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Investigation of Pool Boiling Heat Transfer Characteristics of Graphene-Water Nanofluids

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***Abstract*: In this study, pool boiling heat transfer characteristics of Graphene-water nanofluids are reported. Graphene-water nanofluid of 0.05% and 0.1% concentration are prepared. The pool boiling experiments are conducted with Nichrome wire as the heater surface. The fundamental heat transfer characteristics for designing heat transfer devices such as Critical Heat Flux, Boiling Heat Transfer Coefficient and Wire Temperature are observed for the both concentrations of nanofluids, and the variation of these characteristics with different volume concentration are plotted. At the end of the Boiling Experiment, it was observed that the Critical Heat Flux showed an increasing trend with increase in nanoparticle concentration with a maximum enhancement of 28.04% compared to DI water. The Boiling Heat Transfer Coefficient also displayed an increasing trend with increase in nanoparticle concentration with a maximum enhancement of 65.74% compared to DI water. The Wire Temperature showed a decreasing trend with increase in nanoparticle concentration with a decrement of 47.2% compared to DI water. The burnout wire is observed under a Scanning Electron Microscope and the accumulation of Graphene nanoparticles on the Nichrome wire surface has been validated with the help of SEM and EDS data.**

***Keywords*: burnout, critical heat flux, energy dispersive spectroscopy, functionalization, ultrasonication.**

1. Introduction

Boiling heat transfer is a major application in most of the industrial and technological applications today. It has been identified as a cost effective and successful method in heat transfer applications. Boiling can be described as a process involving change of liquid phase to vapour phase. Boiling happens when a liquid interacts with a surface that has a temperature higher than the boiling point of the liquid. Practical applications of boiling range from air conditioners, electronic chips to nuclear reactors. It is therefore crucial to study and investigate the fundamental characterstics of boiling for efficient and safe designing and manufacturing of these heat exchange devices. The Heat Transfer characterstics in Aluminum oxide-water nanofluid with the condition of ultrasonic wave propagation under different regimes of flow were studied. It was observed that heat transfer efficiency reduces when heat flux is increased and the CHF was low during the ultrasonic irradiation stage and ultrasound is applied to improve the CHF [1]. The Pool Boiling Heat transfer characterstics of Silicon dioxide -water nanofluids quenching a vertical cylinder with four different volume concentrations showed that the HTC of the given nanofluid is similar to that of the water and the heat transfer coefficient decreased in the nucleate boiling regime compared to water due to the quenching tests performed causing decrease in deposition of SiO_2 [2]. The pool boiling HTC of Zinc Oxide - ethylene glycol nanofluids showed a 40% enhancement in thermal conductivity and 22% rise in BHTC along with a 11% enhancement in CHF compared to pure ethylene glycol [3]. It is observed that thermal conductivity is improved by 15% compared to water and CHF was enhanced by 49.84% for 0.1% Conc for CuO and alumina nanofluids with the CHF being higher for hybrid nanofluids when compared to single nanofluids [4]. The boiling performance characteristics for copper oxide and Zinc oxide nanofluids with sodium lauryl sulfate as a surfactant was observed. It is also found that highest enhancement in boiling performance characteristics was observed at maximum surfactant and nanoparticle concentration [5]. The pool boiling HTC of dil Aluminium oxide-ethylene glycol nanofluids with 3 volume fractions was observed and the fouling resistance was found to have a higher value for nucleate boiling comapred to free convection boiling [6]. The influence pool boiling CHF and transient heat transfer characterstics of aqua based Graphene oxide nanofluids on a thin nichrome wire was studied and it was observed that bubble density and CHF is enhanced with increase in nanoparticle concentration. The CHF was also found to be constant for repetitive experiments while investigating the bonding strength values and deteriorates beyond a limit [7]. The Pool boiling HTC with nickel oxide nanoparticle using deionized water in a magnetic field shows that the HTC is controlled by magnetic field and the field can alter the sedimentation high concentrated Nickel Oxide. The increase in heat transfer enhancement could be accounted to the rise in the intensity of magnetic field [8].

