire.

Following surface roughness graphs are obtained.

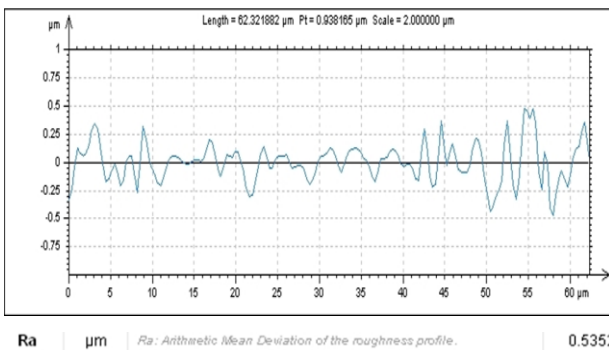


Fig 4.1- Surface roughness of Bare nichrome wire

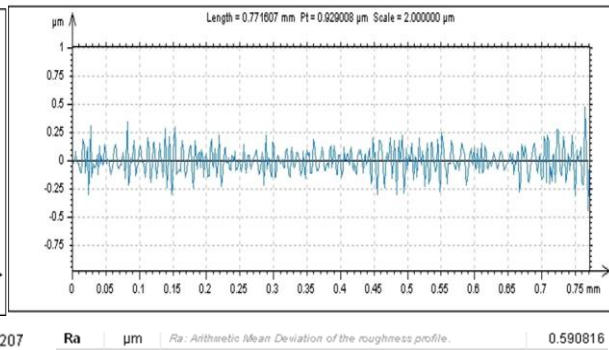


Fig 4.2- Surface roughness of wire used in distilled water.

Further the  $R_a$  value of three different volume concentration of  $\text{TiO}_2$  and  $\text{MgO}$  nanofluid were taken, compared .

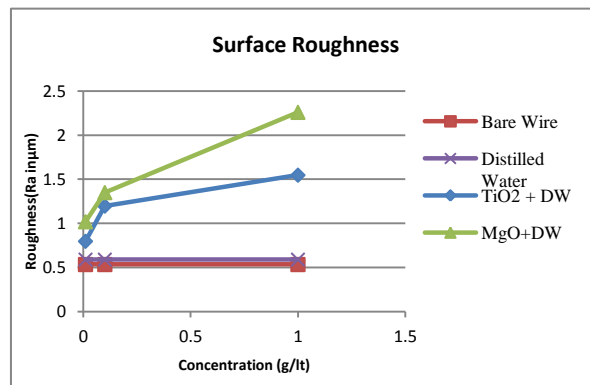


Fig 4.8.2- Variation of Roughness with increase in concentration

Surface roughness values for  $\text{TiO}_2$  and  $\text{MgO}$  nanofluids are increasing in order which indicates the surface coating of nanoparticles over the heater surface. Which is the reason behind the enhancement of CHF.

## V. CONCLUSIONS

1. Critical Heat Flux of  $\text{TiO}_2$  and  $\text{MgO}$  nanofluid are superior to the Distilled Water. And keep on increasing with the volume fraction, both fluids show significant increment in the CHF. This can be due to increased thermal conductivity of nanofluid and other reasons such as presence of Brownian motion and diffusion of nanoparticles in distilled water.
2. Critical Heat Flux of  $\text{TiO}_2$  nanofluid increased upto 52.42% and for  $\text{MgO}$  nanofluid Critical Heat Flux upto 60.88%.



## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 3, March 2017

3. Characterization of Nichrome wire after conducting each experiment in an Optical Profilometer reveals that the surface roughness of nanofluid based Nichrome wire increases compare to the Distilled water. Surface roughness for TiO<sub>2</sub> nanofluid increases upto 161.9% and for MgO nanofluid increases upto 282.46% compare to the surface roughness of Nichrome wire used in Distilled water.
4. Enhancing CHF can lead to substantial cost savings in terms of reduced capital investment.

### REFERENCES

- [1] **You S M et al** "Effect of nanoparticles on critical heat flux of water in pool boiling heat transfer" Applied Physics Letters 2003.
- [2] **Sudev Das et al** "A Correlation for the Prediction of Heat Flux for Nucleate Pool Boiling Heat Transfer of Nanofluid", Arab J SciEng 39:4997–5006,2014.
- [3] **M.Kim et al**, "Experimental study of the characteristics and mechanism of pool boiling CHF enhancement using nanofluids" Springer Journal of Heat and Mass Transfer,2007.
- [4] **Eiamsard S et al**, "Heat transfer enhancement of TiO<sub>2</sub>-water nanofluid in a heat exchanger tube equipped with overlapped dual twisted-tapes" Engineering Science and Technology, an International Journal 1-15, 2015.
- [5] **Jingliang Bi et al**, "Heat transfer characteristics and CHF prediction in nanofluid boiling", International Journal of Heat and Mass Transfer 80, pp 256-265,2015.
- [6] **Choi et al** "Measuring Thermal conductivity of fluid containing oxide nanoparticles" Journal of Heat Transfer,121, pp 280-289,1999.
- [7] **Somchai Wongwises et al** "Heat transfer enhancement and pressure drop characteristics of TiO<sub>2</sub>-water nanofluid in a double-tube counter flow heat exchanger", International Journal of Heat and Mass Transfer, Vol 52, pp 2059 – 2067,2009
- [8] **Zeinali Heris et al** "Experimental Investigation of convective heat transfer of Al<sub>2</sub>O<sub>3</sub>/water nanofluid in a circular tube", International Journal of Heat and Fluid Flow, Vol 28, pp 203 – 210, 2008.
- [9] **Ganesh Matre et al** " A Review of critical Heat Flux enhancement in Nucleate pool boiling of a Nanofluid" IJESRT, vol-3,pp 323-329,2015.
- [10] **Jones et al** "The Influence of Surface Roughness on Nucleate Pool Boiling Heat Transfer" *Birck and NCN Publications*. Paper 480,2009.
- [11] **Nitin A et al** "Pool boiling enhancement by using nanostructured surfaces: a review" Elixir Mech. Engg. 72,25397-25400, 2014
- [12] **Sunil L J et al** " Experimental Studies On Pool Boiling Heat Transfer Using Alumina And Graphene Oxide Nanofluids" International Research Journal of Engineering and Technology, Vol 03, pp 674-679, 2016