BOILING HEAT TRANSFER OF NANOFLUIDS: A REVIEW OF RECENT STUDIES

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Adding solid particles of nanometer scale to fluids is one of the most important passive methods of enhancing heat transfer performance. However, this gives numerous chances to investigate new frontiers, but also raises remarkable difficulties. Nanofluids act as suspension that can be obtained by dispersing nanometer-sized nanoparticles (1-100nm) in host fluids with the aim of enhancing thermal properties. This paper is a review of recent studies on boiling heat transfer of nanofluids for pool and convective flow boiling of nanofluids. The research results, collected since 2012 to present of the recent survey are reviewed and briefly outlined. An emphasis is put on the enhancement and the deterioration of the boiling heat transfer coefficient (BHTC) and critical heat flux (CHF) of pool and convective flow boiling of nanofluids. Other important parameters affecting the boiling of nanofluids are identified and discussed in this review; while preparing future studies is greatly encouraged in order make this phenomenon well understood.

Key words*:* *boiling heat transfer, pool boiling, convective flow boiling, critical heat flux, nanofluids.*

1. Introduction

In the past decade, there has been a lot of efforts of investigators put into the research of boiling heat transfer of nanofluids, in spite of some inconsistent results on this topic, especially due to the complex mechanism of boiling of nanofluids. Attempts are still going on to understand this mechanism and detect the conflicting results. However, pool and convective flow boiling are very efficient modes in many industrial applications, such as power generation, high-tech cooling systems and chemical industrial processes, refrigeration systems, etc. While writing this review paper and collecting data from literature with special attention on the most recent period, since 2012 to present, it has become clear that there are three major groups of researchers presenting their results as regards heat transfer coefficient HTC. The first group has shown enhancement in HTC **[5, 9,11, 17-20, 22, 23, 25-34, 40, 42, 44-46, 49-51, 53, 54, 56-60, 64, 65, 67-69]**. The second group has dealt with deterioration in HTC **[5, 10, 11, 20, 21, 23, 26-28, 30, 31, 33, 43, 49, 51, 52, 54, 55, 59, 60, 62],** while the third one has shown no change in HTC **[17]**. Hence, these contradictions invited us to investigate this field consistently to get a better understanding of this mechanism. Moreover, researchers interested in conducting experimental and theoretical aspects will also need to understand the effect of operating conditions on nanofluids boiling.

One of the most important passive methods for intensifying heat transfer is to use nanoscale particles with conventional fluids (water, ethylene glycol, oil engine, etc.). Nanofluids act as suspension that can be obtained by dispersing nanometer-sized particles in base fluids. Generally solid particles with high thermal conductivity are added, as additives, to the conventional fluids to increase their thermal conductivity. In this way the thermal performance of these systems will be enhanced. Nanofluids have recently attracted much attention due to their potential as high-performance heat transfer fluids improving the thermal properties of the fluids **[1, 2]** in many applications. Nanofluids, first reported by Choi **[3]** in 1995 at Argonne National Laboratory, USA, is a new class of fluids prepared by dispersing nanometer-sized solid particles (1-100nm) in the base fluids. Since 2003, nanofluids boiling has begun to draw research interest and also become an important research area of nanofluids **[4]** ever since. This article provides a detailed review on the HTC and CHF enhancement/deterioration of boiling heat transfer of nanofluids, with recent literature results since 2012 based on the below-mentioned parameters related to nanoparticle roles in boiling heat transfer:

- Bulk effect associated with the thermal properties of nanofluids caused by suspended nanoparticles in base fluids (e.g. Thermal conductivity, viscosity, surface tension, heat capacity and density).
- Surface effect associated with deposit nanoparticles on the heating surface (e.g. wettability, capillary wicking, and surface roughness).

Hence, this may signpost further research directions for researcher interested in this topic.

2. Boiling heat transfer

Boiling heat transfer is one of the most common phenomenon in heat transfer processes taking place in many industrial applications, and it is also a change of phases, from liquid to vapor., Boiling is a complex process and a very efficient mode of heat transfer in heat exchange systems as well as cooling in high-tech applications. Many researchers have been interested in the topic of boiling heat transfer and several studies deal with the enhancement of thermal performance of this phenomenon. When a liquid is in contact with a surface maintained at a temperature above the saturation temperature of the liquid, boiling will eventually occur in that liquid-solid interface. Conventionally, based on the relative bulk motion of the body of a liquid to the heating surface, boiling is divided into two categories; pool boiling and convective flow boiling.

Pool boiling is a mode of boiling where the fluid is stationary at the beginning with respect of the heating surface and the relative motion of the vapor produced, and the surrounding liquid near the heating surface is primarily due to the buoyancy effect of the vapor. At the same time convective flow boiling refers to boiling in a flowing stream of fluid while the heating surface may be the flow channel. Boiling and two-phase flow phenomena are generally utilized as parts of various industrial applications such as refrigeration, air-conditioning, heat pumping systems and cooling high tech-applications like electronics components **[5].** Although most of the research on boiling have been dealing with pool boiling heat transfer, but the most important applications are those related to flow boiling heat transfer, such as boiler tubes, narrow rectangular channels in compact heat exchangers or longitudinal flow through a bundle of rods as in the fuel elements of a nuclear reactor, etc. **[70].**

Critical or burnout heat flux (CHF) is the most important parameter in terms of boiling heat transfer, and is defined as a limited point in which phase-change phenomenon acts in a way that bubble can completely cover and overwhelm the heating surface. Designing and operating heat transfer equipment, especially in high heat flux rate depending on CHF behavior, reveals the need of applying efficient cooling fluids working on the limit of CHF. **Figure 1**. represents the various regimes plotted in terms of relations of heat transfer regions to heat flux and also quality. **Figure 2.** shows the variations of heat transfer coefficient with heat flux and quality. Here the fluid temperature is defined as the saturation temperature for saturated conditions and as the mixed mean liquid temperature for subcooled conditions. In this particular diagram, the critical heat flux transition is a scheduled departure from nucleate boiling (DNB) in the region where nucleate boiling is not suppressed by the stage at which the critical phenomenon occurs **[70].** The heat transfer coefficient in **Figure 2**. is shown as being constantly in the saturated nucleate boiling region. However, the coefficient may decline with increasing quality; a more recent flow boiling map showing detailed similar trends has been published by **[71].**

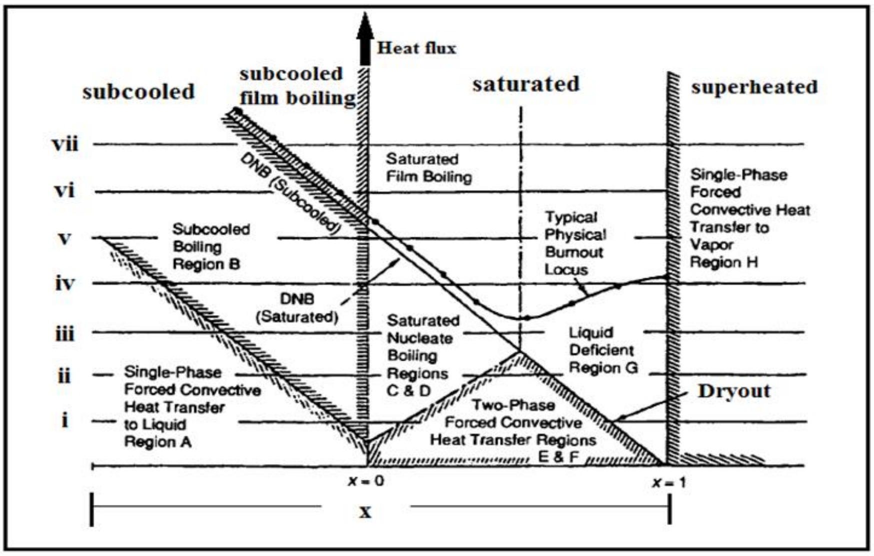

Figure 1. Regions of operation of the various regimes of heat transfer in terms of heat flux and quality [70] by permission of Oxford Universtiy Press.