2. Nanofluid Preparation

Two Volume Concentrations of Graphene water nanofluid (0.05% and .1%) are prepared. Graphene generally has enhanced thermal and electrical conductivity. Deionized Water is the cheapest and prominent heat transfer fluid which can be used for Nanofluid preparation. For that the surface tension of the mixture must be reduced so there is proper dispersion of nanoplatelets with the base fluid. For that to occur, we can add surfactants. But for our experiment, we have used Functionalized Graphene nanoplatelets. The Graphene

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nanoparticles are treated with concentrated Nitric acid HNO_3 (69-72%) and is subjected to reflux condensation. This mixture is then stirred using a magnetic stirrer and the Functionalized Graphene is obtained by filtering it and drying it in an electric furnace. The functional group containing oxygen has been made to react with the surface of Graphene. Due to this process, water attracting surfaces known as hydrophilic surfaces are formed. These hydrophilic surfaces ensure that a homogenous and stable Graphene nanofluid is formed.

Fig. 1. Functionalized Graphene nanoplatelets

Fig. 2. DI water used as Base fluid

Fig. 3. Probe Ultrasonicator

Fig. 4. Controller apparatus

Fig. 5. Sonicated Nanofluid Solution

Fig. 6. Electronic balance

The Functionalized Graphene nanoplatelets are dispersed uniformly in the base fluid, Deionized Water. The mixture is then mixed using a magnetic stirrer. After this process, the stirred nanofluid solution is subjected to ultrasonication process with the help of an Ultrasonic Probe Sonicator. Ultrasonication is an effective process for nanofluid preparation as it involves sound waves, as a result of which the particles in the solution are agitated. Ultrasonication changes the binding properties of nanofluids which prevents sedimentation or coagulation of nanofluids and achieve a uniform and stable suspension. For the experimental work, two volume concentrations of Graphene nanofluids, 0.05% and 0.1% by volume have been prepared. The stirred solution is then kept inside the probe ultrasonicator and then is subjected to Ultrasonication process for 1 hour. Both the volume concentrations of Graphene nanofluids are prepared using this technique.

1000 ml of Graphene nanofluid for each of the volume concentration have been prepared. The amount of Graphene nanoplatelet to be added for each volume concentration can be calculated using the following relation:

$$Volume\ Fraction\ \% = \frac{(\mathrm{Wp}/\rho\mathrm{particle})}{(\mathrm{Wp}/\rho\mathrm{particle} + \mathrm{Volume\ of\ Basefluid})}$$

Where,
Wp = Weight of the particle to be added in gms
ρparticle = Density of Graphene (g/cc)

A high precision electronic balance with an accuracy of 0.0001 g is used to weigh the amount of Graphene nanoplatelets to be added for nanofluid preparation. It is initially set to zero after which the specific mass of nanoplatelet to be added is measured.

3. Experimentation

The test facility consists of a borosilicate cylindrical vessel for holding the nanofluid, a nichrome for heating the fluid, copper electrodes for heating the wire surface, dimmerstat for regulation of voltage, ammeter and voltmeter for current and voltage output monitoring and a temperature sensor for measuring the bath temperature. The main advantage with borosilicate glass is that it has a very limited thermal expansion coefficient. Due to this, it has the ability to withstand thermal stress and thermal shocks. Nichrome alloy has a very high thermal and electrical conductivity. They have the ability to resist a large amount of heat and are generally resistant to corrosion and hence they are used as heating element.

