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The Numerical Research of Bubble Growth and Bubble Frequency in Pool Boiling using Metal Oxide Nano Fluid

Sai Ram Pothuri, K. Ayyappa Swamy, Pilli Sravani

Abstract: ***This category of liquids is in high demand because of the substantial increase in thermal efficiency as well as other nano fluid properties. During this study, the numerical assessment of nano fluids, such as CuO and ZnO, is considered to explore the nucleate boiling phenomenon. Critical improvement of the heat flux during the boiling of the adopted nano fluids at specific VOF levels has been visualized. Computational findings show that thermal properties of nano fluids such as heat transfer coefficient, surface heat flux, bubble frequency increase with the maximum concentration of nano fluids. The results show a similar trend with the literature. ZnO nano fluid delivers better results after a time period of 1 s, especially in comparison to CuO and other nano fluids due to higher thermal conductivity.***

Key Words: nucleate boiling, heat flux, nano fluids, bubble frequency.

I. INTRODUCTION

Nano fluids are a composite of Nano-size particulate concentrations of similar base fluids. Nano fluids have drawn an increasing number of investigations because of their higher properties associated with heat transfer and the exciting prospects of industrial applications [2]. Most materials namely chemically stable metals, metal oxides, some carbon allotropes and functionalized nano particles are widely used as nano particles. The key elements of nano fluids which have been observed until now contain abnormally high thermal conductivity at low concentration levels, an non-linear relation between the thermal conductivity and the Nano-tubes of carbon based fluids, a substantial increase in nucleate boiling critical heat flux (CHF) at low concentration[3].

Nano fluids heat transfer was intensively explored by nucleate boiling, primarily by means of experimental procedures. Literature studies have shown that,critical heat flux significantly increased and the emergence of porous layer on the heater surface of deposited nano particles.

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* Correspondence Author
Sai Ram Pothuri*, Mechanical Engineering Department ,NEC, Narasaraopet, India.
K. Ayyappa Swamy,, Mechanical Engineering Department , Birla institute of Technology and Science, Pilani, Rajasthan 333031, India
Pilli Sravani,, Mechanical Engineering Department ,NEC, Narasaraopet, India.

Almost all investigations, including those with incredibly low nano particle concentrations of dilute nano fluids [4, 5]. Modifying the thermal properties of nano fluids, such as thermal conductivity, heat capacity, surface wettability and density, is the key benefit of using nano fluids in heat transfer technologies. Computational analyses have been carried out by many investigators for direct analysis of bubble dynamics and the transfer of heat in single bubble nucleate boiling.

Yikun wei et al. (2015) the individual phenomenon's of bubbles during variable conditions of gravity, wall superheat, contact angle, interfacial shape, time of detachment and heat flux are examined [6].Woorim lee et al. (2010) he enhanced the level-set method to be generalized to measure a solid substrate nucleate boiling with submerged configurations like micro-cavities and the composition of the evaporative heat flux on the solid surface is simple and effective from inside the liquid micro-layer. He also performed quantitative strategy is used to properly assess the emergence and withdrawal of the bubbles throughout nucleate boiling [7].

Afsaneh rostamzadeh (2016) a pseudo-potential framework Boltzmann's multi-grid approach is used to visualize pool boiling nano fluids. Explores complex vapour bubble growth and thermal consequences in a nano fluid. Effective criteria for heat transfer from the heater interfaces to the hot fluids such as growth time, frequency of the bubble and departure diameter of the bubble are inherited and contrasted with pure liquids and nano fluids [8]. The analysis of CuO and ZnO nano fluids was carried out using a computational approach at different VOF levels in the present study. Parameters such as critical surface heat flux, coefficient of heat transfer, bubble dynamics and bubble detachment frequency are analysed and the outcomes are compared to studies of swamy et al. [1] under transient conditions.

