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Numerical and Experimental Analysis of Pool Boiling Heat Transfer Using Graphene Nanofluid

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ABSTRACT: *Boiling of Nanofluid is an important area of research due to its potential to offer enhancement in heat transfer rate. Graphene nanoparticles based nanofluid is one of the most investigated nanofluids due to its wide range of advantages such as high thermal conductivity, high stability, low erosion, higher carrier mobility etc.; however, the disparity on the effect of boiling heat transfer subsists still. The present work investigates the effect of variation in graphene nanofluid concentration (0.1 and 0.2 volume % concentration) on the pool boiling heat transfer of a smooth copper sample. Subsequently, the results are compared with water as a working fluid for the purpose of estimating the effect of nanofluid on the heat transfer coefficient. Employing the volume of fluid method, numerical simulation is performed to study the effect of nanoparticle concentration. The experimental results are compared with the numerical simulation results and found in good agreement. It is seen that the rate of heat transfer increases significantly with graphene nanofluids as compared to pure water as working fluid.*

Keywords: pool boiling heat transfer; graphene nanofluid; numerical analysis; VOF method.

1. INTRODUCTION

Heat transfer enhancement technique is mainly classified into two categories: (i) active technique and (ii) passive technique. The fundamental difference between these two techniques is that: 'Passive technique' does not require any external driving force; whereas, an 'active technique' an external driving force such as a pump or fan, is required. Both the methods of heat transfer fundamentally depend on the mode of heat transfer, ranging from conduction, convection and radiation, and also depend on the thermodynamic state of the working fluid and transition from single phase to multiphase. Literature suggests that the presence of phase variation and transition in a typical heat transfer process is more useful due to augmentation in ineffective heat transfer as compared to a single phase heat transfer process. The boiling heat transfer process, i.e., one of the multiphase heat transfer processes, enables a greater perspective of improvement in the heat transfer coefficient due to the presence of complex interfacial evolution and latent heat transection. In general, boiling performance can be enhanced by the induction of heating surface modification or by improving the thermal characteristics of the working fluid. In the case of the former, the prime objective is to increase the available cavities to increase micro nucleation sites. The presence of myriad early literature indicates attention and volume of research directed towards this aspect of heat transfer improvement. Contrarily, the latter approach has received relatively less attention and inhabits discrepancies; some are due to the innovative disruption caused by the rapid development of new materials and methods for improving the thermal properties of a fluid. The current focus of the study is to investigate the effect of graphene nanoparticle on the performance of boiling heat transfer.

Historically, Shiro Nukiyama [1] in 1934 conducted the first experimental study of 'pool-boiling' of water at atmospheric pressure with nichrome and platinum wire. He found that "heat transfer increases as and when wall superheat increases; however, after a point, heat transfer coefficient decreases when the bubbles generated around the heated surface act as insulation around the surface". In the later years, multiple researchers conducted experiments using a different working fluid such as DI water, Dielectric fluid, and Non-dielectric fluid to investigate the boiling characteristics. Notably, properties like high thermal conductivity, high specific heat capacity and low viscosity make water one of the efficient working fluid for pool boiling heat transfer. Satish Kandlikar and Arvind Jaikumar [2] developed an extended surface for the experiment using water. They found that there is an enhancement in heat transfer coefficient (HTC) and critical heat flux (CHF) simultaneously. However, due to the high electrical conductivity and high saturation temperature, water is not a good option while dealing with electronic device cooling [2]. Therefore, for such application, dielectric fluid comes into action since it possesses characteristics such as good thermal stability, electrical properties, low inflammability and toxicity. The main dielectric fluids currently in use are FC series and refrigerant. Among all dielectric fluid, perfluorocarbon (FC-72) was mostly used dielectric fluid. FC-72 is thermally and chemically stable [3].

