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Review on the Effect of Various Nanofluids, Concentration and Its Thermophysical Properties in Pool Boiling Performance

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ABSTRACT

In recent years, numerous investigations have been carried out for the enhancement of nucleate pool boiling by modifying the fluid properties and hybrid the nanofluids. Nanofluids are the nanoparticle mixed the base liquid such as H_2O, deionized water, ethylene glycol, and so on. This paper is dedicated to the review of enhancement of pool boiling using nanofluids. The liquids have been considered by the investigator to acquire individual CHF, thermophysical properties on different applications such as the generation of power, cooling systems, solar devices, and so on. Many researchers have made different attempts in the literature of nanofluids to show the inconsistency in the critical heat flux (CHF). A detailed description of important factors, instability, and contradictions in the existing research is mentioned.

KEYWORDS

Nanofluids, Pool Boiling, Heat Transfer Coefficient, Critical Heat Flux (CHF).

Introduction

For the preparation of nanofluid various techniques and methods implemented for the enhancement of the CHF. Normally, Heat transfer liquids are used as conventional fluid such as deionized water, ethylene glycol and oil. For the enhancement of the CHF and heat rate researchers have been undergone with different techniques like coating the material, nano-structured material, sandblasting, nanofluid and usage of hybrid nanofluid and so on. In this study, the nanofluid research have been explained. A fluid colloidal with nanoparticle and base liquid is called nanofluid. To upgrade the heat transfer characteristics, thermal conductivity should be improved. The application of nanofluid plays an important role in pool boiling heat transfer such as reactors, fossil fuel boilers, air-conditioning and so on. In the upcoming sections preparation of the nanofluids, current investigations on thermal properties and heat transfer performance are discussed. During the time of CHF reaches the heating surface is covered with bubbles. It causes the increase in temperature and reaches the burn-out point drastically. To improve critical heat flux different investigations are carried out.

Enhancement of CHF is very much important to make the boiling systems safe and secure. The CHF express the thermal limit of the phenomena while heating takes place. When CHF attained in boiling systems suddenly the burn-out point will be reached. So, to ensure that CHF should not exceed the safety of the system.

Choi et al. [1] reported about the first nanofluid in 1995. Choi found that to enhance the thermal conductivity the metal and metal oxide should be added in the base liquid and created the new range of fluid use nanoparticles (1-100m) in the base fluid. In recent days, the researchers attracted to use nanofluids for the enhancement of pool boiling heat transfer and critical heat flux (CHF) [2-8]. The most detailed recent review on HT and CHF was presented by Gangtao Liang [2], where the enhancement methodologies of surfactant, additives and nanofluids were discussed. The detailed review was organized according to the recent process in HT and CHF and progress in

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nanofluids. Xiande Fang [3], where conducted a review on Heat Transfer and CHF of boiling nanofluids. Kamatchi [5] conducted an analysis on the enhancement of CHF in pool boiling with nanofluids. The evaluation was organized according to the different aspect for the improvement of CHF and according to the parameters such as size of the particle, surface and so on. The impact of nanoparticles on the thermal conductivity and pool boiling Heat Transfer and CHF was reviewed by Kshirsagar and Shrivastava [6].

Found that only one study article which specify the nucleate boiling of nanofluids [7]. This paper reviewed on the pool boiling Heat Transfer of nanofluids which stress on HT, CHF, drop in pressure, bubbles and so on. Nanofluid reviews in the thermophysical properties, boiling Heat Transfer performance, and CHF enhancement was reviewed by Wu and Zhao [8]. By using alumina-water nanofluids, you et al. [9] showed an CHF enhancement about 200% when compared to the CHF enhancement of 60% was viewed by using SiO_2 by Vassallo. [10]. Few researchers undergone the method of adding surfactant to the material and other researchers introduced the nanostructured method. Still nanofluid has an important attraction towards the researchers.