Fig. 7. Fabricated experimental setup

The experimental test facility is fabricated and all the connections are checked properly. Nichrome wire is inserted between the electrodes and locked with the lead screws. Deionized water and two different concentrations of Graphene nanofluid (0.05% and 0.1%) are used as the Working Fluids. Before starting the experiment, it is ensured that the boiling test is conducted at standard temperature and pressure. Initially the dimmerstat is set at 0V at the start of the experiment. With the help of dimmerstat, the voltage is increased uniformly and as a result the current slowly increases. The voltage is increased in small steps and the boiling process is observed carefully. The voltage and current values are noted consecutively for each bath temperature reading. The voltage is increased in large steps initially after which it is increased in small steps till the CHF point is reached. After supplying voltage for a longer period of time, a very drastic increase in wire resistance with rapid bubble formation along with a hissing sound is observed. If the voltage is increased beyond this point, CHF point is reached and the wire gets burnout. The Voltage, Current and Temperature values at the CHF point are noted. The experiment is repeated 2-3 times to validate repeatability. The CHF is calculated using the formula that has been listed in the Formulas section below. The BHTC and wire temperature is also calculated using the formulas given below. These values are calculated for DI water and both the Volume Concentrations of Graphene nanofluid. After calculation the values are compared graphically to analyze the variation and enhancement of heat transfer characteristics with respect to various conc. The sample of burnout wire is collected and observed under a Scanning Electron Microscope to validate the coating of Graphene nanoparticle on the wire. The measured CHF value of Distilled water is compared with the experimental value using the equation, known as the Zuber's correlation. This is done in order to predict the error percentage between experimental and theoretical CHF values. The results are analysed and the most effective nanofluid concentration is determined.

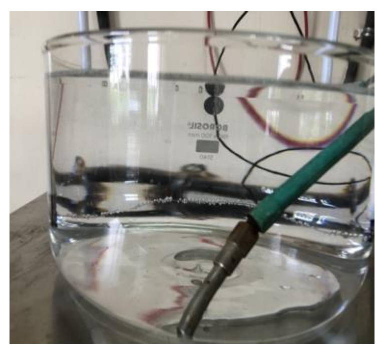


Fig. 8. Bubble formation across wire

Fig. 9. Wire Burnout at CHF point

4. Results and Discussions

The pool boiling experiment for the three different solutions performed includes: Deionized Water, Graphene nanofluid (0.05% vol) and Graphene nanofluid (0.1% vol) Heat transfer characterstics such as Critical Heat Flux, Wire Temperature and Boiling Heat Transfer Coefficient for these solutions are studied. Effects of each parameter on these solutions is discussed.

The CHF is calculated for different Conc. of nanofluid using the following relation:

$$\text{CHF} = \frac{V*I}{\pi*D*L}\ \text{KW/m}^2$$

V-voltage, I-Current, D and L- diameter and length of wire.

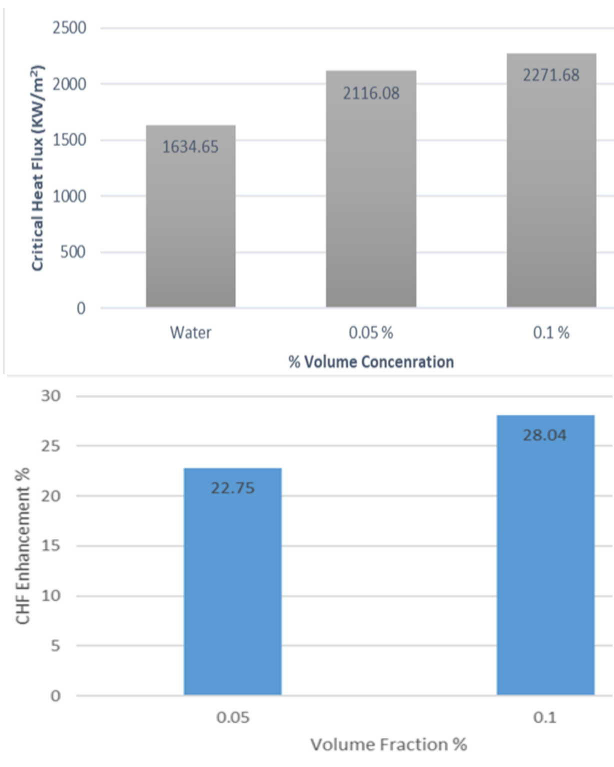


Fig. 10. CHF Variation and Enhancement with Volume Conc.