Wu et al. [4] conducted an experimental study to investigate nucleate boiling and CHF of water and FC-72 dielectric fluid on hydrophilic titanium nanoparticle modified surface. Comparing the result of the coated surface with a smooth surface they found that there is an increase of 50.4% for water and 38.2% for FC-72. This variation was because of their wettability characteristics. FC-72 is a highly wetting fluid than water. Eric Forrest et al. [5] used a new dielectric fluid, fluorinated ketone, which has high dielectric strength and low global warming potential (GWP). They found nucleate boiling heat transfer coefficient and CHF for fluorinated ketone and compared the result with results obtained for FC-72, a fluorocarbon widely used for the direct cooling of electronic devices. They found that pool boiling heat transfer properties of $C_2F_5C(O)CF(CF_3)_2$ are comparable to those of the commonly used perfluorocarbon FC-72 so increasing worldwide concern over global warming and the likelihood of reduction of HFC's and PFC's through the Kyoto protocol, NovecTM 649 may prove to be an attractive alternative to the haloalkanes. Implementation of nanotechnology in every field increases the generation of heat flux; furthermore, researchers come up with new effective fluid to transfer more heat, which is nanofluid. Some of the researchers used the nanofluid for coating purposes such as Sameer Gajghate et al. [6] conducted an experimental analysis for estimating the effect of the Zirconia nanoparticles coated layer on pool boiling heat transfer. He found that nanofluid coating enhances the HTC, and as the coating thickness increases, heat transfer also increases. Sameer Gajghate et al. [7, 8] and Akash Bhise et al. [9] also investigated the experimental and numerical analysis of pool boiling heat transfer of water on graphene – poly (3, 4 - ethylene dioxythiophene): poly (styrene sulfonate) and with graphene-coated copper sample. They found that coating improves the heat transfer coefficient, and a maximum of 52.6% increment in the heat transfer coefficient is observed for the highest coating thickness. At the same time, some researchers used nanofluid as a working fluid for pool boiling experiments. Kim et al. [10] were studied the pool boiling characteristics of nanofluid, which are prepared by the alumina, silica and zirconium. It was found that using nanoparticle in water significantly enhances the CHF in boiling experiments with a wire heater. Iqbal et al. [11] conducted an experiment for comparing thermo-physical properties of different three nanofluids, which are prepared by adding Al_2O_3, SiO_2, ZrO_2 in DI Water and enhancement was found to be 10.13%, 6.5%, and 8.5%, respectively. Fatemeh Dareh et al. [12] conducted an Experiments to investigate the nucleate pool boiling heat transfer of pure water and alumina/water nanofluids on different micro and nano-structured surfaces prepared via the thermal spray coating method. Results indicate that nanofluids boiling on all the test surfaces led to CHF values greater than that obtained for the base fluid. R. Kamatchi1 [13] dispersed rGO flakes in Millipore water to obtain 0.0005, 0.001, and 0.002 wt. % of rGO-water nanofluids. They conducted pool boiling heat transfer test on the smooth and sandblasted surface and found an enhancement in HTC. Seong Park et al. [14] conducted an experimental investigation for solving the problem of high heat generation at the nuclear reactors. They used graphene-oxide nanofluid to improve the critical heat flux during External reactor vessel cooling (ERVC). It was observed that the used nanofluid was very stable under the ERVC coolant chemical environment, and a 40% enhancement in CHF was obtained in the vertical orientation of the heater surface, and 200% enhancement was obtained for the horizontal orientation of the heater than water. Sunil L J et al. [15] prepared different concentrations of alumina and graphene oxide nanofluid for conducting an experiment to investigate pool boiling CHF characteristics. Even though GO has more good quality than Al_2O_3, due to the lack of molecular mixing of GO powder in water, GO nanofluid gives less performance than Al_2O_3 nanofluid. They observed an increase of 51.5% in CHF at 1g/1l concentration of GO nanofluid, whereas an increase in 56.27%in CHF observed for Al_2O_3 nanofluid for the same concentration. At the same time, some researchers are busy with the numerical investigation of nanofluid pool boiling. For conducting numerical simulation using nanofluid it is required to have the thermo-physical properties of graphene nanofluid. Margret Johnson et al. [16] conducted an experimental study to find the thermo-physical properties. They prepared graphene nanofluid by two-step method and find the properties such as thermal conductivity, viscosity and surface tension using hot wire apparatus, viscometer and tensiometer, respectively.

Aminfar et al. [17] conducted numerical analysis of pool boiling heat transfer using nanofluids first time ever. They used Two-phase and three-phase mixture model and control volume technique to study the pool boiling behavior of nanofluid. The found the numerical results are well accurate with experimental results. Afsaneh Rostamzadeh et al. [18] used the pseudo-potential multiphase lattice Boltzmann method to simulate nucleate pool boiling with a pure liquid and a nanofluid. The numerical result shows that the bubble departure diameter is greater for pure liquid, while bubble release frequency is higher in nanofluid.

