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Thermal conductivity, viscosity, and heat transfer process in nanofluids: A critical review

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ABSTRACT

Heat transfer efficiency has always been at the center of attractions for many researchers and industries, and demand for higher efficiency methods and materials are increased in the last decades. Among the different methods of heat transfer enhancement, using nanofluids has proven to be an effective technique. In the present paper, the properties of nanofluids including viscosity, thermal conductivity as well as convective heat transfer are discussed and useful conclusions about the reported results by different researchers are presented. The effect of volume fraction, temperature, size and shape of particles, base fluid properties, and other factors on viscosity, and thermal conductivity of nanofluids are reviewed. Also, in the present manuscript, the methods of stable nanofluid preparation, and the effective factors on the stability of nanofluids are exhibited in detail. Besides, a summarized number of experimental and mathematical studies on the properties, and stability of nanofluids are listed, compared, and analyzed. The works about the Nusselt number in fluids and nanofluids are presented in detail to determine the future challenges of nanofluids.

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1. Introduction

The rising energy demands and concerns about environmental pollutions have motivated the engineers to utilize new sources of energy such as solar, wind, and biogas [1–4]. The optimization of thermal systems is inevitable to increase the efficiency and reduce the cost and air pollution [2, 5–9]. The energy-efficient systems are obtained by enhancing the heat transfer rate using different passive or active methods [10, 11]. Active methods benefit the external energies such as electric or magnetic field, vibrating surface, or a mechanical mixer. However, the passive methods don't need external sources and the heat transfer enhancement is obtained by a change in geometry or fluid properties [12, 13]. The miniaturization of the channels, using the fins, or utilizing nanofluids are some common passive methods [11, 14–17]. In the last decades, due to the developments of miniaturized devices, such as computer electron-

ic components, the old techniques of cooling became inadequate [15, 18–20]. Besides, the evolutions in technology have created an urgent demand for new and efficient cooling methods to maintain the device temperatures below the critical area. This need for new methods has motivated the researchers to study and find a profitable way. Nanofluid, which is the mixture of nano-sized particles in the base fluid, proved to be a novel heat transfer method in heat transfer issues [21].

Nanofluids are known as a new generation of fluids with hidden and unknown thermal capabilities.

Choi [22, 23] introduced nanofluids and claimed that they showed better heat transfer characteristics than their base fluids. Adding nanoparticles to the base fluid is a passive method for improving heat transfer processes [24]. The volume fraction of the nanoparticles as well as their size and type are significant factors that result in the mentioned improvements. Also, the working temperature and type of fluid play role in enhancement [25, 26].

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Nomenclature			
A	Area (m ²)	vol	Volume fraction
c _p	Heat capacity (J/kg.K)	wt	Weight fraction
CTAB	Cetyltrimethylammonium bromide		
d	Diameter (m)	<i>Greek Letters</i>	
EG	Ethylene glycol	α	Thermal diffusivity
EO	Engine oil	β	A constant
GA	Gum Arabic	μ	Dynamic viscosity (Pa.s)
h	Convective heat transfer coefficient (W/m ² K)	ρ	density (kg/m ³)
k	Thermal conductivity (W/m.K)	σ	A constant
L	Length (m)	φ	Particle volume fraction
n	Shape factor	ψ	Sphericity
Nu	Nusselt number		
PG	Propylene glycol	<i>Subscripts</i>	
Pr	Prandtl number	bf	Base fluid
PVP	Polyvinyl pyrrolidone nanofluids	c	Critical
R	Thermal resistance (m ² K/W)	eff	Effective
r	Radius (m)	l	Laminar
Re	Reynolds number	p	Particle
SDBS	Sodium dodecylbenzene sulfonate	t	turbulent
SDS	Sodium dodecyl sulfate		
T	Temperature (K)		

Nowadays, nanofluids have been used in many fields of industries such as electronic, nuclear, medicine, and transportation systems [27].

Nanofluids preparation, stability, characterizations, thermal features, conduction, and convection heat transfer processes have been studied widely by the researchers [28]. For the first time, Choi [22] dispersed the nano-sized particles in a base fluid and called the mixture as nanofluid. After introducing nanofluids, Lee et al. [29], Eastman et al. [30], Yu et al. [31], and many other researchers investigated the thermal behavior of nanofluids, and heat transfer rate enhancement by use of nanofluids was proved. It was also shown that the unique behavior of nanofluids may originate from some mechanisms such as the Brownian motion of nanoparticles and decreases in the thermal boundary layer [32].

As mentioned above, the stability of nanofluids is a crucial factor that determines the applicability of nanofluids. Researchers always looking for stable nanofluids. So, many stability tests have been accomplished and the results showed the three main different methods to prepare a stable suspension, that is surfactants, ultrasonic bath, and pH control [33–35]. Also, there are other factors such as viscosity that are critically related to the pumping power of nanofluid. Although there are a lot of experimental studies of the nanofluids behavior, numerical methods are still a strong tool to obtain detailed information about the investigated phenomenon and have wide applications in heat and mass transfer, bio-mechanics, and solid mechanics [36, 37, 46, 38–45].

In the present paper, a critical review of the preparation, characterization, and heat transfer enhancement nanofluids has been done. We are attempting to provide a comprehensive review of the factors that affect the thermos-physical properties of nanofluids. Also, the experimental correlations and results have been compiled. The present review mainly aims to summarize the recent researches on thermophysical properties and the stability of nanofluids and applications of nanofluids in various industries and devices.