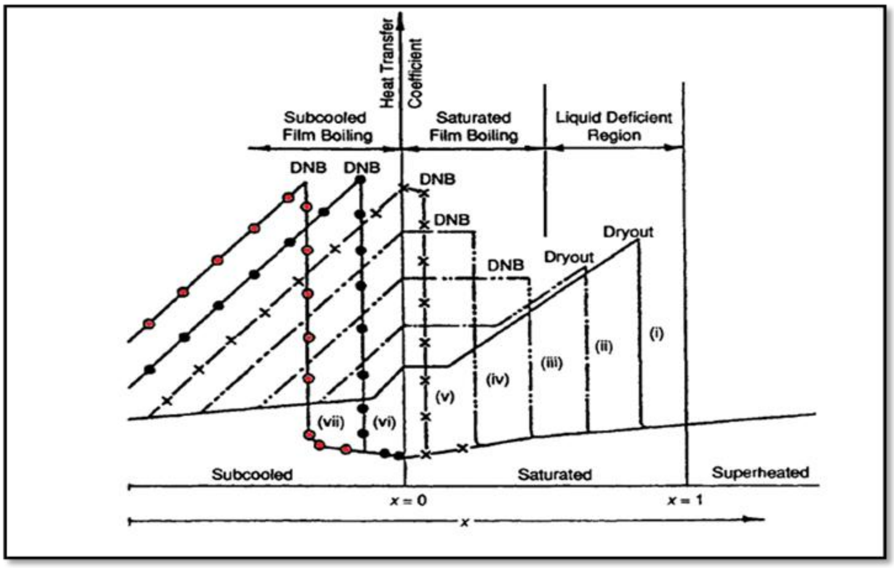

Figure 2. Variations of heat transfer coefficient with quality of various heat flux levels. Note that the numbers on the curves are cross-references to the various levels indicated in Figure. 1. [70] by permission of Oxford Universtiy Press.

3. Boiling heat transfer of nanofluids: recently studied

Boiling plays a vital role in any industrial application and technological areas, such as energy production. For instance subcooled boiling heat transfer can provide huge heat fluxes, and this can be befittingly engaged in the cooling of some components of fusion reactors. Furthermore, very compact heat exchangers can be manufactured with high heat transfer rate obtained by boiling heat transfer. Such improvments will be beneficial for the efficiency of the power plant cycle **[6].** To get a more efficient cooling system for high heat flux systems, CHF should be prevented because it may invite the degradation of heat exchange coefficient; whereas high heat fluxes can at least harm the surface, and heat cannot be exchanged from surface to coolant. Nanofluids are designated a promising approach to improve the thermal efficiency of cooling systems and a divine choice for CHF aversion purposes. Nano-suspension has higher thermal conductivity in comparison with traditional fluids, so it can be used for high heat flux applications and as productive media for cooling **[7].**

Figure. 3. illustrates the most recent records related to the development of annual research publications on the topics of boiling heat transfer of nanofluids. Browsing through the Web of Science, 293 publications related to boiling heat transfer using nanofluids have been found since 2012. The highest percentage of publications is 24.232% representing 293 matches in 2016.

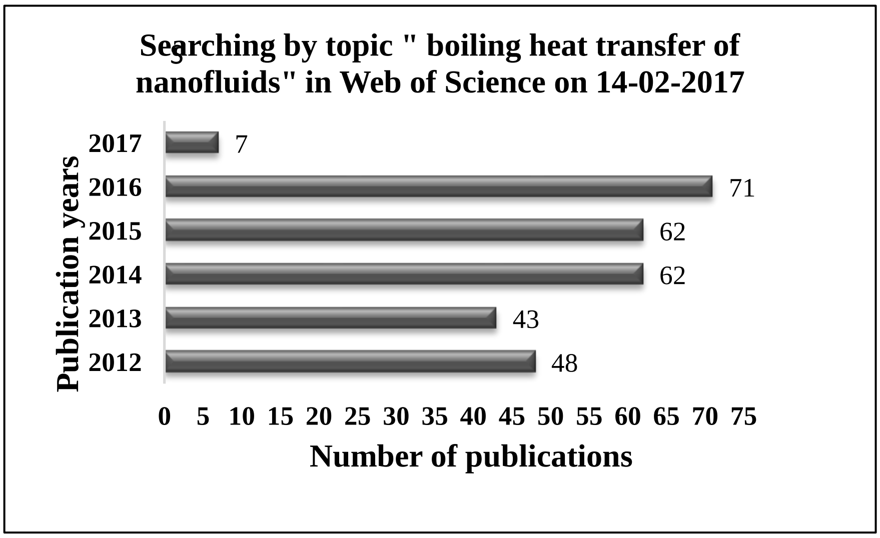

Figure 3. Publications by topic (boiling heat transfer of Nanofluids) since 2012. Web of Science on 14/02/2017.

3.1. Recent studies on pool boiling of nanofluids

Since 2012 numerous results have been published on nanofluids pool boiling, which are summarized in **Table 1**. In these studies, the effects of nanofluids on the most important parameters, such as HTC and CHF, in pool boiling have been investigated. **Yang et al. [8],** the first researchers who used the suspended alumina particles ranging in size from 50nm to 1μm at low concentration

(0.1-0.5 wt. %) observed an improvement in pool boiling heat transfer in their study. **Madhusree Kole et al. [9]** studied the effect of ZnO/ethylene glycol in pool boiling on HTC and CHF. The results showed that HTC enhanced with ZnO concentration and attained a maximum of 22% compared to that of the base fluid for a ZnO volume fraction of 1.6%. Also, there was an enhancement in CHF with increasing ZnO loading and displayed a maximum enhancement of 117% for nanofluids containing 2.6% volume fractions of ZnO.

Jung et al. [10] studied the CHF and pool boiling HTC of binary nanofluids ($H_2O/LiBr+Al_2O_3$) and the results concluded that the boiling heat transfer coefficient of the binary nanofluids became lower than that of the base fluid as the concentration of nanoparticles increased, while its CHF became higher. They obtained an enhanced CHF about 48.5% (compared to the base fluid) with the 0.1 vol.% Al_2O_3 in 10 wt. % LiBr aqueous solution. **Sarafraz et al. [11]** reported in their study that by increasing the heat flux, the pool boiling HTC of nanofluids significantly increased. In contrast, with increasing the concentration of nanofluids, due to the deposition of nanoparticles on the surface, the average roughness of the surface and the heat transfer coefficient dramatically deteriorated, while a significant increase in fouling resistance was also reported.