II. THERMAL PROPERTIES OF NANO FLUID

Upon analysing all parameters such as VOF, particle size and Nano particle structure, Akilu et al. (2016) [19] has provided the correlation for the gathering of thermo-physical properties. The nano particle size influence has been reported on nano fluid viscosity that will impact formation of the bubble and frequency of the bubbles [Koca et al. (2018)]. In order to determine the nano fluid properties the following formulations are used.

$$\rho_{nf} = (1-\emptyset)\rho_{bf} + \emptyset_{\rho_p}$$

$$\mu_{nf} = (1 - 2.5\emptyset)\mu_{bf}$$

$$C_{p_{nf}} = \frac{(1-\emptyset)\rho_{bf} C_{p_{bf}} + \emptyset_{\rho_p} C_{p_p}}{\rho_{nf}}$$

$$K_{eff} = \frac{k_p + 2k_{bf} + 2(k_p - k_{bf})\emptyset_p}{k_p + 2k_{bf} - (k_p - k_{bf})\emptyset_p} k_{bf}$$

$$Nu = 0.4328(1 + 11.285\emptyset^{0.754} Pe^{0.218}) Re^{0.218} Pr^{0.4}$$

Where,
ρ = Density, kg/m^3,
φ = Particles volume concentration,
μ = Viscosity, kg/ms,
C_p = Heat capacity, J/kg°C,
K = thermal conductivity, W/m°C,
Φ = volume fraction,
Φ = Volume fraction,
Pe = peclet number,
Re = Reynolds number,
Pr = prandtl number.
Suffix
nf = nano fluid,
bf = base fluid,
ρ_p = Density of the nano particles, kg/m^3,
nf = nano fluid,
bf = base fluid,
p = nano particle,
bf = base fluid.

Tables [1-3] below give determined nano fluid property values:

Table 1: Properties of CuO - Water Nano fluid

CuO - Water				
Volume fraction	**Density [kg/m^3]**	**C_p [J/kg-k]**	**μ [kg/m-s]**	**K [W/m-k]**
0.05	1272.2	3250	9.585E-4	0.658
0.1	1547.4	2650	1.065E-3	0.692
0.15	1822.5	2232	1.1715E-3	0.716

Table 2: Properties of ZnO - Water Nano fluid

ZnO - Water				
Volume fraction	Density [kg/m^3]	C_p [J/kg-k]	μ [kg/m-s]	K [W/m-k]
0.05	1227.24	3338.52	9.585E-4	0.6967
0.1	1457.39	2763.505	1.065E-3	0.788
0.15	1687.535	2345.234	1.1715E-3	0.88927

Table 3: Properties of Water

Water			
Density [kg/m^3]	**C_p [J/kg-k]**	**μ [kg/m-s]**	**K [W/m-k]**
998.2	4182	0.6	0.001003

2.1 Computational Domain

For the bubble capture a rectangular 0.004m × 0.008m domain is generated which appears like a cylindrical vessel taken in two-dimensional.

III. MESH METHOD

Statistics were consistently, adequately and reliably obtained through studies of grid independence. The volume of elements and nodes continuing to increase until the water coefficient of heat transfer becomes stable is identified. The following was a tabled description of the computational tests carried out for the grid size assessment.

Table 4: Statistics of grid Independence

Volume of elements	Water Heat transfer Coefficient at 0.2 s
14560	1.842
16355	1.876
18011	1.985
20516	2.030
20788	2.029
30485	2.031

Mesh was developed using meshing tool, ICEM-CFD to establish less computational times and space depending on the above numerical observations. At 20516, the volume of elements and 2000 the number of nodes were fixed.

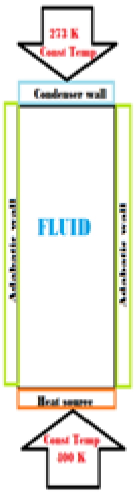

Figure 1: Line diagram with specified boundary conditions

Figure 1 represents the line diagram of boundary conditions given to the domain. Fine meshing is provided on the heater surface to capture the dynamics and departure of bubbles at 0.0001mm.

3.1 Governing Equations

This framework consists of a 3D turbulent flow, two phase, and transient with a Boussineq buoyancy parameter interpretation and a VOF model to visualize a multi-phase dynamic bubble profile.

3.2 Continuity Equation:

$$\frac{\partial}{\partial t}(\alpha_q \rho_q) + \nabla(\alpha_q \rho_q \vartheta_q)$$

3.3 Momentum Equation:

$$\frac{\partial}{\partial t}(\alpha_q \rho_q \vec{\vartheta}_q) + \nabla(\alpha_q\rho_q\vec{\vartheta}_q\vec{\vartheta}_q) = -\alpha\nabla P + \nabla\bar{\bar{\tau}} + \alpha_q\rho_q\vec{g} + \overrightarrow{R_{pq}} + (\overrightarrow{F_{lift}} + \overrightarrow{F_{ld,q}})$$