By using alumina-water nanofluids, Bang and Chang [11] conducted an experiment under barometric pressure and found the Critical Heat Flux enhancement. Kathiravan et al. [12] determined that when compared with deionized (DI) water, Copper based water nanofluid with addition of surfactant reduced with 75% in CHF. With increase of deposited layer thickness, the surface wettability increased which results in the enhancement of CHF [13]. The study related to the nano-refrigerants including pool boiling and flow boiling was performed by Celen et al. [14], where nano-refrigerants as nanofluid with refrigerant as base fluid. Some researchers used multi-walled carbon nanotube (MWCNT) mixed with water as a nanofluid. In which Multi-Wall CNT with addition of surfactant has lower CHF value than Multi-Wall CNT without surfactant and DI [15].

The nanofluids thermophysical properties have been measured by many researches whereas few used well-known predictive correlations [16]. Few researchers correlate the new technique which is hybrid nanofluid, which can be produced by suspending two or more nanoparticles as base liquid. This hybrid nanofluids achieve better thermal conductivity when compared to single nanofluid [17]. The researches on the hybrid nanofluid are very less and need to experiment a lot to overcome many challenges. Preparation methods of nanofluids were discussed in a few review articles [18-20]. From this we can understood that nanofluid in pool boiling helps for the enhancement of critical heat flux (CHF). The present review focuses on the preparation of nanofluid, thermophysical properties. Although, the results were varied according to the various factors implemented on the experiments.

Nanofluid

Definition of Nanofluid

Masuda et al. [21] attributed the first study about nanofluids in 1993 and proposed the deep change to the thermal conductivity and viscosity of the nanofluid. Nanofluid was dispersed with ultra-fine (13nm) nanoparticles of $Al2O_3$, SiO_2, and TiO_2 which is compared with pure water. To prepare nanofluid, nanoparticle will mix with chemical stable metals (eg: copper, gold, silver), metals oxides (eg: alumina, silica, titania) and other carbons (eg: diamond, graphite) [22]. From the past decades, researchers started experimenting with nanofluids. Nanoparticles (1-100nm) that are uniformly mixed in the fluid [23].

Preparation of Nanofluids

Nanoparticles of nanometre dimension suspended with liquid such as H_2O, oil and ethylene glycol are termed as nanofluid. In synthesis of nanofluid the major problem is agglomeration [24]. Nanofluids are synthesised using either one-step or two-step processes [23]. Two-step process is the top-down approach through reduction in size. Single-step method is the bottom-top approach through constant dispersion and production of nanoparticles. Nanofluids properties and behaviour mainly depends on the base fluid properties and dispersed phase, size and surfactant. Additives of nanofluid plays a vital role in changing the thermal properties. At present, various types of nanoparticles have been used in nanofluid preparation such as ceramic nanoparticles and metallic nanoparticles. There are different methods available in two-step method and one-step method. As denoted by Biswas et al [25], each method has its own advantages and disadvantages. By reducing the size of the nanoparticle there will be decrease in sedimentation rate of the nanoparticles and improvement in the stability of nanofluids. According to the Brownian motion of nanoparticles, when size of the nanoparticles decreases no sedimentation will take place. Therefore, applying smaller nanoparticles strongly improved for the stability of nanofluids and to prevent aggregation process [18]. In following parts, we will present the two techniques of nanofluid preparation. According to the study, few information on preparation of nanofluids are summarized on Table 1.

- **One-Step Method**

The combination of dispersion of nanoparticles and production of nanofluids takes place in single step is the single-step method. When differentiated to two-step method, the advantage of single-step method is increase in stability and reduction in agglomeration. The main drawback of the one-step method is only compatible with low vapor pressure fluids. This single-step method is classified into physical method and chemical vapor method.

Found that few researchers followed single-step physical vapour method to prepare the nanofluids. In this direct evaporation single-step method is one of the common techniques to produce nanofluid by the petrification of nanoparticles, which are at first in gaseous phase inside the base liquid. Akoh et al. [26] expanded the first one-step direct evaporation method, which is known as Vacuum Evaporation onto a Running Oil Substrate technique (VEROS). This method was developed for the production of nanofluid. But it was hard to separate the particles subsequently from the liquids to produce dry nanoparticles. Then a modified Vacuum Evaporation onto a Running Oil Substrate technique (VEROS) to cause low pressure Cu based ethylene glycol nanofluids was developed by Eastman et al. [27]. Wagener et al. [28] for the suspension preparation with metal nanoparticles such as silver and iron, which employed high pressure magnetron sputtering. To produce alumina nanofluids, another one step laser ablation method is used [29].