After the wide literature survey, it was observed that lots of works had been conducted on pool boiling heat transfer. Very few studies have conducted on pool boiling using nanofluid. In that graphene nanofluid is less touched area. The present numerical and experimental study deals with the effect of different concentrations of Graphene nanofluid on pool boiling heat transfer coefficient under atmospheric conditions.

2. EXPERIMENTAL AND NUMERICAL METHODS

This section deals with the sample preparation, nanofluid preparation, experimental setup and its working and numerical method

2. 1 Sample Preparation

A copper piece of 6mm thickness is cut from 99.99% pure copper rod of diameter 35 mm. With the use of a lathe machine sample of diameter, 7 mm is prepared. For the better hold, a step cut is made on the sample from 3 mm thickness from the top with a diameter of 10 mm, as shown in Fig 2.1.

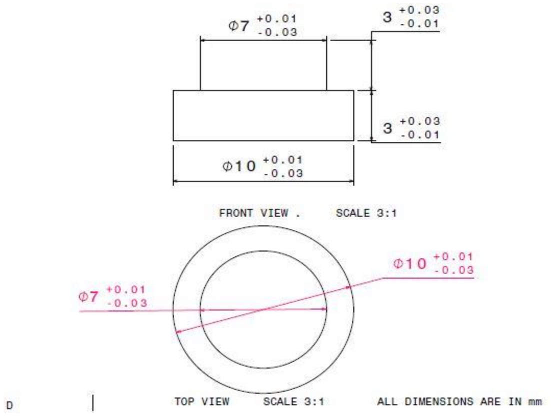

Fig. 2.1 Sample dimension

2. 2. Nanofluid Preparation

The sol-gel method is adopted to prepare the graphene based nanofluid for the present study. Before the nanofluid preparation, nanoparticles of graphene is procured form M/S Nano Wings Pvt. Ltd., Telangana INDIA. A Dimethylformamide (DMF) solvent is used for the dispersion of Graphene nanoparticles to prepare sol-gel. Two concentrations of nanofluids are prepared, i.e., 0.1 and 0.2 vol. % according to the required concentration, graphene nanopowder is measured by electronic weighing machine and measured graphene powder was immersed in 750 ml of DMF and passed through bath type ultrasonicator for 3 hour and magnetic stirrer with an rpm of 300 for 1 hour, the different concentration of graphene nanofluids are prepared in Nano Electronics laboratory at NIT Agartala.

2.3 Experimental Setup and Procedure

Figure 2. 2 and 2.3, shows the schematic diagram of the pool boiling setup and the heater block. Four cartridge heater of 150W is inserted inside a copper block, and the copper block is wrapped using Teflon for better insulation. This insulation helps to procure one-dimensional heat transfer. On top of the heater, the sample is placed. The sample is fixed on the heater using a Teflon cap. To avoid leaking of the working fluid, a step cut is provided on the sample. The whole assembly is submerged in a working fluid that is taken inside a boiling chamber through the bottom side. A primary heater is used to heat the working fluid to near the saturation temperature. Once it reaches near to saturation temperature primary heater switched off, and fluid is heated through the taken sample. Three thermocouple is used to measure the temperature of the heater at a different location. These temperatures and working fluid temperature is monitored in the control panel monitor. It also shows the input power.

Experiments are conducted at the atmospheric condition. Before doing the experiments, the boiling chamber was cleaned well using DI water and acetone and dried well. After fixing the whole heater assembly, initially, DI water is poured into the chamber and switch on both primary and test heater. Once the working liquid reaches the saturation condition, the primary heater switched off, and power input to the test heater increase gradually in an interval of time 30 min and readings are taken. After the same experiments have been conducted by using graphene nanofluid as working fluid and continued with other concentration also.