3.4 Energy Equation:

$$\frac{\partial}{\partial t}(\alpha_q \rho_q h_q) + \nabla(\alpha_q\rho_q\overrightarrow{u_q}h_q) = \alpha_q\frac{dP}{dt} + \bar{\bar{\tau}}\nabla\overrightarrow{u_q} - \nabla\dot{q}_q + \sum_{p=1}^{n} Q_{pq}$$

3.5 Boundary Conditions:

At a constant temperature of 400k, the bottom edge is considered as a heater and a condenser wall has a constant temperature of 273k on the top edge and adiabatic constraints are set on the remaining edges

IV. RESULTS AND DISCUSSION:

This analysis would numerically examine the initial growth and departure time of the bubble. At a constant temperature of 400k, the bottom edge is considered as a heater and a condenser wall has a constant temperature of 273k on the top edge and adiabatic constraints are set on the remaining edges. Numerical analysis was performed on nano fluids, CuO-water and ZnO-water at different VOF levels in order to visualize the bubble dynamics and growth of the bubble at a negligible time step of 1×10^{-5} sec. The results of these nano fluids are compared with Al_2O_3-water and TiO_2-water nano fluids at the same levels of VOF (**Ayyappa swamy et al. 2019**).The targeted VOF values are 0.05, 0.1 and 0.15.

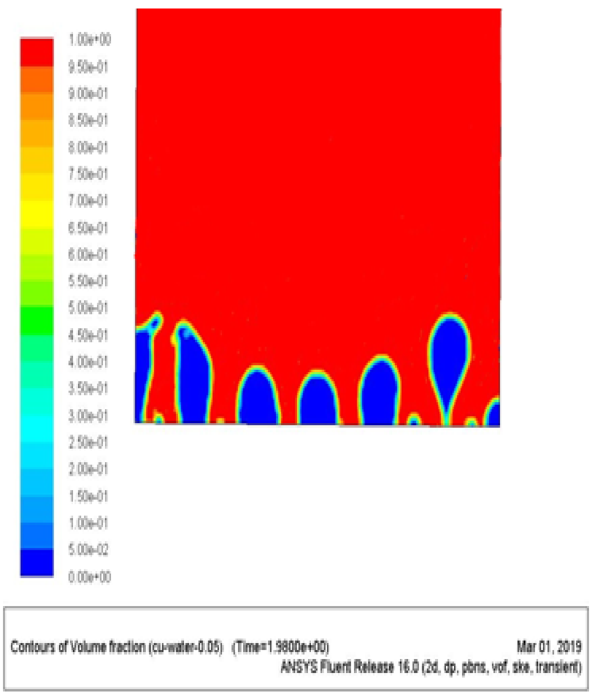

Figure 2a: Cuo - Water Nano fluid Phase Contour with 0.05 VOF during Bubble Departure (The Red Colour Symbolizes the Liquid phase and the Blue Colour Symbolizes the Vapour phase)

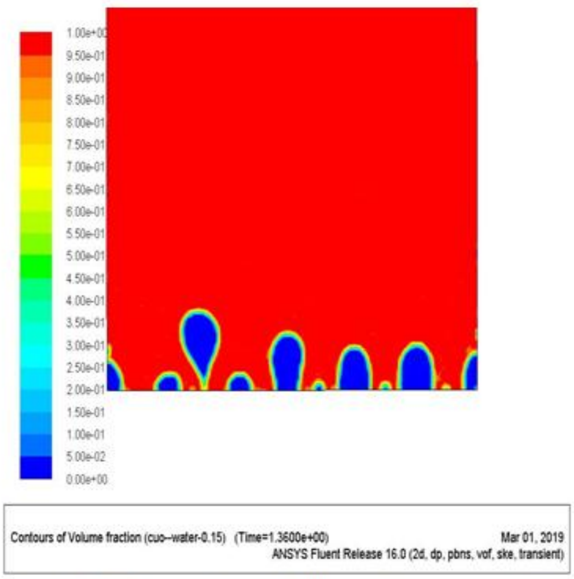

Figure 2c: Cuo - Water Nano fluid Phase Contour with 0.15 VOF during Bubble Departure (The Red Colour Symbolizes the Liquid phase and the Blue Colour Symbolizes the Vapour phase)