Many researchers are attracted by one-step chemical vapour technique due to the dispersion stability and increase in thermal conductivity. Zhu et al. [30] prepared copper nanofluid using one-step chemical process. Under microwave radiation, in ethylene glycol reducing $CuSO_4.5H_2O$ with $NaH_2PO_2.H_2O$. Results showed two significant factor which affect the properties of copper nanofluids and the reaction rate by the addition of NaH_2PO_2 with H_2O and adaption of microwave irradiation. Lo et al. [31] employed a vacuum- SANSS (submerged arc nanoparticle synthesis system) method to prepare copper based nanofluids with various dielectric liquids. Lo et al. [32] also produced the Ni nanomagnetic fluid using SANSS method. Indium-polyalphaeolefin nanofluids was produced by Han et al. [33] using chemical vapor method, which results in the thermal conductivity and specific heat enhancement. In the preparation of Ag-ethanol nanofluid, Polyvinylpyrrolidone (PVP) was used as a stabilizer by microwave assisted single step method [33].

- **Two-Step Method**

In two-step method, nanoparticles were generated and then dispersed in the base liquids. In the synthesis of nanofluids, the two-step method is extensively used. The nanoparticles are collected in the form of powders from several reputed companies. By using the hydrogen reduction technique, it is dispersed in base liquid, Jeena et al. [34] developed nanocomposites from the chemically prepared reactant mixtures using the two-step method. Nanoparticles are blend through vapor, liquid and mechanical routes. For high and large-scale production and improved properties as well as economic considerations, Vapor Phase state is preferred than liquid and mechanical routes [35]. By using an ultrasonic vibrator, nanofluid was produced by dispersing a specified quantity of nanoparticles in DI water with sodium lauryl sulfate as dispersant [36]. Although, in the preparation of oxide particles the two-step method is used [37-39]. Also, the other particles like Ag, graphene oxide, carbon nanotubes (CNT) are also prepared in this method [40-42]. For application with the particle concentrations higher than 20% volume, where two-step method is useful but it is less achievable with metal nanoparticles [43]. In application the usage of nanofluids heavily depends on its stability. By using ultra sonicator, the stability of the dispersion of nanofluids is obtained. In different research studies sedimentation and placing of nanofluid in sonicator appears in different time period. Different techniques like mechanisms for stability, pH control, nanoparticle with modified surfaces and addition of surfactants are incorporated in order to avoid particle cluster and for the improvement of the surface properties of the nanofluids [44]. The high stability without any inclination of sedimentation for three days was observed in electro stabilized nanofluids [45]. By adding 0.1% mol concentration of Hydrochloric to alumina-based water nanofluid gives low pH

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value and improvement in dispersion stability. The drawback is it corroded the surface of heating during boiling of nanofluid [46]. Instead of ultrasonic equipment, some other methods like pH control, addition of surfactant are also implemented to reach the stability of the suspension of the nanofluids without any sedimentation. To change the properties of the surface of suspended particles and to crush the tendency to form particle clusters, these methods are used. Especially, at high temperature the addition of dispersants can influence the heat transfer performance of nanofluids. When compared to the single-step method, the two-step method functions well for oxide nanoparticles but it is less successful with metallic particles.