The variation of Critical Heat Flux with % Volume Fraction is plotted. From the graph it is observed that there is an increase in CHF with increase in Volume Conc. Of nanofluid. We can observe that the CHF is highest corresponding to 0.1% Volume Conc. Also, there is a 22.75% enhancement in CHF for 0.05% volume Conc. compared to deionized water and there is a 28.04% enhancement in CHF for 0.1% volume Conc. compared to deionized water. Therefore, from the two graphs we can clearly observe that an increase in nanoparticle concentration leads to increase in CHF. The reason for the enhancement in CHF is because of the raise in the Conc. of nanoparticles in deionized water, capability of the solution to conduct heat increases. Due to addition of nanoparticles, a thin layer deposition of nanoparticle on the wire surface is formed, preventing the overheating of the surface and eventually delays the burnout of the wire. As a result of this delay, more heat transfer takes place and this is the cause for the enhancement in CHF.

The Wire Temperature for different Conc. of nanofluids are calculated using the relation:

$$\text{Wire Temperature} = [(R_w/R_s)-1] * [1/\propto] + [T_s + 273]\ \text{K}$$

R_w – Wire resistance, R_s - Resistance at CHF point, $\propto$ - Coefficient of Resistance, T_s – Bath temperature

The variation of Wire Temperature with volume concentration is plotted above. It is observed that wire temperature decreases with increase in Vol Conc. There is a Wire Temperature decrement of 0.05% and 0.1% Vol Conc. by 38.82% and 47.2% compared to DI water. Therefore, we can observe from the two graphs that wire temperature decreases as the nanoparticle concentration increases. This decrease can be attributed to the formation of a thin layer deposition of graphene on the wire surface which reduces the heater temperature. As a result, there is a better cooling capability and effective performance for heat transfer devices.

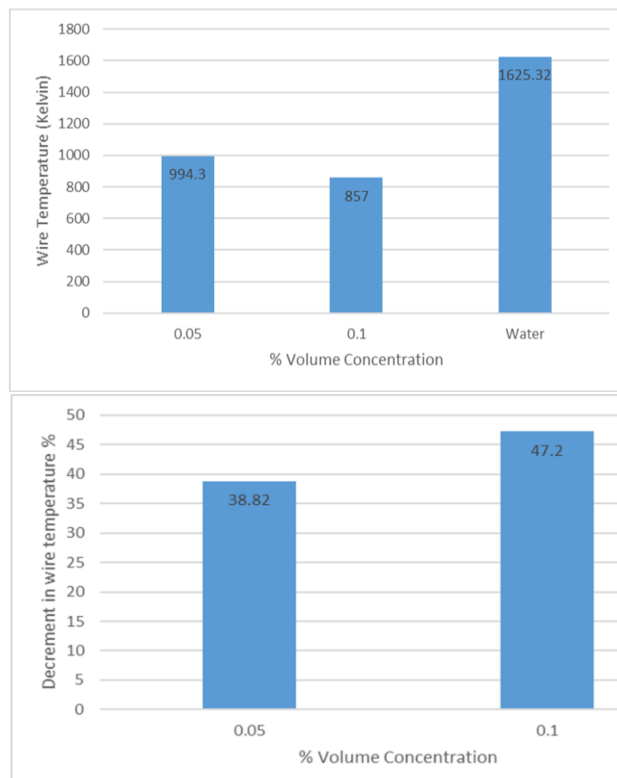


Fig. 11. Wire Temperature variation and Enhancement vs. Volume Conc.

The Boiling Heat Transfer Coefficient for different Conc. of nanofluids are calculated using the following relation:

$$\text{BHTC} = [\text{CHF}/((\pi DL) * \Delta T)]\ \text{W/m}^2\text{K})$$

ΔT – Difference between bath and wire temperature.