Kim et al. [12] studied the effect of a graphene-oxide coating layer on critical heat flux enhancement under pool boiling phenomena, and they were reporting that nucleate boiling resulted in the deposition of the GO (Graphene-oxide) colloids onto the heated wire, whereby the GO flakes formed a smooth laminated film, and that the thickness of this layer was approximately proportional to the observed increase in the CHF. **J. Ham et al. [13]** carried out a theoretical analysis of pool boiling characteristics of Al_2O_3 nanofluids according to volume concentration and nanoparticle size. It was found that the nucleate site density at CHF increased from 32.97 to 30.53 sites/cm$^{2.}$ with the increase of the volume concentration at 50 nm-nanoparticle size. However, the increase was significantly lower than that of the base fluid, which was 65.90 sites/cm^2.

An experimental study was carried out by **Yanwei et al. [14]** to show the effect of nanoparticle size and concentration on boiling performance of SiO_2 nanoparticles based on two types of base fluids, water and EG. Results showed that the boiling heat-transfer coefficient (HTC) increased when the nanoparticle diameter was decreasing from 120 nm to 84 nm. In addition, with the increase of nanoparticle concentration, the HTC first increased rapidly and then exhibited negative growth in the concentration range 0.25-1.00%. Moreover, the HTC deteriorated nanoparticle volume fractions above 0.75%. **Sina et al. [15]** reported their experimental results on the overall effect of three types of nanoparticles suspended in water. The ZnO and Al_2O_3 nanoparticles were deteriorating heat transfer while adding MWCNTs resulted in improving heat transfer.

Kiyomura et al. [16] studied the effects of nanoparticles deposition on characteristics of the heating surface of pool boiling of water, and in their study, they tested several types of surfaces as follows: Smooth Surface (SS), Rough Surface (RS), Smooth Surface -Low Concentration (SS-LC), Smooth Surface - High Concentration (SS-HC), Rough Surface -High Concentration (RS-HC) and Rough Surface -Low concentration (SS-LC). Results showed that both surfaces (RS-HC and RS-LC) presented deteriorated HTC when compared with the surface without deposition.

This may be explained by the decrease of nucleation site density that may affect bubble frequency and its departure diameter, since the active sites, corresponding to larger surface cavities, are filled with nanoparticles. Consequently, cavities with a smaller mouth diameter can be formed. However, to maintain such cavities active, higher wall superheating is necessary, which is detrimental to the heat transfer coefficient. Also, the heat transfer coefficient results of the SS-LC surface is about 20% higher than the HTC of the SS-HC and SS surfaces. This behavior seems mainly related to the fact that the roughness of the smooth surface increases with nanoparticle deposition.

Table 1. Summary of nanofluids pool boiling since 2012.

Reference	Years	Nanofluids type	Concentration	HTC results	CHF results
[9]	2012	ZnO/EG	0.5-3.7 vol.%	Enhancement 22% at φ=1.6 %	Maximum enhancement of 117% at φ=2.6 %
[17]	2012	α-Al_2O_3/water	0.001-0.1 vol.%	Enhancement of smooth surface Unchanged of roughness surface	No data recorded
[18]	2012	TiO_2/water	0.000094-0.047 vol.%	Degraded, then improved	Enhancement about 91%
[10]	2013	H_2O/LiBr+Al_2O_3	0 -0.1 vol.% Dispersed in H_2O/LiBr solutions (3, 7 and 10 wt. % of LiBr).	Deterioration when volume friction increases	Enhanced about 48.5% with the 0.1 vol.% Al_2O_3 in 10 wt. % LiBr aqueous solution
[19,20]	2013	Al_2O_3/ water-EG	0.05-1 vol.%	Enhanced about 64% at φ=0.75 %	No data recorded
[21]	2013	Al_2O_3/ water	0 -0.1 vol.%	Reduced	Increased
[11]	2014	Al_2O_3/ EG	0.1-0.3 wt. %	Enhanced with increase heat flux and decrease with increase concentration	No data recorded
[22]	2014	ɤ-Al_2O_3/ R141b	0.001 vol.%, 0.01 vol.% And 0.1 vol.%	Increased with concentrations of 0.001 vol.% And 0.01 vol.% With and without the surfactant SDBS. Decreased with 0.1 vol. % concentration without the surfactant	No data recorded
[23, 20]	2014	MWCNT / water	0.01-0.1 wt. %	Enhancement for covalent nanofluids.	Enhanced about

				Deterioration for non-covalent nanofluids	274.2%
[24]	2014	Graphene oxide (GO) /water	0.0001, 0.0005 , ,0.0010and 0.0050 wt. %	No data recorded	Increase in the CHF with increasing GO layer thickness
[25]	2015	CuO/ pentane	0.005% and 0.01%	Enhancement of 20–30%. For brass surface and 15–25% at φ=0.005 %	No data recorded
[26, 20]	2015	TiO_2/water	0.0011 vol.%	Degradation	Enhancement about 220%
[27, 20]	2015	CuO/water	0.1-0.4 wt. %	Deterioration	No data recorded
[28]	2016	MWNTs/ water	0.1-1 wt. %	Enhancement for covalent nanofluids about 34.2% and 53.4% for MWNTs-COOH and MWNTs-OH Deterioration for non-covalent nanofluids.	No data recorded
[29]	2016	ZrO_2 / water–ethylene glycol mixture (50:50)	0.025, 0.05, 0.075, and 0.1 vol. %	Enhanced up to 12% at φ=0.1 vol. %	Increase up to 29%
[30]	2016	Al_2O_3/ water	0.1, 0.3 wt. %	Deteriorated and then enhanced	Intensified by increasing the mass concentration of nanofluids
[63]	2016	Reduced GO/water	0.01, 0.1, and 0.3 g/l	No data recorded	Enhancement about 145 to 245 %
[65]	2016	ZnO/ EG-DI water	5.25-7.25 wt. %	Enhanced	Enhanced
[31]	2017	SiO_2/ water, EG	0.25–1.00 vol.%	Increased when decreasing the nanoparticle diameter	No data recorded

				and increased firstly with increasing volume fraction of nanofluids and then deteriorated for nanoparticle volume fractions above 0.75%.	
[32]	2017	Fe_3O_4/water	0.1% vol.%	Increased up to 43%	No data recorded
[33]	2017	ZnO, α-Al_2O_3 and MWCNTs/water	0.01 wt. % CNT + 0.01 wt. % SDS and 0.02 wt. % CNT + 0.01 wt. % SDS and (0.01 and 0.05 wt.%) for ZnO, α-Al_2O_3	ZnO and Al_2O_3 deteriorated HTC but MWCNTs improved it	No data recorded
[64]	2017	TiO_2/ water	12 and 15 wt. %	Enhanced with increase φ	No data recorded

3.2. Recent studies on flow boiling heat transfer of nanofluids

Flow boiling heat transfer refers to boiling in a flowing stream of fluid, while the heating surface may be the channel containing the flow. It is used in many industrial applications, such as air conditioning, power plant components (boiler), refrigeration, petroleum industry, nuclear reactor cooling, and high-tech electronic component cooling. To make these applications more efficient in terms of heat removal or cooling systems, it is necessary to enhance the flow boiling heat transfer process to obtain significant detraction of energy consumption. One of the most effective methods to improve the flow boiling heat transfer is to use solid nanoscale particles with conventional cooling fluids This solution would offer new and conceivable energizing outcomes to improve thermal exchange performance compared to host fluids. Nanofluids make a new class of fluids and a promising next-generation for those fluids.