Hybrid Nanofluids

Nanoparticles composed with two or more materials with different nanometre in size is termed as hybrid nanoparticles or composite nanoparticles, where combining of hybrid nanoparticles with the base liquid like H_2O, oil and ethylene glycol are known as hybrid nanofluids. In recent days, researchers are attracted with this hybrid nanofluid for the enhancement of the thermal conductivity of the nanofluids. A single nanofluid does not gives enhancement in all the characteristics required for a specific purpose. But hybrid nanofluid gives required properties in many practical applications. To synthesize the copper based Al_2O_3 nanocomposite powders, Shehata [47] used mechanochemical method with two various routes. Shehata et al. carried out two different routes, one is addition of copper to aqueous solution of aluminium nitrate and another one is addition of copper to aqueous solution of aluminium nitrate and ammonium hydroxide. R. Vidhya [48] proposed that hybrid nanofluid can be prepared by using two-step method, which contain dispersion of nanoparticles in the base liquid. By mixing of ZnO and MgO nanoparticles, hybrid nanofluids have been prepared with the weight concentration of 50:50% mixed with the base fluid distilled water and ethylene glycol. By hydrogen reduction technique from the powder mixture of Al_2O_3 and copper oxide in 90:10 weight, Suresh et al [49] prepared Al_2O_3–copper hybrid particles from a chemical route synthesis. By using Scherrer formula, the average grain size of the hybrid particles was calculated to be 15 nm. DavoodToghrai [50] experimented the two-stage method to produce ZnO-Ag/water nanofluid also with an ultrasonic device, a magnetic mixture, and acidity control technique. In this study, at different temperatures have produced various results given an increase in thermal conductivity. From this study, it is understood that, for several nanofluid preparation method producing homogenous nanofluids with long-term stability and negligible agglomeration without affecting the thermo-physical properties.

Table 1. Summary of few experiments on Nanofluids.

Researchers	Year	Particles	Base Fluid	Concentration
Pak and Cho. [51]	1998	alpha-Al_2O_3	water	1-3 vol.%
Eastman et al. [52]	1999	CuO	water	0.9 vol.%
S. Witharana [53]	2003	Au, SiO_2	water, EG	0.01 wt.% and 50 wt.%
Das SK [54]	2003	Al_2O_3	water	1–4 vol%
J. Tu [55]	2004	Al_2O_3	water	No data
Bang and Chang [56]	2005	Al_2O_3	water	0–4 vol.%
Lai et al [57]	2006	Al_2O_3	water	0-1 vol.%
Z. Liu [58]	2007	CuO	water	0.1-2 wt.%
Esfahany et al [59]	2007	alpha-Al_2O_3	water	0.2-2.5 vol.%
Bang et al. [60]	2008	Al_2O_3	ethanol	0.01 vol.%
Z. Liu [61]	2008	SiO_2, CuO	water	0.057-0.57 vol.%
M. Chopkar [62]	2008	ZrO_2	water	0.005-0.15 vol.%
K.J. Park [63]	2009	CNT	water	10^{-4}-0.05vol.%
H. Kim & J. Kim [64]	2009	SiO_2	water	0.0001–1 vol.%
M.N. Golubovic [65]	2009	Al_2O_3, BiO_2	water	0-0.01 vol.%
S. Soltan [66]	2010	Al_2O_3	Water	0.8-1.4 wt.%
A. Suriyawong [67]	2010	TiO_2	water	0.00005-0.01 vol. %
S.Z. Heris [68]	2011	CuO	EG-water	0.1-0.5 wt.%
B. Stutz [69]	2011	Alpha-Fe_2O_3	water	0.1 wt%
Park et al. [70]	2012	Graphene-oxide, Al_2O_3, SiO_2	water	0.0001 vol.%
M. Kole [71]	2012	ZnO	EG	0.5-3.75 vol.%
S.N. Shoghl [72]	2013	CuO, ZnO	water	0.01-0.02 wt.%
Y. Jung [73]	2013	Al_2O_3	LiBr-water mixture	0.01–0.1 vol.%
Song et al [74]	2014	SiC	water	0.0001–0.01 vol.%
H. Kim [75]	2014	TiO_2	water	0.01 vol.%
M.M. Sarafraz [76]	2015	CuO	water	0.1-0.4 wt.%

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Park and Kim [77]	2015	CNT	water	0.0001–0.1 vol.%
He et al. [78]	2016	ZnO	EG-water	5.25 wt.%
Hu et al [79]	2016	Graphene	EG-water	0.005–0.1 wt.%
Dadjoo et al [80]	2017	SiO_2	water	0.001–0.005 vol.%
Ciloglu [81]	2017	SiO_2	water	0.01–0.1 vol.%
Rostamian [82]	2018	SiO_2	water	0.005 vol.%
Kumar et al [83]	2018	Fe_2O_3, Al_2O_3, CuO	water	0.01–0.1 vol.%