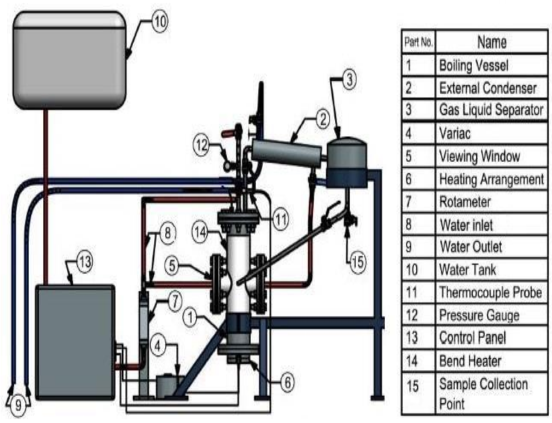

Fig. 2.2 Schematic diagram of Experimental setup

2.4 Numerical Analysis

Numerical analysis has been done in 'Ansys 17.2 Fluent' volume of fluid (VOF) model. The computational domain is a rectangular fluid domain of 35 X 60 mm dimension, in which 7 mm of the lower side of the rectangle is considered as the heater. Fig. 2.4 shows the fluid domain considered for the current numerical simulation. The portion of the bottom side of the rectangle is considered as the heater. The left and right side of the rectangle is taken as an adiabatic wall, and the top portion of the rectangle is taken as an outlet open to the atmosphere.

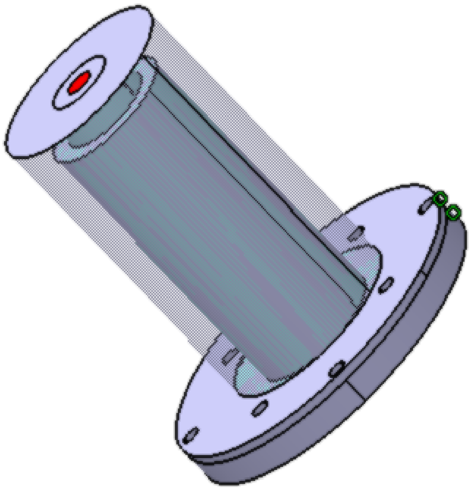

Fig. 2.3 Schematic diagram of heater block

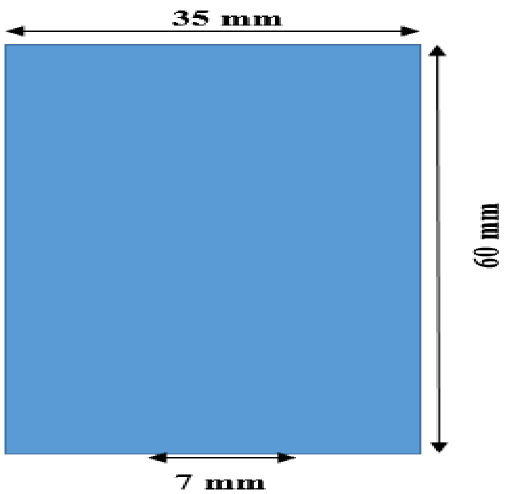

Fig. 2. 4 Computational Fluid Domain

Grid independent tests have been conducted to find the optimum number of the node. By increasing the number of node quality of mesh has confirmed by checking orthogonal quality and Skewness. For better mesh quality, orthogonal quality should be more than 0.85, and Skewness should be less than 0.25. Five cases have taken for independent grind tests and in each case, the above-mentioned quality has been satisfied. By increasing the number of nodes from 26759 to 327660, the maximum heat flux becomes almost constant. So the optimum number of nodes has taken as 27660.

The current problem is taken as transient and turbulent. The properties of each phase are assumed to be constant under the specified operating condition. The heater at the bottom is taken as a constant temperature. A time step of size 10^{-5} s is chosen for the simulation. Moreover, the iteration count per time step was set to assure that the solution is fairly converged at each time step. This value was achieved through a try and error procedure. The walls of the pool are considered to be adiabatic and no-slip condition and constant heat flux are set on the tube walls. The upper side of the pool is considered to be open to attain the saturation condition corresponding to the working fluid.

3. RESULT AND DISCUSSION

3.1 Experimental results

Figure 3.1 describes the variation of wall superheat with the variation of total surface heat flux of the smooth copper sample in water, 0.1 and 0.2 vol. % Graphene nanofluid. It is evident from the graph that the wall superheat is considerably reduced by using Nanofluid than water. Moreover, if the concentration increases, the wall superheat also decreases. A maximum of 45.95% reduction in wall superheat is observed for 0.2% vol. graphene nanofluid and 33.22% reduction is observed for 0.1% vol. graphene nanofluid at lower heat fluxes when compared with water as a working fluid. This might be due to the better heat transfer property of graphene nanofluid than water and also due to the sedimentation of nanoparticle on the surface, which will result in increment in nucleation site density. The reduction in wall superheat with the graphene nanofluid is prominent, but the use of structured surface or nanofluid coating may reduce the wall superheat furthermore undoubtedly.