The boiling heat transfer of nanofluids has begun to draw research interest since 2003 and has become a focus of researchers' attention in nanofluids research activities. Most of the recent studies on boiling heat transfer deal with pool boiling and some with flow boiling heat transfer. Flow boiling heat transfer has more applications in heat exchange systems than pool boiling does, and it has the potential to remarkably enhance heat transfer and thermal efficiency **[34-36]**. This is the reason why it should still be an essential research topic,. However, research studies on flow boiling of nanofluids, in a secondary position, got into focus only in 2007. For a researcher interested in this topic there was altogether one related paper published before 2007 available **[34, 37]**. Therefore, in the recent years, there has been a growing interesting in flow boiling heat transfer, and some of the published papers deal with the most important parameters such as HTC, CHF and pressure drop in the testing channel.

On the other hand, bulk effects, like thermal conductivity, viscosity, and stability of nanofluids in this phenomenon, are also taken into consideration. In this section, **Table 2., 3.**, important results on HTC and CHF of flow boiling are summarized.

Seung et al. [38] experimentally studied the critical heat flux enhancement in flow boiling of Al_2O_3 and SiC nanofluids under low pressure and low flow conditions. Their experiment was performed in round tubes, with an inner diameter of 0.01041 m and a length of 0.5 m, under low pressure and low flow (LPLF) conditions at a fixed inlet temperature, while using water, 0.01 vol. %, Al_2O_3/water nanofluids, and SiC/ water nanofluids. It was found that the CHF of the nanofluids was significantly enhanced, and the CHF of the SiC/ water nanofluid was even more enhanced than that of the Al_2O_3/water nanofluid. Also, as seen in **Figure 5.**, the contact angle on the inner surface of the test section after the CHF experiment using SiC/ water nanofluid (38.8°) was smaller than the one after the CHF experiment with water (60.5°), and Al_2O_3/water nanofluid (52.3°) after injecting 10 milliliters of water. These results demonstrated that the nanoparticle deposition increased the surface wettability.

Abedini et al. [39] numerically investigated the subcooled flow boiling of a nanofluid with water and Al_2O_3 by using a two-phase mixture model. Their results observed that the convective heat transfer coefficient of a nanofluid in subcooled flow boiling was higher than that of the base fluid. Heat transfer coefficient increased parallel with nanoparticles concentration increase. However, the effect of nanoparticle concentration on the heat transfer coefficient in the case of high inlet velocity was insignificant. On the other hand, in subcooled flow boiling, decreasing the inlet mass flow rate could cause either a decrease or an increase in the heat transfer coefficient, that depended on the effect of forced convection and latent heat transport on the overall heat transfer coefficient.

Om Shankar et al. [40] studied the flow boiling heat transfer enhancement by using ZnO-water nanofluids. Their loop was a closed fluid test facility. The annular test section was of 780mm long and consisted of an electrically heated rod and an outer borosilicate glass tube of 21.8mm inner diameter. The heater was manufactured of 12.7mm diameter hollow stainless steel rods welded to solid copper rods at both ends. The results indicated that heat transfer increased along with the increase of heat flux for all concentrations of ZnO/ water nanofluids due to the increased energy gained by the nanoparticles. The increase in the heat transfer coefficient was significant at 0.1% volume concentration of nanoparticles. Its reasons are as follows, at higher concentration of nanoparticles (0.1%) 120% increased thermal conductivity of ZnO/ water nanofluid, and 1367% increased surface roughness of heater rod, due to the deposition of ZnO/ water nanofluid, the nanoparticles were deposited more on the heater surface occurred. Thereby, the surface area of the heater rod was increased and thus, the heat transfer by convection was also increasing due to the increased Brownian motion, the particle driven natural convection, and the increased conduction between nanoparticles.

Sarafraz et al. [41] conducted an experimental study on flow boiling heat transfer coefficients of deionized water and copper oxide water-based nanofluids at different operating conditions in an annular space. Their results demonstrated that by increasing the applied heat flux, the flow boiling heat transfer coefficient increased for DI-water and CuO-water nanofluid at forced convective and nucleate boiling regions. In addition, by increasing the flow rate of fluids, the heat transfer coefficient dramatically increased in both regions. Also, results showed that the inlet temperature of fluids played a vital role on HTC, especially in the nucleate boiling region.

Wang et al. [42] investigated experimentally the Al_2O_3/ water and AlN/water nanofluids flow boiling heat transfer in a vertical tube under different pressure values and the influence of heat flux and mass flow rate were also considered. Moreover, nanoparticle size and shape were observed by transmission electron microscope (TEM) to confirm that the nanoparticle had not obviously changed before and after boiling. In the experiment, new correlation for nanofluid saturated flow boiling was presented with 300 experimental points. This correlation applied to both AlN/ water nanofluid and Al_2O_3/ water nanofluid (0.1-0.5 Vol. %).

Table 2. Summarized HTC flow boiling of nanofluids since 2012 .

Reference/ Years	**Operating conditions: *D* (mm)/*L* (mm)/*G* (kg m^{-2} s^{-1})/*q* (kW m^{-2})/ outlet *p* (kPa)**	**Nanofluids; Concentration; nanoparticles diameter (nm)**	**HTC results**
[43]/ 2012	10/ 1000/ 137-303/ 50-102/ 101	TiO_2/water; 0.1-2.5 vol.%; 20	Deteriorated by increasing φ in vertical and horizontal tubes
[44, 34]/ 2012, 2015	0.143/ 7.5/ 171-401/ 0-1000/ 101	Al_2O_3/water; 0.2 wt. %; 40	17% enhancement
[45, 46]/ 2013	5.94/ 1000/ 2500/9000/ 101	Al_2O_3, ZnO, diamond/water; ≤ 0.1 vol.%; 30	Enhanced with increased φ
[49]/ 2014	D_h= 30/ 300/ 353-1059 / 19/ 101	Al_2O_3/ water; 0.5-1.5 vol.%; 50	Enhanced with increasing heat flux and mass flow rate and deteriorated in the nucleate boiling region with increasing φ
[40]/ 2014	D_h= 9.1/ 780/ 400/ 0-400/ 100-250	ZnO/ water; 0.0001-0.1 vol.%; < 100 (30-50)	Increased
[51]/ 2014	D_h= 30/ 140/353-1059 / 0-190/ 101	CuO/ water; 0.5-1.5 vol.%; 50	Enhanced with increasing heat flux and mass flow rate and deteriorated region with increasing φ
[41]/ 2015	D_h= 30/ 300/ 0-400 / 50-132/ 101	CuO/ water; 0.1-0.3 wt.%; 50	Increased with the mass flow rate
[52]/ 2015	1.1/ 200/ 200-600/ 100-400/101	Al_2O_3/ DI-water; 0.001-0.1 vol.%; 20-30	Decreased with increased φ
[53]/ 2015	D_h= 12/ 300 / 490-880 / 0-5500/ 120	Al_2O_3 / water; 0.25 vol.%; 20-30	Enhanced with surface roughness and mass flow rate
[54]/ 2015	D_h= 30/ 400/350-1060 / 0-175/ 101	CuO_2/ water; 0.001-0.004 wt. %; 50	Increased for convective regime and deteriorated with a nucleate regime with increasing φ
[55]/ 2015	1.09/ 306/ 680-3100/ 15-406/ 120-175	Al_2O_3 / water; 0.01-0.1 vol.%; 20-30	Degraded
[56]/ 2016	11.5/ 1500/ 390-1400/ 0-1200/ 100	Al_2O_3/ water; 0.1-0.3 vol.%; ~ 26	Improved
[57]/ 2016	6/ 1100/ 350-1100/ 50-300/ 200-800	ɤ-Al_2O_3/water; 0.1-0.5 vol.%; 20	Enhanced
[58]/ 2016	20/ 300/ 24-56/ 8-110/ 101	ZnO/ water; 0.005-0.02 vol.%; *	Enhanced with the mass flow rate and heat flux
[59]/ 2016	D_h= 30/ 300/100-1200 / 2.3-210.1/ 101	MWCNT, CuO and Al_2O_3/ water; 0.1-0.3 wt.%; 12-14nm×1.5-2μm for MWCNT and 50nm for metal oxide particles	Enhanced for MWCNT and enhanced then deteriorated for metal oxide particles