Charaterization of Nanofluids

The techniques are discussed in this section which are used frequently used by the researchers who are attempting to classify nanofluids are discussed. Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), X-Ray Diffraction (XRD), Fourier Transform Infrared Spectroscopy (FT-IR), Dynamic Light Scanning (DLS), and Zeta Potential Analysis are some of the techniques used to classify the nanofluids. Nanoparticles or nanostructured materials are studied for their microstructure and morphology, SEM analysis is carried out. TEM is also like SEM but much higher resolution than SEM. The surface chemistry of solid particles and solid or liquid particles is being studied, FT-IR is done. To identify and study the crystal structure of nanoparticles, XRD images are taken. In order to determine the average, dispersed size of nanoparticles in the base liquid media, DLS analysis is performed. To check the stability of nanoparticle dispersion in base fluid, Zeta potential value is used. Some literatures are listed in Table 2 for the characterization techniques.

From the review of characterization studies, it was observed that characterization techniques provide essential details such as nanoparticle size, shape, chemical bonds, distribution, and stability. However, it was based on a variety of techniques used by the researchers, and there are no recommended standard tests to validate the homogeneous and stable nanofluid.

Table 2. Characterization techniques

Researchers	Particles	Base fluid	Concentration	Characterization Technique used
S.K. Das [54]	Al_2O_3	water	1-4 vol.%	TEM
S.K. Das [105]	Au, SiO_2	EG-water	0.01 wt% and 50 wt%	SEM
Bang IC [109]	Al_2O_3	water	0.5–4 vol%	Photograph
Z. Liu [58]	CuO	water	0.1–2 wt%	AFM
Liu ZH [40]	CNT	water	0.5–4 wt%	TEM
Phan HT [110]	TiO_2, Au, Al_2O_3	water	0.0003–0.01 vol%	FEGSEM
Nader Nikkam et al. [126]	SiC	water/EG	1.6 wt%	SEM, TEM, XRD, DLS, FT-IR and Zeta potential analysis
Abareshi et al. [127]	Fe_3O_4	DI-water	0.02-0.1 wt%	XRD, TEM, FT-IR, VSM
R. Kathiravan [15]	CNT	water	0.25–1 vol%	XRD, TEM
Pham QT [111]	Al_2O_3, CNT, Al_2O_3+CNT	water	0.05 vol%	SEM, EDS
Hegde RN [112]	CuO	water	0.01–0.5 vol%	SEM, TEM
Raveshi MR [113]	Al_2O_3	EG-water	0.05–1 vol%	Profilometer
Shahmoradi Z [114]	Al_2O_3	water	0.001–0.1 vol%	AFM
Vazquez DM [115]	SiO_2	water	0.1–2 vol%	SEM
Jung JY [116]	TiO_2	Water	10^{5} –10^{1} vol%	SEM, TEM
Shoghl SN [117]	MWCNT, CuO	water	0.01–0.02 wt%	AFM
Vafaei S [118]	Al_2O_3	water	0.001–0.1 vol%	SEM, AFM

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Kamatchi R [119]	rGO	water	0.01–0.3 g/L	XRD, SEM, FT-IR
Sakashita H [120]	TiO_2	water	0.0011 wt%	SEM
Sarafraz MM [121]	ZrO_2	EG-water	0.025–0.1 vol%	SEM, XRD, PSC
Amiri A [122]	CNT	water	0.01–0.1 wt%	SEM
Mourgues A [123]	ZnO	water	0.01 vol%	Photograph
Wen D [124]	Alpha- Al_2O_3	water	0.001–0.1 vol%	SEM, AFM
Stutz B [125]	γ-Fe_2O_3	water	0.1 wt%	SEM, AFM