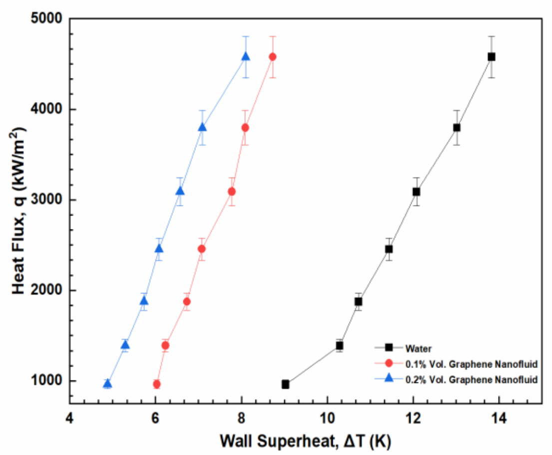

Fig. 3.1 Wall Superheat vs. Heat Flux

Figure 3.2 describes the variation of wall superheat with the variation of HTC of the copper sample with Graphene nanofluid (0.1% and 0.2% vol. concentration) and with water. It is evident from the graph that the HTC prominently improved for the considered Graphene nanofluids. A maximum of 48.59% increment in HTC is observed for 0.2 vol. % graphene nanofluid, and a 39.45% increment is observed for 0.1 vol. % than that of the water. This might be due to the improved convection heat transfer property of graphene nanofluid than water. Precipitation of nanoparticle on the heater surface also increases the heat transfer. Also, the use of structured surface or nanofluid coating may reduce the wall superheat furthermore, undoubtedly

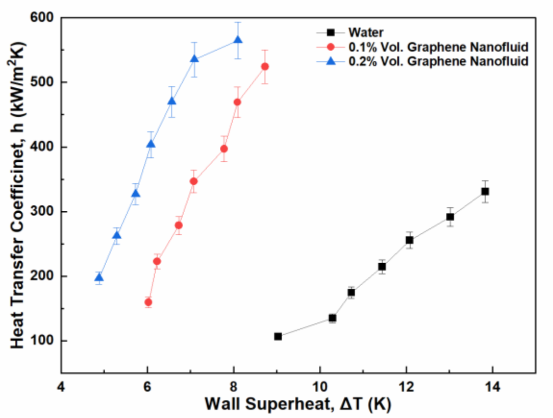

Fig. 3.2 Wall superheat vs. Heat transfer coefficient

The variation of HTC with heat flux is examined and described in Fig. 3.3. The boiling performance of the copper sample with graphene nanofluid was proved to be better than the copper with water. The increased thermal property of graphene nanofluid helps the augmentation of HTC. Moreover during boiling nanoparticles in the nanofluid get separate and start to sediment on the heater surface. This sedimentation produces new nucleation sites and helps to improve the heat transfer. Therefore by increasing the nanofluid concentration results in improving the heat transfer.

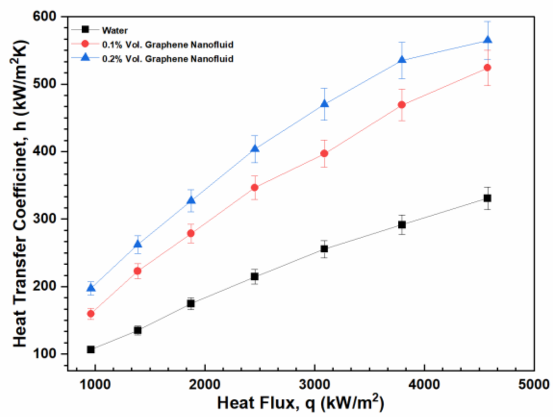

Fig. 3.3 Heat flux vs. Heat transfer coefficient

3.2 Numerical Result

Figure 3.4 shows the deviation of the experimental results with the numerical results of water as a working fluid. The numerical results are found to be fit well with the numerical results with a maximum deviation of 8%; the maximum deviation was observed at higher heat fluxes. This might be due to the lack of a prominent effect of convection in the boiling fluid. At lower heat fluxes, a minimum of 2% deviation was observed. Hence by this graph, the considered computational model gives the near accurate values for the considered numerical problem