Figures 2a, 2b, 2c shows the emergence of the bubble and departure of the bubble for VOF 0.05, 0.1, 1.15 Cuo – water nano fluid. We may note from the above statistics that by Figures 2a, 2b, 2c shows the emergence of the bubble and departure of the bubble for VOF 0.05, 0.1, 1.15 Cuo – water nano fluid. We may note from the above statistics that by raising the nano particles number, the heat flux enhances and the departure of the bubble from the interface with the timeframe and the waiting period for new bubble development reduces. This means that the bubbles emerge from the heated surface gradually by rising the volume concentration. The bubble lift diameter decreases

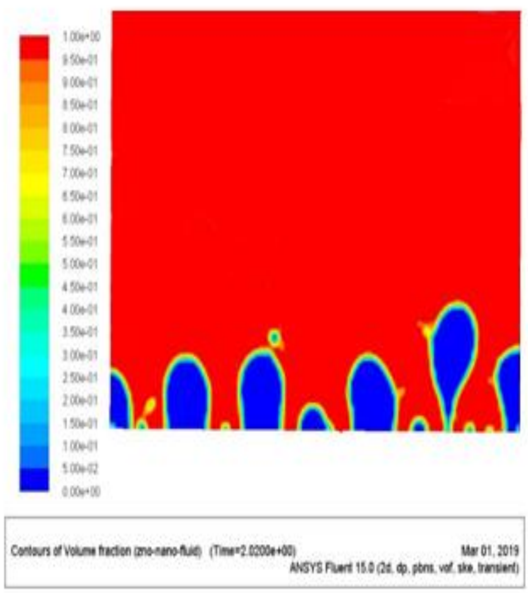

Figure 3a: ZnO - Water Nano fluid Phase Contour with 0.05 VOF during Bubble Departure (The Red Colour Symbolizes the Liquid phase and the Blue Colour

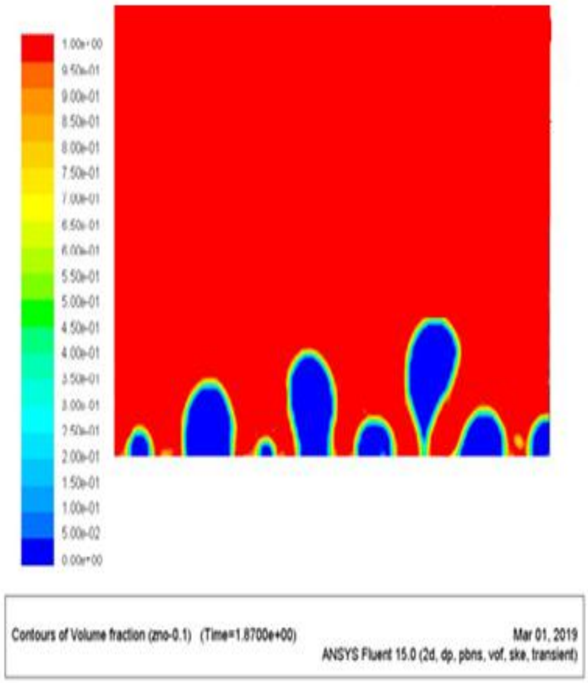

Figure 3b: Zno - Water Nanofluid Phase Contour with 0.1 VOF during Bubble Departure (The Red Colour Symbolizes the Liquid phase and the Blue Colour Symbolizes the Vapour phase)

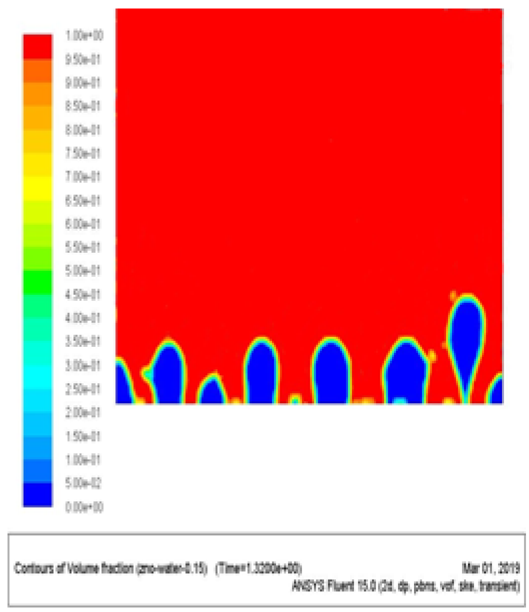

Figure 3c: Zno - Water Nano fluid Phase Contour with 0.15 VOF during Bubble Departure (The Red Colour Symbolizes the Liquid phase and the Blue Colour Symbolizes the Vapour phase)

significantly by rising volume concentration due to an increase in heat flux.