Thermophysical Properties

Thermal Conductivity

The main aim of implementing the nanofluids in conventional fluids is to improve the thermal conductivity. In order to improve heat transfer, thermal conductivity is the most important properties and many researchers have been reported on this aspect. Many researchers emphasised the increase in with the addition of nanofluid, thermal conductivity improves [84]. Because of the nanofluids, the fluid has an effective thermal conductivity, which entails the incorporation of nanoparticles into the underlying fluid. Materials can be improved by incorporating a low concentration of nanoparticles, Thermal conductivity can be increased by using fluids with a higher thermal conductivity than the base fluid [1]. Nanofluid thermal conductivity can be measured experimentally or analytically. Some experimental techniques, such as the transient hot wire process, can be used to test the thermal conductivity of nanofluids [85], parallel plate technique in a stable state [38], and the methodology of temperature oscillation [86]. There are a variety of computational models available for predicting thermal conductivity [87-90]. Maxwell proposed the first effective model for determining the thermal conductivity of a liquid-solid suspension. Only homogeneous and low volume liquid-solid suspensions are suitable for the maxwell model. When compared with the Hamilton-Crosser [91] and Yu and Choi [92] models, maxwell [93] model predicts lower valve and due to increase of nanofluid concentrations, the difference increases [94]. It is observed that results of theoretical models are found to be much lower than the experimental results. Inducing 5% volume of nanocrystalline copper oxide particles in water results in a 60% increase in thermal conductivity was observed by Eastman et al. [95].

It is clearly understood that the effect of nanofluid thermal conductivity on CHF enhancement is important. When adding between 5% and 8% Al2O3 nano powders to the mix, Ethylene glycol's effective thermal conductivity improves by around 26% and 40%, respectively and it was observed by Wang et al. [38]. It was discovered that the increase in CHF was not due to nanofluids' thermal conductivity. By You et al. [9] concluded by using low concentration of nanofluids for CHF which was lower than concentrations of thermal conductivity of nanofluids used for enhancement. The effect of thermal conductivity of nanofluids on the rate of deposition of nanoparticles on the surface at lower concentrations was more influential than the effect of thermal conductivity of nanofluids [96]. Additional research into particle size, shape, method of nanofluid preparation, and stability is needed to improve CHF. The thermal conductivity of Al70Cu30 nanofluids is highly dependent on the size of the nanoparticles were fist experimented by Chopkar et al. [97], which is a key characteristic of nanofluids. Yang and Liu [98] proposed that there was an unbelievable thermal conductivity of functionalized silica nanofluid increases. However, it has little impact on CHF enhancement, and the performance CHF value is comparable to that of pure water. The thermal conductivity of Al_2O_3–Cu/water hybrid nanofluids increases dramatically with rising particle volume concentration [49].

For the thermal conductivity of nanofluid enhancement, a theoretical model with four modes contributing to energy transfer was developed, which was proposed by Jang et al. [99]. Hence, it is found that for the enhancement of CHF, at lower concentrations, the thermal conductivity of nanofluid plays a significant part. The only way to make a definitive statement about CHF enhancement is to investigate a broad variety of nanoparticle sizes and materials.

Viscosity

As like thermal conductivity, the viscosity of nanofluids is deserving of equal consideration in CHF enhancement. Resistance offered to the liquid flow is known as viscosity. And also, it is the shear stress to shear rate ratio. The

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viscosity of nanofluid was found to be higher than that of the base fluid in most cases. And the viscosity of liquids was discovered to be dependent on particle form and concentration. The constant viscosity at various shear rates is referred to as Newtonian. Though non-Newtonian varies with shear rate, it is a constant. Just a few reports on the rheological behaviour of nanofluids have been published, when compared to previous studies on nanofluid thermal conductivity.

The phenomenological hydrodynamic equations were used, Einstein [100] was first, determine the effective viscosity of a spherical solid suspension. Einstein equation was extended by Mooney to refer to a finite concentration suspension [103]. Brinkman later updated Einstein's equation to a more generalised form. [101].The Brinkman equation can be used to measure the viscosity of nanofluid. Nguyen et al. measurements [102] are in agreement with the results of CuO nanofluids. Alumina/propylene glycol (PG) nanofluid viscosity to shear rate was independently showed by Prasher et al [104]. By increasing nanoparticle volume concentration, the nature of nanofluids and viscosity growth was demonstrated to be Newtonian. With increasing concentration, the kinematic viscosity of nanofluid increased, Ganapathy et al. published a paper on this. [46]. The key explanation is that the electro viscous force induced during the electro stabilisation operation.