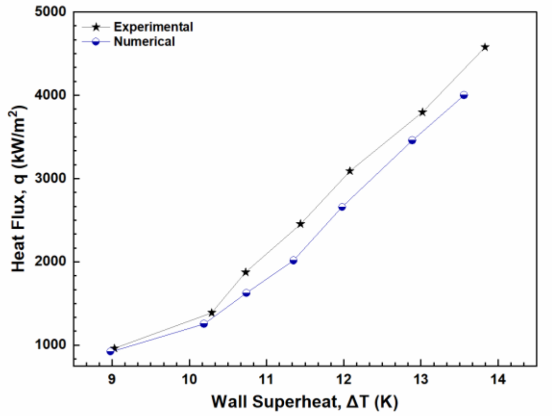

Fig. 3.4. Experimental Result vs. Numerical result

Figure 3.5 and 3.6 shows the velocity magnitude at a different point in the fluid domain and phase interaction along with the heater for water as the working fluid. Whereas Fig. 3.7 and 3.8 show the velocity vector in the bubble region and phase interaction of graphene nanofluid along with the heater. In Fig. 3.7 of velocity contours in the bubble region show the upward thrust gained by the bubble due to the surface tension, buoyance and micro convection effects. Since the graphene nanofluid is black in color, it is not possible to visualize the bubble dynamics during the experiment trails. Therefore a comparison of bubble dynamics is not possible with numerical analysis. But obtained bubble dynamics of water match with the experimental bubble dynamics.