Figures 3a, 3b & 3c show the emergence of the bubbles and departure of the bubble from the heated ZnO – water nano fluid interface for 0.05, 0.1, 0.15 VOF numbers. Equating CuO and ZnO nano fluids, the thermal conductivity was determined to be greater for ZnO nano fluids, which basically states that a good proportion of ZnO nano fluid bubbles can be reported. The subsequent emergence of a bubble in CuO is higher due to the lower specific heat capacity of CuO relative to ZnOnano fluids. This shows that CuO nano fluid displays a greater bubble frequency.

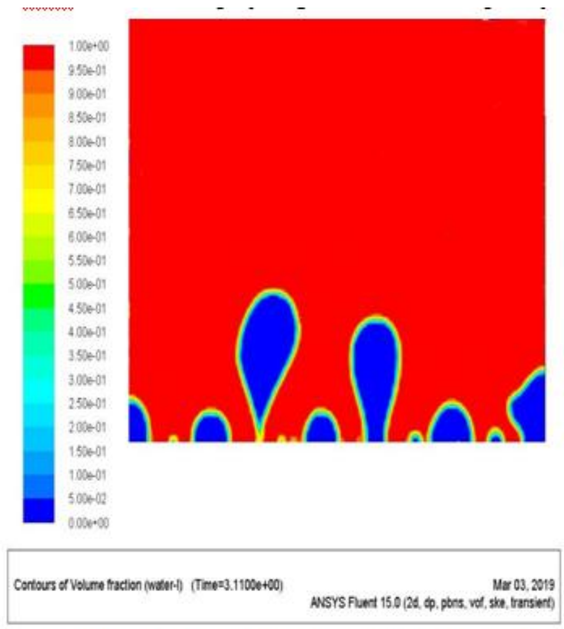

Figure 4: Water phase contour during bubble departure (The Red Colour Symbolizes the Liquid phase and the Blue Colour Symbolizes the Vapour phase)

The detachment and growth of the bubble in the heated interface is shown in the figure4. At the center of the compaction a bubble detachment was carried out. The bubble experience an upward force that contribute to its shape and to its lifting takes the wall surface due to the differing gravity and density. This ensures that the bubble slowly breaks down over time from the heated surface. Deformation in the shape of the bubble is detected when the bubble moves away from the wall due to the lack of balance caused by the surrounding fluid's bouncy and viscous drag force. The growth and departure bubbles shown in the above figures are equated with the outcomes of swamy et al. (2019) [1].

The relation of the CuO and ZnO concentrations of TSHF vs. HTC is shown at distinct time intervals in the figures 5 and 6. It is clear that for all CuO and ZnO proportions there is a linear variation is observed. This highlights the heat flux dependence on the heat transfer coefficient. Peak heat fluxes are notified at higher heat transfer coefficients at all VOF concentrations.

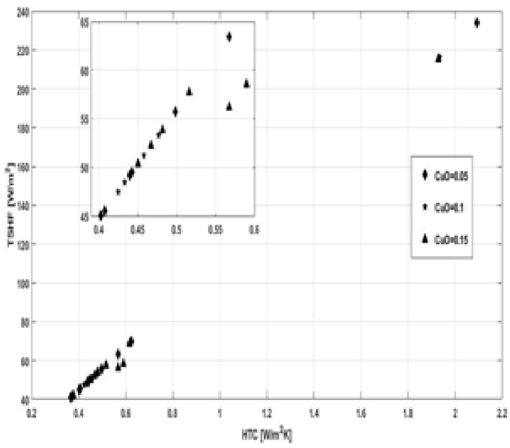

Figure 5: Comparison of HTC vs. TSHF of CuO (VOF of 0.05, 0.1, 0.15)