[5]/ 2016	D_h= 30/ 200/0-400 / 0-175/ 101	Al_2O_3/ water; 0.5-1 vol.%; 5, 50 and 80	Enhanced in short-time study and deteriorated in the extended time - study
[67]/ 2016	10/ 1000/ 138-308/ 50-112/ 101	TiO_2/water; 0.01-5 vol.%; 20	Augments in single-phase and degraded with a subcooled flow regime with φ
[42]/ 2017	6/ 1100/ 350-1100/ 48-289/ 200-800	AlN/water and Al_2O_3/water; 0.1-0.5 vol.%; 20 for Al_2O_3 and 30 for ALN	Depend on some parameter according new correlation proposed
[60]/ 2017	10/ 1000/ 137-210/ 13-77/101	TiO_2, Al_2O_3 and CuO/ water; 0.1-2.5 vol.%; 10, 20	Enhanced for single phase and degraded for subcooled regime
[62]/ 2017	10/ 1000/ 137-303/ 13-88/101	TiO_2, Al_2O_3/ water; 0.1-2.5 vol.%; 20, 40	Deteriorated in both directions with increasing φ
[68, 69, 34]/ 2013, 2014, 2015	21.8/ 500/ 405-710/ 100-550/101	ZnO/ water; 0.001-0.01 vol.%; 40	Enhanced with increasing φ
* data not recorded			

Table 3. Summarized CHF flow boiling of nanofluids since 2012.

Reference/ Years	**Operating conditions: D (mm)/L (mm)/G (kg m^{-2} s^{-1})/q (kW m^{-2})/ outlet p (kPa)**	**Nanofluids; Concentration; nanoparticles diameter (nm)**	**CHF results**
[38]/ 2012	12.7/ 500/ 100-250/ 75/ 101	Al_2O_3/water and SiC/water; 0.01Vol. %; Al_2O_3 smaller than 50 and SiC larger than 50	Enhanced for both nanofluids
[45, 46]/ 2013	5.94/ 1000/ 2500/9000/ 101	Al_2O_3, ZnO, diamond/water; ≤ 0.1 vol.%; 30	Enhanced about 40-50%
[47]/ 2013	10.92/ 550/ 100-500/ 0-100/ 101	Fe_3O_4, Al_2O_3/ water, 0.0001, 0.001 vol.%, 25	Enhanced for magnetic nanofluid
[61]/ 2013	12.7/ 500/ 100-250/ 100-3500/ 101	GO/ water; 0.01 vol.%; *	100% enhanced
[48]/ 2014	10.92/ 550/ 100-500/ 0-100/ 101	Fe_3O_4 / water, 0.0001, 0.001 vol.%, *	Enhanced for magnetic nanofluid
[50]/ 2014	D_h= 7/ 750/ 0-150/ 1018/ 88	Fe_3O_4 / water; 0.01, 0.1 vol.%; (15-20)	Enhancement for pure water and ferrofluids under an external magnetic field.
* data not recorded			

3.3. Recent studies in other parameter effect

Although there are many researchers shown wide interest in boiling heat transfer coefficient and critical heat flux using nanofluids **[8-62]**. yet, there are a group of researchers interested in presenting other sub-phenomena, such as flow boiling instabilities, bubble formation and flow patterns regarding flow boiling heat transfer of nanofluids. **Leyuan Yu et al. [55**], for instance, conducted an experimental study on forced convective flow boiling and two-phase flow of Al_2O_3/ water nanofluids through a minichannel. They were studying the effects of nanofluids on the onset of nucleate boiling

(ONB) and two-phase flow instabilities with an emphasis on the transition boundaries of onset of flow instabilities (OFI). It was found that the presence of nanoparticles delayed ONB and suppressed OFI, and the extent of delay/suppression was proportional to the nanoparticle concentration. These effects were attributed to the changes in available nucleation sites and surface wettability, as well as thinning of thermal boundary layers in nanofluid flow.

Abedini et al. [43] experimentally investigated the subcooled flow boiling of TiO_2/ water. Their results showed that the increase of heating surface wettability due to TiO_2 nanoparticles deposition on the surface increased the departure size of bubbles and decreased their frequency. This made the heat transfer coefficient degraded.

Wang et al. [67] numerically studied the growth and departure of a single bubble behavior in Al_2O_3/ water and pure water flow boiling processes by an improved Moving Particle Semi-implicit method in different flow boiling conditions. They concluded that the bubble in Al_2O_3/ water grew faster and the bubble departure frequency of Al_2O_3/ water was greater than that in pure water. The effects of nanoparticle concentrations and diameters of Al_2O_3/ water on the bubble behavior were also investigated and compared under the same flow conditions. It was found that the increase of nanoparticle volume concentration might increase the bubble departure frequency and departure diameter, while the increase rates of departure frequency and departure diameter were lessened with the increase of nanoparticle volume concentration. The intriguing finding was that in the same nanoparticle volume concentration condition, the bubble departure frequency for the nanofluid with a nanoparticle diameter of 29 nm showed a maximum value. Increasing nanoparticle diameter lead to the decrease of bubble departure diameter. It is a brave prediction to say, however, that an optimal nanoparticle diameter range between (20-38nm) should be beneficial to enhance flow boiling heat transfer of Al_2O_3/ water.

Rana et al. [68] preformed an experimental visualization study on subcooled flow boiling of ZnO/water nanofluids with different low particle concentrations (≤0.01 volume %) in horizontal annulus. The results showed that heat flux increase lead to the increase in bubble diameter. Adding nanoparticles into the base fluid enhanced the maximum bubble diameter and decreased bubble density. Both bubble diameter and bubble density decreased in both water and nanofluids with the increase of flow rate.