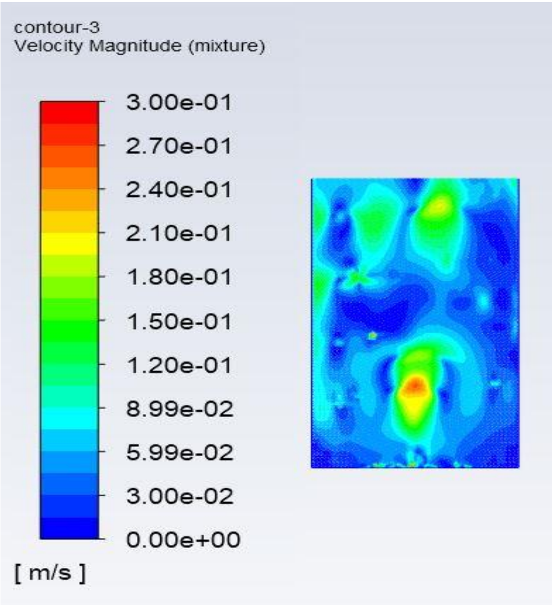

Fig. 3.5 Contours of velocity magnitude of water as working fluid

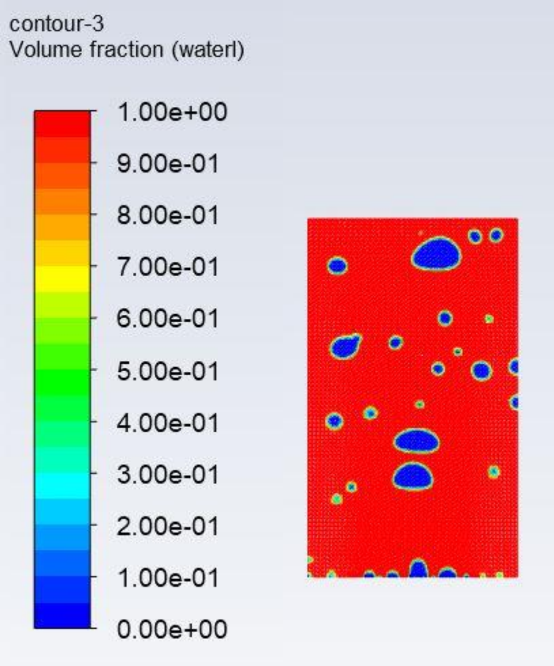

Fig. 3.6 Phase interaction of water along the heater

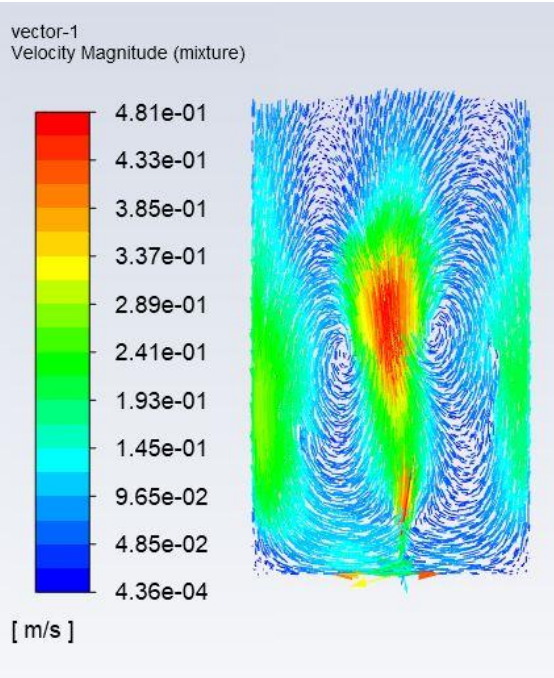

Fig 3.7 velocity vector in bubble region of graphene nanofluid

4. CONCLUSIONS AND FUTURE SCOPE

From the obtained experimental and numerical results, the following conclusions are made. It is to be wryly noted that these conclusions are restricted to the following experimental conditions and may vary due to the experimental uncertainties.

- The pool boiling heat transfer is augmented with the use of graphene nanofluid compared to DI water.

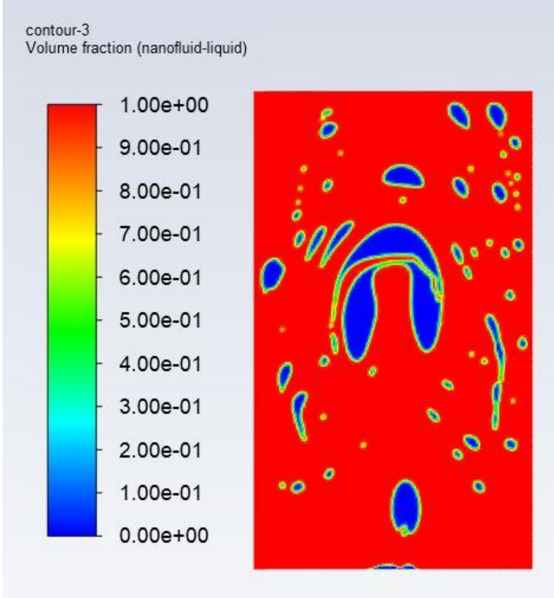

Fig. 3.8 phase interaction of graphene nanofluid

- As the concentration of nanofluid increases, augmentation of heat transfer also increases.
- A maximum of 45.95% reduction in wall superheat is observed for 0.2 vol. % graphene nanofluid and 33.22% reduction is observed for 0.1 vol. % graphene nanofluid at a lower heat flux of 961.934 kW/m^2 than DI water.
- At a higher heat flux of 4575.5788 kW/m^2 these reduction is about 41.43% and 36.87%, respectively, for 0.2 vol. % and 0.1 vol. % of graphene nanofluid.
- A maximum of 48.59% increment in HTC is observed for 0.2 vol. % graphene nanofluid and a 39.45 % increment are observed for 0.1 vol. % graphene nanofluid than water.
- The computational model is fitted well with the experimental results.

The scope of pool boiling heat transfer enhancement is vast and wide, from a simple electronics chip cooling to a very big nuclear vessel cooling in nuclear power plants. The past research has been suggested excellent, efficient methods of pool boiling heat transfer augmentation. But, there is still a wide research gap in the methods of pool boiling heat transfer enhancement and its estimation. Numerical methods have given great insight into the prediction of pool boiling heat transfer, where mechanistic models boosted the research with its efficiency to predict within less computational time. But these models are suitable only for the particular problems which are clearly specified, for instance. The authors suggest the researches investigate the boiling heat transfer enhancements with different shapes of nanostructures with high thermal conductivity nanofluids. And, the use of Artificial Neural Networks for the prediction of pool boiling parameters.

5. REFERENCES

[1] S. Nukiyama, The maximum and minimum values of the heat Q transmitted from metal to boiling water under atmospheric pressure, Int. J Heat Mass Transf., 9(12) (1966), 1419-1433.

[2]https://www.electronicscooling.com/2015/12/enhanced-pool-boiling-using-separate-liquid-vapor-pathways-for-cooling-high-heat-flux-electronics-devices/(access 01.12.2015)

[3] S. An et al., Supersonically sprayed reduced graphene oxide film to enhance critical heat flux in pool boiling, Int. J. Heat Mass Transf., 98 (2016), 124–130.