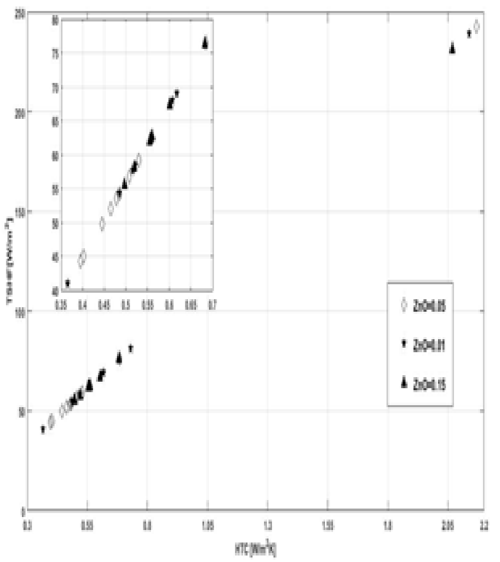

Figure 6: Comparison of HTC vs. TSHF of ZnO (VOF of 0.05, 0.1, 0.15)

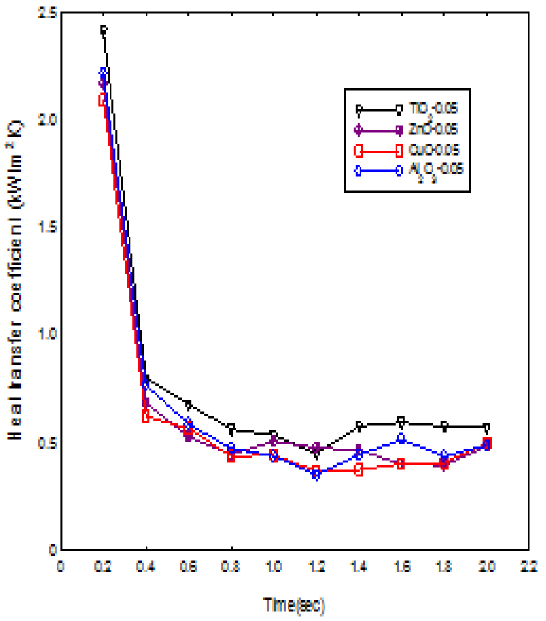

Figure 7: HTC vs. Time comparison of TiO_2, Al_2O_3, ZnO, CuOnano fluids at 0.05 VOF number

Figure 7 shows the investigation and resemblance of variation of HTC with respect to the time on the heated surface among CuO, ZnO nano fluids considered in present study and TiO_2 and Al_2O_3nano fluids adopted by swamy et al. (2019) [1] in his study at 0.05 VOF number.

The plot reveals that the HTC tends to reduce from 0.2 to 0.4 s rapidly and thereafter keeps consistent in CuO nano fluid and also large coefficients of heat transfer can be noticed. At 0.05 VOF number, the heat capacity of CuO is smaller than the existing nano fluids due to the fact that the bubble dynamics of CuO nano fluids are competitive.

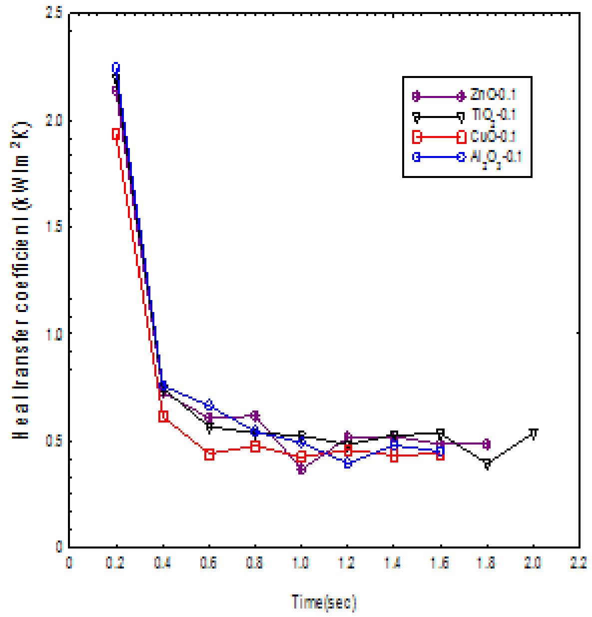

Figure 8: HTC vs. Time comparison of TiO_2, Al_2O_3, ZnO, CuO nano fluids at 0.1 VOF number

Figure 8 shows the investigation and resemblance of variation of HTC with respect to the time on the heated surface among CuO, ZnO nano fluids considered in present study and TiO_2 and Al_2O_3nano fluids adopted by swamy et al. (2019) [1] in his study at 0.1 VOF number.

The plot reveals that the HTC tends to reduce from 0.2 to 0.4 s rapidly and thereafter keeps consistent from 0.06 s in CuO nano fluid. The bubble grows uniformly across the pool.