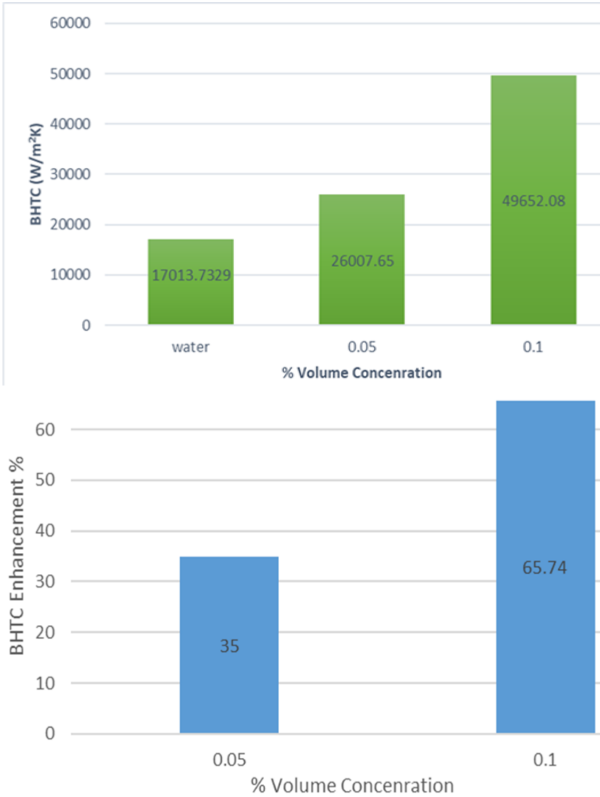


Fig. 12. BHTC Variation and Enhancement vs. Volume Conc.

From the graphs, we can observe that there is an increase in BHTC with increase in nanoparticle concentration. From the graphs we can observe that BHTC is highest for 0.1% Volume Conc. The Enhancement in BHTC was found to be 35% for 0.05% Volume Conc. and 65.74% for 0.1% Volume Conc. compared to the BHTC of Deionized water. From the above graphs, we can conclude that increase in nanoparticle concentration results in BHTC Enhancement. The reason for the enhancement in BHTC is because with the increase in the concentration of nanoparticles in DI water, the capability of the solution to conduct heat increases. Due to addition of nanoparticles, a thin layer deposition of nanoparticle on the wire surface is formed and this prevents the overheating of the surface and eventually delays the burnout of the wire. As a result of this delay, more heat transfer takes place and this can be the cause for the enhancement in BHTC.

After performing the boiling experiment, the burnout wire is examined under a Scanning Electron Microscope. If we observe closely at the test surface before and after boiling with nanofluid, we can see that the test surface is coated with a porous layer of particle which is possibly the nanoparticle. The presence of this porous layer distinguishes the heater surface before and after experimentation. The burnt wire sample is examined under SEM and various micrographs of the sample are obtained and observed.