4. Conclusion and recommendations

Recent progress in researching on boiling heat transfer of nanofluids has been reported and reviewed in the present paper. **Figure 4**. illustrates pictorially the main factors affecting nanofluid boiling enhancement. It has been shown by researchers that there are several factors that individually, or in combination, can play an important role in enhancing nanofluid boiling, especially for HTC and CHF. The possibilities to develop a cooling effectiveness system, on the ground of nanofluid coolants application, have received interesting efforts from many researchers. However, the inconsistent results that related to convective and boiling heat transfer coefficient CHTC, BHTC, and critical heat flux, CHF, of nanofluid can be found in data published in literature. There is no hypothesis or theory that clarifies the mechanism of heat transfer process in nanofluids, especially for boiling process. So, work and unremitting efforts need to be made to accelerate the engineering applications of nanofluids related to the boiling of nanofluids, especially on matters below.

1- A determined efforts should be made to find a reliable nanofluid database with worldwide cooperation of researchers for thermal transport properties including more details of nanoparticle types, size, concentration, stabilizing additives (if used), and appropriate preparation methods giving more understanding to promising nanofluid calculation, modeling and analysis.
2- More effort is needed to find some suitable nanofluids for different engineering systems. From this point of view, we need to test more types of nanoparticles.
3- Stability is very important to make nanofluids applicable so, it should be tested and improved in boiling nanofluids for both stationary and flow conditions.
4- There are numerous chances to investigate new frontiers by preparing hybrid (composite) nanoparticles. Hybrid nanoparticles are defined as nanoparticles composed of two or more different materials of nanometer size with an aim to improve thermal conductivity of nanoparticles for hybrid nanofluids.
5- Nanoparticles composed by two or more different materials of nanometer size.
6- The major roles of nanoparticles affected by nanofluid boiling heat transfer should be well understood including the bulk effect associated with suspended nanoparticles of the fluid and their thermal properties (thermal conductivity, viscosity, heat capacity and density). The surface effect associated with deposit nanoparticles, which modified the characteristics of heating surface (wettability, homogeneity, roughness and solid surface tension, etc.). That will be achieved by careful experimental observations and numerical simulations.
7- Boiling sub-phenomena such as bubble formation with suspended nanoparticles, stabilizer (if used) and nanoparticles allocation should be studied numerically and experimentally to provide more details about the enhancement of HTC and CHF.
8- More effort on numerical analysis and theoretical studies regarding boiling of nanofluid, especially flow boiling of nanofluid, should be made because these types of analyses play an important role in developing new CFD models for CHF.
9- The mixed convection flow of nanofluids (combined forced and natural convection) in tubes, especially in inclined tubes, is significant in many industrial applications of flow boiling using nanofluid, such as solar energy collectors, supercritical boilers, and nuclear reactors. So, further studies are needed to develop the different single- and two-phase CFD models for analyzing the nanofluid heat transfer during mixed convection.
10- In some special applications, systems of managing emergency core cooling (ECC) for both pressurized-water reactor, and boiling-water reactor, boiling heat transfer of nanofluids should be studied carefully with consideration of other practice factors, such as orientation of heating surface, material composition, and other physical conditions related to the environment.

In the view of these impediments, nanofluids are not commercialized in numerous industrial applications, for example, nuclear reactors, boilers, spray cooling, and high-tech hardware cooling. Once the key issues tend to, it will give trust to doing experiments with thermal engineering systems.

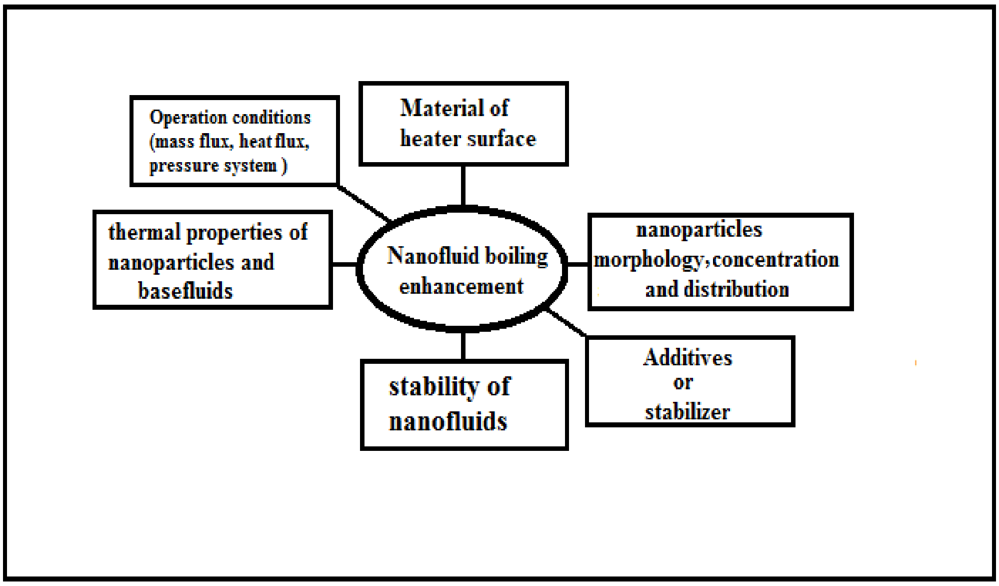

Figure 4. Factors affecting nanofluid boiling enhancement

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Nomenclature

h [kW m^{-2} K^{-1}]	Heat transfer coefficient	HTC	Heat transfer coefficient
q'' [kW m^{-2}]	Heat flux	BHTC	Boiling heat transfer coefficient
G [kg m^{-2} s^{-1}]	Mass flux	CHF	Critical heat flux
D_{in} [mm]	Inner diameter	LPLF	Low pressure, low flow
L [mm]	Length of tube	EG	Ethylene glycol
P [KPa]	Atmospheric pressure	EO	Engine oil
D_h [mm]	Hydraulic diameter	GO	Graphene oxide
Greek symbols		MWCNTs	Multi-wall carbon nanotubes
α	Alpha	SDBS	Sodium dodecyl benzene sulfonate
ɤ	Gamma	CFD	Computational fluid dynamics
φ	Concentration, volume friction [%]	ECC	Emergency core cooling

Abbreviations

BHT	Boiling heat transfer
DNB	Departure from nucleate boiling
TEM	Transmission electron microscope

References

[1] Murshed, S., *et al.*, A review of boiling and convective heat transfer with nanofluids, *Renewable and Sustainable Energy Reviews*, *15* (2011), pp. 2342-2354.

[2] Kamel, M.S., *et al.*, Heat Transfer Enhancement Using Nanofluids: A Review of the Recent Literature, *American Journal of Nano Research and Applications, 4*, (2016), 1, pp. 1-5.

[3] Choi, S.U.S., Estman, J., Enhancing thermal conductivity of fluids with nanoparticles, *Procceding* Int. Mechanical engineering congress and exhibition, San Francisco, CA, United States, 1995, pp. 99-105.

[4] Fang, X., *et al.*, Heat transfer and critical heat flux of nanofluid boiling: A comprehensive review, *Renewable and Sustainable Energy Reviews 62* (2016), pp. 924-940.