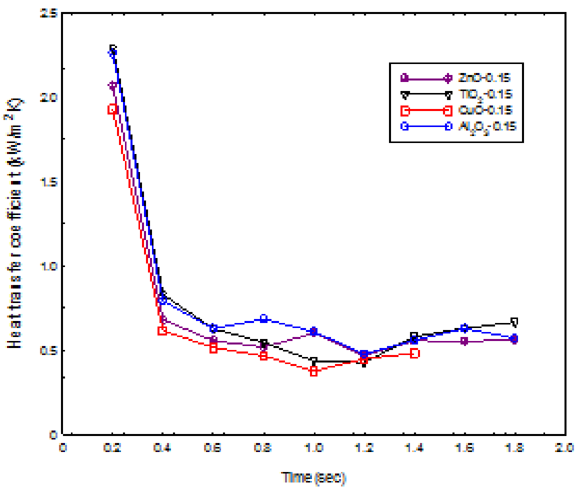

Figure 9: HTC vs. Time comparison of TiO_2, Al_2O_3, ZnO, CuO nano fluids at 0.15 VOF number

Figure 9 shows the investigation and resemblance of variation of HTC with respect to the time on the heated surface among CuO, ZnO nano fluids considered in present study and TiO_2 and Al_2O_3nano fluids adopted by swamy et al. (2019) [1] in his study at 0.15 VOF number.

Similar trends in heat transfer coefficients are observed in nano fluids at 0.15 VOF at a time interval between 0.2 to 0.4 s as recorded in figure 9.

This is due to the influential role of convection current and from 0.6 s onwards small bubbles begin to rise from the surface and collapse due to buoyancy. Throughout the HTC plots, ZnO is obvious from the duration of 1.0 sec as it has a greater thermal conductivity at all the levels of VOF than CuO.

Table 5: Bubble Frequency and Wait Time of Bubble at all VOF Concentrations

S. No.	VOF	Departure Time (Sec)	Second Bubble	Wait time of Bubble	Bubble frequency
1	Water				
	-	3.11	3.37	0.26	3.8461
2	Al_2O_3 - Water				
	0.05	1.92	2.13	0.21	4.7619
	0.1	1.87	2.04	0.17	5.8823
	0.15	1.78	1.93	0.15	6.6666
3	CuO - Water				
	0.05	1.98	2.2	0.22	4.5454
	0.1	1.63	1.81	0.18	5.5555
	0.15	1.36	1.52	0.16	6.25
4	TiO_2 - Water				
	0.05	1.97	2.16	0.19	5.2631
	0.1	1.62	1.77	0.15	6.6666
	0.15	1.61	1.74	0.13	7.6923
5	ZnO - Water				
	0.05	2.02	2.25	0.23	4.3478
	0.1	1.87	2.06	0.19	5.2631
	0.15	1.32	1.49	0.17	5.8823

The table above shows the start and subsequent time of departure of the bubble. Wait time for the bubble is the difference from initial bubble to second, allowing us to measure the time gap in the next bubble. The bubble frequency is determined using the wait time of the bubble. The reciprocal of wait time for the bubble is bubble frequency.

According to the above statistics, the larger the bubble frequency is the lower the wait time for the bubble, which also better involves HTC and TSHF in contrast to swamy et al. studies.

V. CONCLUSIONS:

A two-phase euler description of the flow (V O F model) was analysed for bubble nucleation, growth and separation from the air, the smooth, warmed surface is performed using ANSYS-CFD. The results of the computational analysis affirm the ability of the euler two-phase flow visualization on boiling for industrial installations. The study findings inferred that rising in bubble frequency with respect to VOFs of CuO and ZnO nano fluids can be validated by the HTC values achieved. It has proven that in contrast to ZnO nano particles, after certain periods of time CuO nano fluids demonstrate the consistent trend of heat transfer coefficients at all levels of VOF due to the greater bubble density.

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AUTHORS PROFILE

Mr. Sai Ram Pothuri M. Tech Student, Department of Mechanical Engineering, Narasaraopeta Engineering College, Narasaraopet, India

Mr. K. Ayyappa Swamy Department of Mechanical Engineering, Birla institute of Technology and Science, Pilani, Rajasthan 333031, India

Ms. Pilli Sravani Assistant professor, Department of Mechanical Engineering, Narasaraopeta Engineering College, Narasaraopet, India