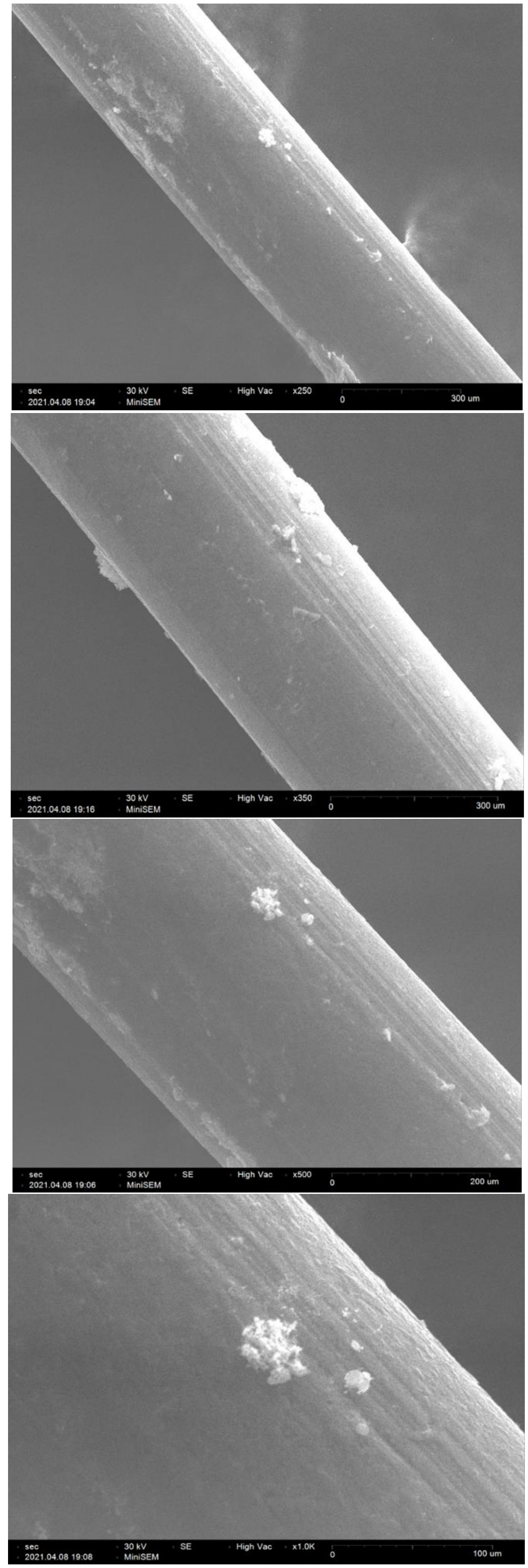
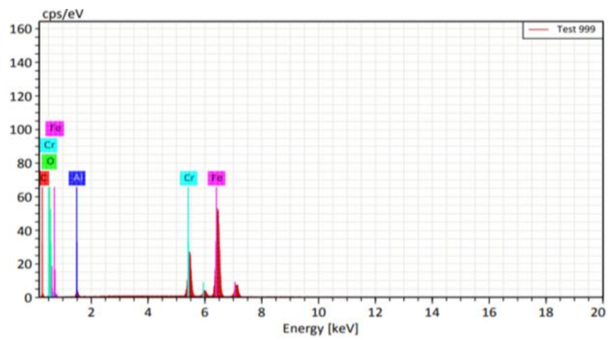


Fig. 13. Graphene (0.1% conc.) wire at 250X, 350X, 500X and 1000X magnifications

From the above figures, we can see the Scanning Electron micrograms of Ni-Cr wire at various magnifications for the 0.1% Volume Conc. of Graphene nanofluid. There are small irregular patches seen on the wire surface. This small irregular surface formed acts as a nucleation site during boiling which will result in the Enhancement of CHF. Therefore, we can deduce that the Enhancement in CHF and BHTC for 0.1% Volume Conc. is due to the irregular patches formed on the wire surface. To validate the presence of Graphene nanoparticles on the wire surface and to show the composition of particles present in the wire, the EDS test is done. EDAX is the software which is used for the analysis of EDS data. The data is analysed on 0.1% Volume Conc. Graphene nanofluid. The above data shows the presence of Carbon on the wire sample. The normalized mass percentage shows 18.74% of Carbon. This clearly validates the presence of Graphene nanoparticle on the wire surface.