[5] Salari, E., Boiling Heat Transfer of Alumina Nano-Fluids: Role of Nanoparticle Deposition on the Boiling Heat Transfer Coefficient, *Periodica Polytechnica Chemical Engineering*, *60* (2016) , 4, pp. 252-258.

[6] Salari, E., Boiling Thermal Performance of TiO_2 Aqueous Nanofluids as a Coolant on a Disc Copper Block, *Periodica Polytechnica Chemical Engineering*, *60*, (2016), 2, pp. 106-122.

[7] Afrand, A., *et al.*, Experimental investigation and simulation of flow boiling of nanofluids in different flow directions, *Physica E* (2016), http://dx.doi.org/10.1016/j.physe.2016.10.026.

[8] Yang, Y.M., Maa J.R., Boiling of suspension of solid particles in water, *International Journal of Heat and Mass Transfer, 2* (1984) , pp.145-147.

[9] Madhusree, K., Dey T.K., Investigations on the pool boiling heat transfer and critical heat flux of ZnO-ethylene glycol nanofluids, *Applied Thermal Engineering, 37* (2012), pp. 112-119.

[10] Jung, J., *et al.*, The study on the critical heat flux and pool boiling heat transfer coefficient of binary nanofluids (H_2O/LiBr + Al_2O_3), *international journal of refrigeration, 36* (2013), pp. 1056-1061.

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

[12] Kim, J., *et al.*, Effect of a graphene oxide coating layer on critical heat flux enhancement under pool boiling, *International Journal of Heat and Mass Transfer, 77* (2014) , pp.919-927.

[13] Ham, J., Cho H, Theoretical analysis of pool boiling characteristics of Al_2O_3 nanofluid according to volume concentration and nanoparticle size, *Applied Thermal Engineering*, *108* (2016), pp. 158-171.

[14] Yanwei, H., *et al.*, Effect of nanoparticle size and concentration on boiling performance of SiO_2 nanofluid, *International Journal of Heat and Mass Transfer, 107* (2017), pp. 820-828.

[15] Shoghl, S., *et al.*, The boiling performance of ZnO, α-Al_2O_3 and MWCNTs/ water nanofluids: An experimental study, *Experimental Thermal and Fluid Science, 80* (2017), pp. 27-39.

[16] Kiyomura, I.S., *et al.*, An analysis of the effects of nanoparticles deposition on characteristics of the heating surface and ON pool boiling of water, *International Journal Heat Mass Transfer* (2016), http://dx.doi.org/10.1016/j.ijheatmasstransfer.2016.09.051

[17] Wen, D., Influence of nanoparticles on boiling heat transfer, *Applied Thermal Engineering*, *41* (2012), pp. 2-9.

[18] Okawa, T., *et al.*, Boiling time effect on CHF enhancement in pool boiling of nanofluids, *International Journal of Heat and Mass Transfer, 55* (2012), pp. 2719-2725.

[19] Raveshi, M.R., *et al.*, Experimental investigation of pool boiling heat transfer enhancement of alumina-water-ethylene glycol nanofluids, *Experimental Thermal and Fluid Science, 44* (2013), pp. 805-814.

[20] Ciloglu, D., Bolukbasi .A, A comprehensive review on pool boiling of nanofluids, *Applied Thermal Engineering, 84* (2015), pp. 45-63.

[21] Shahmoradi, Z., *et al.*, Pool boiling characteristics of nanofluid on flat plate based on heater surface analysis, *International Communications in Heat and Mass Transfer, 47* (2013), pp. 113-120.

[22] Tang, X., *et al.*, Experimental investigation of the nucleate pool boiling heat transfer characteristics of ɤ-Al_2O_3-R141b nanofluids on a horizontal plate, *Experimental Thermal and Fluid Science, 52* (2014), pp. 88-96.

[23] Amiri, A., Pool boiling heat transfer of CNT/water nanofluids, *Applied Thermal Engineering, 71* (2014), pp. 450-459.

[24] Kim, J., Effect of a graphene oxide coating layer on critical heat flux enhancement under pool boiling, *International Journal of Heat and Mass Transfer, 77* (2014), pp. 919-927.

[25] Umesh, V., Raja B., A study on nucleate boiling heat transfer characteristics of pentane and CuO-pentane nanofluid on smooth and milled surfaces, *Experimental Thermal and Fluid Science, 64* (2015), pp. 23-29.

[26] Mori, S., *et al.*, Enhancement of the critical heat flux in saturated pool boiling of water by nanoparticle-coating and a honeycomb porous plate, *International Journal of Heat and Mass Transfer, 80* (2015), pp. 1-6.

[27] Sarafraz, M.M ., Hormozi F., Pool boiling heat transfer to dilute copper oxide aqueous nanofluids, *International Journal of Thermal Sciences, 90* (2015), pp. 224-237.

[28] Xing, M., *et al.*, Effects of surface modification on the pool boiling heat transfer of MWNTs/water nanofluids, *International Journal of Heat and Mass Transfer, 103* (2016), pp. 914-919.

[29] Sarafraz, M.M., *et al.,* Critical heat flux and pool boiling heat transfer analysis of synthesized zirconia aqueous nano-fluids, *International Communications in Heat and Mass Transfer, 70* (2016), pp. 75-83.

[30] Sarafraz, M.M., *et al.*, Pool boiling heat transfer to aqueous alumina nano-fluids on the plain and concentric circular micro-structured (CCM) surfaces, *Experimental Thermal and Fluid Science, 72* (2016), pp. 125-139.

[31] Yanwei, H., *et al.*, Effect of nanoparticle size and concentration on boiling performance of SiO_2 nanofluid, *International Journal of Heat and Mass Transfer, 107* (2017), pp. 820-828.

[32] Abdollahi, A., *et al.*, Experimental analysis of magnetic field effect on the pool boiling heat transfer of a ferrofluid, *Applied Thermal Engineering, 111* (2017), pp.1101-1110.

[33] Shoghl, S., *et al.*, The boiling performance of ZnO, α-Al_2O_3 and MWCNTs/ water nanofluids: An experimental study, *Experimental Thermal and Fluid Science, 80* (2017), pp. 27-39.

[34] Fang, X., *et al.,* A review of flow boiling heat transfer of nanofluids, *Applied Thermal Engineering, 91* (2015), pp. 1003-1017.

[35] Cheng, L., Liu L, Boiling and two-phase flow phenomena of refrigerant-based nanofluids: Fundamentals, applications and challenges, *International journal of refrigeration, 36* (2013), pp. 421-446.

[36] Chehade., A.A, *et al.*, boiling local heat transfer enhancement in minichannels using nanofluids, *Nanoscale Research Letters*, *8*, (2013), 1, pp.1-20.

[37] Faukner, D., *et al.*, Practical design of a 1000 W/cm^2 cooling system, *Proceeding*. 19th IEEE Semiconductor Thermal Measurement and Management Symposium, San Jose, CA, 2003, pp.11-13.

[38] Lee, S., *et al.*, Critical heat flux enhancement in flow boiling of Al_2O_3 and SiC nanofluids under low pressure and low flow conditions, *Nuclear Engineering And Technology*, *44* (2012), 4.

[39] Abedini, E., *et al.*, Numerical investigation of subcooled flow boiling of a nanofluid, *International Journal of Thermal Sciences, 64* (2013), pp. 232-239.