[4] W. Wu et al., Nucleate boiling heat transfer enhancement for water and FC-72 on titanium oxide and silicon oxide surfaces, Int. J. Heat Mass Transf., 53(9-10) (2010), 1773–1777.

[5] E. Forrest, L. W. Hu, J. Buongiorno, and T. McKrell, Pool Boiling Performance of Novec 649 Engineered Fluid, ECI Int. Conf. Boil. Heat Transf. Florianop., 1(2009), 7.

[6] S. S. Gajghate, A. V. Bandurkar, S. Das, B. B. Saha and S. Bhaumik, Effect of ZrO_2 Nanoparticle Deposited Layer on Pool Boiling Heat Transfer Enhancement, Heat Transfer Engineering, (2020). DOI: 10.1080/01457632.2020.1777011

[7] S. S. Gajghate, S. Vashishtha, S. Das, B. B. Saha and S. Bhaumik, Experimental and Numerical Investigation of Pool Boiling Heat Transfer over Different Thickness of Graphene–Poly(3,4-Ethylenedioxythiophene):Poly(Styrenesulfonate) Layers on Copper Heater Surface, Heat Transfer Engineering, (2020). DOI: 10.1080/01457632.2020.1777013

[8] S. S. Gajghate, S. Barathula, S. Das, B. B. Saha and S._Bhaumik, Experimental investigation and optimization of pool boiling heat transfer enhancement over graphene-coated copper surface, J. Therm. Anal. Calorim., vol. 140, pp. 1393–1411, Sep. 2019. DOI:_10.1007/s10973-019-087405.

[9] A. Bhise, S. S. Gajghate, S. Bhaumik, and S. Das, Effect of Graphene Coated Surface on Pool Boiling Heat Transfer by Spin Coating Method," Proc. 24th National and 2nd Inter. ISHMT-ASTFE Heat and Mass Transf. Conf, pp. 1621–1627, BITS Pilani, Dec. 27–30, Hyderabad, Telangana, India, 2017. DOI: 10. 1615/IHMTC-2017.2250.

[10] S. J. Kim, I. C. Bang, J. Buongiorno, L. W. Hu, Study of pool boiling and critical heat flux enhancement in nanofluids, Bull Pol Acad Sci.: Tech Sci, 55(2) (2007), 211 – 216.

[11] S. M Iqbal, C. S. Raj, J. J Michael, A. M. Irfan, A Comparative Investigation of Al_2O_3 / H_2O, SiO_2/H_2O and ZrO_2/H_2O Nanofluid for Heat Transfer Applications, Dig J Nanomater Biostructures, 12(2) (2017), 255–263.

[12] F. R. Dareh, M. Haghshenasfard, M. Nasr Esfahany, and H. Reza Salimi Jazi, An experimental investigation of pool boiling characteristics of alumina-water nanofluid over micro-/nanostructured surfaces, Heat Trans Engg, 40 (20) (2019), 1691-1708.

[13] R. Kamatchi, S. Kumar, and L. N. Upadhyay, Synthesis, characterization, stability analysis, and thermophysical properties of reduced graphene oxide-water nanofluids for solar collectors, Int. Conf Trends Adv Res in Green Energy Techno., 2010.

[14] S. D. Park, S. W. Lee, S. Kang, S. M. Kim, and I. C. Bang, Pool boiling CHF enhancement by graphene-oxide nanofluid under nuclear coolant chemical environments, Nucl. Eng. Des., 252 (2012), 184-191.

[15] L. J. Sunil, S. Kumarappa, R. K. Hegde, M. T. Thermal and P. Engineering, Experimental studies on pool boiling heat transfer using alumina and graphene oxide nanofluids, Int. Res J of Engg. and Technol, 3(1) (2016), 674–679.

[16] M. Johnson, J. R. Bose, and J. Livingston, Experimental study of thermo- physical properties of graphene water nanofluid below boiling temperature, Int J Mech Engg Technol, 9 (10) (2018), 1423–1433.

[17] H. Aminfar, M. Mohammadpourfard, and M. Sahraro, Numerical simulation of nucleate pool boiling on the horizontal surface for nano-fluid using wall heat flux partitioning method, Comput. Fluids, 66(2012), 29–38.

[18] A. Rostamzadeh, K. Jafarpur, and E. G. Rad, Numerical investigation of pool nucleate boiling in nanofluid with lattice Boltzmann method, J. Theor. Appl. Mech., 54(3) (2016), 811–825.