Test 999

Element	At. No.	Netto	Mass [%]	Mass Norm. [%]	Atom [%]	abs. error [%] (1 sigma)	rel. error [%] (1 sigma)
Carbon	6	1684	1.86	18.74	49.34	0.39	21.09
Oxygen	8	516	0.27	2.69	5.32	0.10	36.96
Aluminium	13	315	0.08	0.84	0.99	0.03	38.62
Chromium	24	16746	0.80	8.00	4.87	0.05	5.96
Iron	26	71410	6.93	69.73	39.49	0.21	3.04
		Sum	9.94	100.00	100.00		

Fig. 14. EDS data

5. Conclusion

The pool boiling experiment was conducted using Ni-Cr wire for DI Water, 0.05% and 0.1% Volume Concentrations of Graphene nanofluid. The CHF calculated using Nichrome wire showed an increment in Graphene-water nanofluid with a maximum value of 2271.68 KW/m^2 for 0.1% Volume Conc. and showed a maximum increment of 28.04% in CHF corresponding to Graphene nanofluid when compared to DI water. The BHTC calculated using Nichrome wire showed a significant increment in Graphene-water nanofluid with a maximum value of 49652.08 W/m^{2}K for 0.1% Volume Conc. and showed a high increment of 65.74% in BHTC corresponding to Graphene nanofluid when compared to DI water. The wire Temperature measured showed a decreasing trend with increasing concentration of Graphene and it reaches a minimum value of 857 K for 0.1% Volume Conc. and showed the highest decrement of 47.2% in wire temperature compared to DI water. The presence of Graphene nanoparticles on the wire surface has been validated using SEM and EDS data.

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Abbreviations

CHF-Critical Heat Flux, BHTC-Boiling Heat Transfer Coefficient, HTC-Heat Transfer Characteristics, GnP-Graphene Nano platelets, ZnO-Zinc Oxide, SiO_2-Silicon dioxide, CuO-Copper Oxide, Conc.-Concentration, SEM-Scanning Electron Microscope, EDS-Energy Dispersive Spectroscopy, DI-Deionized

References

[1] Guoqing Shen, Likang Ma, Shuxiao Zhang, Shiping Zhang, Liansuo, (2019). “Effect of ultrasonic waves on heat transfer in Al_2O_3 nanofluid under natural convection and pool boiling”, in *International Journal of Heat and Mass Transfer*, vol. 138, pp. 516-523, 2019.

[2] Abdurrahim Bolukbasi and Dogan Ciloglu, “Pool boiling heat transfer characteristics of vertical cylinder quenched by SiO_2–water nanofluids,” in *International Journal of Thermal Sciences*, vol. 50, pp. 1013-1021, 2011.

[3] Madhusree Kole and T. K. Dey, “Investigations on the pool boiling heat transfer and critical heat flux of ZnO-ethylene glycol nanofluids”, in *Applied Thermal Engineering*, vol. 37, pp. 112-119, 2012.

[4] Yagnem Anil Reddy and S. Venkatachalapathy, “Heat Transfer Enhancement Studies in Pool Boiling using Hybrid Nanofluids,” in *Thermochimica Acta*, vol. 672, pp. 93-100, 2018.

[5] Sina N. Shoghl and M. Bahrami, “Experimental investigation on pool boiling heat transfer of ZnO, and CuO water-based nanofluids and effect of surfactant on heat transfer coefficient,” in *International Communications in Heat and Mass Transfer*, vol. 45, pp. 122-129, 2013.

[6] M. M. Sarafraz and F. Hormozi, “Nucleate pool boiling heat transfer characteristics of dilute Al_2O_3–ethyleneglycol nanofluids,” in *International Communications in Heat and Mass Transfer*, vol. 58, pp. 96-104, 2014.

[7] R. Kamatchi and G. Kumaresan, “Investigations on pool boiling critical heat flux, transient characteristics and bonding strength of heater wire with aqua based reduced graphene oxide nanofluids,” in *Chinese Journal of Chemical Engineering*, vol. 26, pp. 445-454, 2017.

[8] Sara Rostami, Ehsan Raki, Ali Abdollahi, and Aysan Shahsavar Goldanlou, “Effects of different magnetic fields on the boiling heat transfer coefficient of the NiO/deionized water nanofluid, an experimental investigation”, in *Powder Technology*, vol. 376, pp. 398-409, 2020.