[40] Om Shankar Prajapati, Nirupam Rohatgi, Flow Boiling Heat Transfer Enhancement by Using ZnO-Water Nanofluids, Hindawi Publishing Corporation, Science and Technology of Nuclear Installations, Volume 2014, Article ID 890316, 7 pages.

[41] Sarafraz, M. M., *et al.*, Upward Flow Boiling to DI-Water and CuO Nanofluids Inside the Concentric Annuli, *Journal of Applied Fluid Mechanics*, *8*, (2015), 4, pp. 651-659.

[42] Wang, Y., *et al.*, A correlation of nanofluid flow boiling heat transfer based on the experimental results of AlN/H_2O and Al_2O_3/H_2O nanofluid, *Experimental Thermal and Fluid Science, 80* (2017), pp. 376-383.

[43] Abedini, E., *et al.,* Experimental investigation and comparison of subcooled flow boiling of TiO_2 nanofluid in a vertical and horizontal tube, *Journal of Mechanical Engineering Science, 227*, (2012), 8, pp. 1-12.

[44] Xu, L., Xu, J., Nanofluid stabilizes and enhances convective boiling heat transfer in a single microchannel, *International Journal of Heat and Mass Transfer, 55* (2012), 21-22, pp. 5673-5686.

[45] Abedini, E., *et al.*, Numerical investigation of subcooled flow boiling of a nanofluid, *International Journal of Thermal Sciences*, *64* (2013), pp. 232-239.

[46] Kim, J., *et al.,* Subcooled flow boiling heat transfer of dilute alumina, zinc oxide, and diamond nanofluids at atmospheric pressure, *Nuclear Engineering and Design, 240* (2010), pp. 1186-1194.

[47] Lee, T., *et al.*, Flow boiling critical heat flux characteristics of magnetic nanofluid at atmospheric pressure and low mass flux conditions, *International Journal of Heat and Mass Transfer*, *56* (2013), pp. 101-106.

[48] Lee, T., *et al.,* Effects of two-phase flow conditions on flow boiling CHF enhancement of magnetite-water nanofluids, *International Journal of Heat and Mass Transfer, 74* (2014), pp. 278-284.

[49] Sarafraz, M.M., Hormozi F., Forced Convective and Nucleate Flow Boiling Heat Transfer to Alumina Nanofluids, *periodica polytechnic Chemical Engineering*, 58 (2014), 1, pp. 37-46.

[50] Aminfar, H., *et al.,* Experimental study on the effect of magnetic field on critical heat flux of ferrofluid flow boiling in a vertical annulus, *Experimental Thermal and Fluid Science, 58* (2014), pp. 156-169.

[51] Sarafraz, M.M., Hormozi F., Scale formation and subcooled flow boiling heat transfer of CuO-water nanofluid inside the vertical annulus, *Experimental Thermal and Fluid Science, 52* (2014), pp. 205-214.

[52] Moreira, T.A., *et al.,* Flow boiling of nanofluids of water and Al_2O_3 inside a 1.1 mm round channel, *procceding*, 9th International Conference on Boiling and Condensation Heat Transfer, Boulder, Colo, USA, 2015.

[53] Setoodeh, h., *et al.,* Subcooled flow boiling of alumina/water nanofluid in a channel with a hot spot: An experimental study, *Applied Thermal Engineering*, *90* (2015), pp. 384-394.

[54] Nikkhah, V., *et al.,* Application of spherical copper oxide (II) water nano-fluid as a potential coolant in a boiling annular heat exchanger, *Chem Bio chem Eng, 29* (2015), 3, pp. 405–415.

[55] Yu, L., *et al.*, Flow boiling heat transfer and two-phase flow instability of nanofluids in a minichannel, *Journal of Heat Transfer*, 137 (2015), pp. 1-11.

[56] Paul G., *et al.,* Assessment of the process of boiling heat transfer during rewetting of a vertical tube bottom flooded by alumina nanofluid, *International Journal of Heat and Mass Transfer, 94* (2016), pp. 390-402.

[57] Wang, Y., Su G.H., experimental investigation on nanofluid flow boiling heat transfer in a vertical tube under different pressure condition, *Experimental thermal and fluid science, 77* (2016), pp. 116-123.

[58] Zangeneh, A., et al., Experimental study of forced convection and subcooled flow boiling heat transfer in a vertical annulus using different novel functionalized ZnO nanoparticles, *Applied Thermal Engineering, 109* (2016), pp. 789-802.

[59] Sarafraz, M.M., Hormozi F., Comparatively experimental study on the boiling thermal performance of metal oxide and multi-walled carbon nanotube nanofluids, *Powder Technology*, 287 (2016), pp. 412-430.

[60] Abedini, E., *et al.*, Experimental study of Transition Flow from Single Phase to Two Phase flow boiling in Nanofluids, *Journal of Molecular Liquids*, (2017), doi:10.1016/j.molliq.2017.01.049.

[61] Lee, S., *et al.,* Study on flow boiling critical heat flux enhancement of graphene oxide/water nanofluid, *International Journal of Heat and Mass Transfer, 65* (2013), pp. 348-356.

[62] Afranda, M., *et al.*, Experimental investigation and simulation of flow boiling of nanofluids in different flow directions, *Physica E, 87* (2017), pp. 248-253.

[63] Kamatchi, R., *et al.*, Experimental investigation and mechanism of critical heat flux enhancement in pool boiling heat transfer with nanofluids, *International journal of Heat and Mass Transfer, 52* (2016), pp. 2357–2366.

[64] Ali, H.M., *et al.*, Experimental investigation of nucleate pool boiling heat transfer enhancement of TiO2/ water based nanofluids, *Applied Thermal Engineering, 113* (2017), pp. 1146-1151.

[65] He, Y., *et al.*, Boiling heat transfer characteristics of ethylene glycol and water mixture based ZnO nanofluids in a cylindrical vessel, *International Journal of Heat and Mass Transfer, 98* (2016), pp. 611-615.

[66] Rajabnia, H., *et al.*, Experimental Investigation of Subcooled Flow Boiling of Water/ TiO_2 Nanofluid In a Horizontal Tube, *Thermal Science*, *20* (2016), 1, pp. 99-108.

[67] Wang, Y., Wu, J., Numerical simulation on single bubble behavior during Al_2O_3/H_2O nanofluids flow boiling using Moving Particle Simi-implicit method, *Progress in Nuclear Energy*, *85* (2015), pp. 130-139.

[68] Rana, K.B., *et al.*, A visualization study of flow boiling Heat transfer with nanofluids, *Journal of Visualization*, 16 (2013), 2, pp. 133-143.

[69] Rana, K.B., et al., Measurement of void fraction in flow boiling of ZnO/ water nanofluids using image processing technique, *Nuclear Engineering and Design*, *270* (2014) , pp. 217-226.

[70] Collier, J. G. and Thome J. R., *Convective Boiling and Condensation*, Clarendon Press,Oxford, UK, 1994.

[71] Kandlikar, S. G., Development of a Flow Boiling Map for Subcooled and Saturated Flow Boiling of Different Fluids inside Circular Tubes, *Journal of Heat Transfer*, 113 (1991), pp.190-200.