When Al2O3 nanoparticles at a concentration of 3% are added to water, Wang et al. [38] the viscosity of water increased by 20 to 30 percent. The shear rate and the viscosity of alumina-water nanofluids was measured by Das et al. [105]. The results showed that shear increased viscosity, particle size increased, and temperature decreased viscosity. Newtonian behaviour above -10°C and the at temperatures below -10°C, non-Newtonian behaviour in SiO_2 nanofluid was observed by Namburu et al. [106]. Al_2O_3–water and Al_2O_3–ethylene glycol nanofluids have different relative viscosities was measure by Wang et al. [107]. As a result, it was observed that the viscosity of the two nanofluids increased as the solid volume fraction increased and there may be an undesirable pressure drop due to desirable heat transfer. The viscosity of nanofluid is determined by the properties of the base fluid, particle size, particle volume fraction, temperature, surfactants, and other factors, as shown in this analysis. The discussed viscosity models are used to calculate the viscosity of nanofluids. So, there is an increase in viscosity because of inducing nanofluids. At present many researchers are finding out the improvement of CHF using nanofluid.

Future Work Recommendation

This analysis provides an overview of current research in the field of nanofluids. The researchers believe that using nanofluid in pool boiling heat transfer improves the CHF. The findings are dispersed due to the process of nanofluid preparation. Nanofluids are promoting the creation of next-generation fluids for applications such as flow and pool boiling. A good understanding of nanotubes and the role of contact resistance in nanofluid thermal transport was given by Eastman et al. [108]. The following are some potential research directions for these parameters in the future:

1) To avoid particle clustering, In the liquid phase, the relative size effect between nanoparticles must be investigated.
2) Because of the importance of increased visualisations and understanding the mechanisms, the flow characteristic of nanofluid flow boiling is an important research subject.
3) Nanoparticle size is a significant consideration in heat transfer applications, but it is recommended that smaller nanoparticles be used. Finding cost-effective synthesis methods for the preparation of nanoparticles with smaller sizes is critical.
4) Based on a reliable database of nanofluid thermophysical properties, a broad range of experimental studies of nanofluid boiling should be performed in order to develop suitable prediction correlations for the HTC, CHF, and pressure drop of nanofluid boiling.
5) Since pressure is a significant parameter, a study focusing on the irreversible growth of dry patches at various pressures is needed to understand the CHF enhancement.
6) Analysis of the combined effects of surface wettability and capillary wicking structure is needed to investigate the mechanism of CHF enhancement over a broad range of particle sizes and concentrations.
7) Only a few studies have shown that changes in the thermal transport properties of nanofluids cause CHF enhancement.

Conclusion

Even but there are some reviews on the investigate on nanofluids, this paper widely reviews the main aspects of nanofluids such as preparation of nanofluid, characterization techniques and thermophysical properties. For enhancing the critical heat flux, scientists and researchers used nanofluids in pool boiling heat transfer over a decade. The accumulation of nanoparticles on the heating surface during the boiling of nanofluids was clearly the key cause of CHF enhancement. Among the two methods for the preparation of nanofluids, The two-step method is more efficient with oxide nanoparticles than with metallic particles as compared to the one-step method.

To Prepare nanofluids, three different techniques have been used, they are sonification, pH control, and surfactants. The size of nanoparticles and zeta potential are affected by sonification time. To limit the commercialization of nanofluids, sone nanofluids were sonicated will be kept stable throughout the experiment. The value of zeta potential is obtained by changing the pH value according to only one small volume fraction value. In surfactant, to prevent nanoparticles from settling quickly a critical micelle concentration should be respected. Various characterization measures, such as SEM, TEM, XRD, FT-IR, DLS, TGA, and zeta potential analysis, are used to determine the crystal structure, particle size, surface functionality, and surface charge. There should be a well-established set of standard characterization techniques to ensure particle size, distribution, agglomeration, and stability, as well as uniformity among nanofluid characterization studies.

Nanofluid properties are determined by five factors: heat transfer, particles, colloid, thermo fluids, and lubrication. The efficiency of thermal systems is improved by increasing the thermal conductivity of the base fluid. The size of nanoparticles, pH value, form of base fluid (water, ethylene glycol, and engine oil), particle volume fraction, and type of particle coating all affect the thermal conductivity of nanofluids. It is clear from this research that models for the thermo-physical properties of hybrid nanofluids have yet to be established. However, there are many challenges incorporated with theoretical comprehension and models, nanofluids preparation, thermophysical properties and implementation of nanofluids could be realized.

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