Fig. 1. Synthesizing methods of nanoparticles [21].

2. Nanofluids

2.1. Preparation methods

Nanofluids are recognized with their unique thermal properties, such as viscosity, thermal conductivity, and many other properties, compared to common fluids. Many types of nanoparticles are used for synthesizing nanofluids including carbon nanotubes, metals, metal oxides, ceramics, etc. metals generally have considerably high thermal conductivities than fluids, however, some types of advanced ceramics offer interestingly high thermal conductivities even more than common metal, such as ZrB₂ [47, 48, 57–66, 49, 67–76, 50, 77–86, 51, 87–96, 52, 97–102, 53–56], TiB₂ [103, 104, 113–121, 105–112], SiC, AlN [122–125], TiC [126, 127, 136, 128–135], and HfB₂ [137]. These ceramics have proved remarkable thermos-mechanical behaviors in different branches of industry [138, 139, 148–157, 140, 158–164, 141–147]. One of the important factors,

Fig. 2. Effective parameters on thermophysical properties of nanofluids.

which affects the final properties of nanofluids, is the preparation of the nanoparticles [165]. Some of the synthesizing methods of nanoparticles are presented in Fig. 1.

Also, there are various methods for analyzing nanoparticles. The most common methods are Transmission Electron Microscope (TEM), Scanning Electron Microscope (SEM), Optical spectroscopy, X-ray Diffraction (XRD), Infrared and Raman Spectroscopy [166].

The synthesis of a nanofluid is a key role task in researches. The main goal of preparing nanofluids is to obtain a stable suspension without any agglomeration in a specified period and temperature. The agglomeration of nanoparticles in a nanofluid is a significant problem in all nanofluid investigations. Two main methods involved with preparing nanofluids are One-step and Two-step methods [167]. The purpose of the mentioned methods is to generate good nanoparticle suspensions. The unique heat transfer improvements by using nanofluids directly depend on the quality of the suspension. The quality of nanofluid is a function of the synthesis method and the homogeneity of nanoparticles in the base fluid [166]. Overcoming the mentioned problems has become more important in higher nanoparticle concentrations [168].

In the One-step method, in a single process, the nanoparticles are formed and dispersed in the base fluid. In the Two-step method, nanoparticles are prepared in the first step and after that, in the second step, the prepared particles are dispersed in a fluid [167]. From an economical point of view, the Two-step method takes lower costs [169]. In the two-

Fig. 3. Thermal conductivity of various materials at 25°C [211].

Fig. 4. Thermal Conductivity of various fluids at 25°C [211].

step method, nanoparticles can be synthesized and dispersed in base fluid chemically or mechanically [170]. In chemical dispersion, surfactants are commonly added to the fluid, whereas in mechanical dispersion, sonication is often employed to disperse nanoparticles [171]. Besides, there are other significant factors that have remarkable effects on a suspension's quality. According to various studies such as Sonawane et al. [172], and Buonomo et al. [173], particle size and sonication time are

Table 1.

Some of the reported synthesis studies of nanofluids

Synthesis method	Authors	Publish year	Nanoparticle/Base fluid	Particle size (nm)	Fraction (Vol% or wt%)
One-Step	Eastman et al. [30]	2001	Cu/EG	10	0.3
	Hong et al. [174]	2005	Fe/EG	10	0.55
	Liu et al. [175]	2006	Cu/Water	75–100	0.1
	Paul et al. [176]	2012	Ag/Water	-	1
	De Robertis et al. [177]	2012	Cu/EG	-	-
Two-Step	Choi et al. [178]	2001	CNT/Poly oil	25*50000	2
	Murshed et al. [179]	2005	TiO ₂ /Water	15	5
	Meibodi et al. [180]	2010	CNT/Water	1–4	0.12
	Lee et al. [181]	2011	SiC/Water	<100nm	0.001–3
	Singh et al. [182]	2012	Al ₂ O ₃ /EG&Water	130,211,300	0.25–1
	Fazeli et al. [183]	2012	SiO ₂ /Water	18	3.5–5
	Zeinali Heris et al. [184]	2015	MWCNT/Water	10*20000	0.55
	Choudhary et al. [185]	2016	Al ₂ O ₃ /Water	40	0.1–2
	Irani et al. [186]	2018	GO/Water+MDEA	-	0.1 & 0.2

other critical factors that affect the dispersion level of nanoparticles and lead to better thermophysical properties of nanofluids. Some of the synthesized nanofluids utilizing one-step and two-step methods reported in various articles are presented in Table 1.

2.2. Stability of nanofluids

Synthesizing a stable and durable homogenous nanofluid has always been challenging for researchers due to the agglomeration of nanoparticles as a result of the van der Waals forces [187]. To avoid particle agglomeration, some physical and chemical methods have been proposed and investigated [165]. The most common method that researchers use while confronting agglomerations is adding surfactants which is a chemical method [188]. The addition of surfactants makes hydrophobic materials disperse in an aqueous suspension better than normal situations [189]. There are many types of surfactants such as Gum Arabic, CTAB, SDS, SDBS, NADDBS, CMC, HCTAB, TX-100, etc. [190]. Besides, the fraction of surfactants that are used for making a suspension stable is very important. If used less than the limit, causes inadequate stability and if overused, causes agglomeration of nanoparticles in the suspension due to the osmotic pressure [191].

Also, there are other methods that enhance the stability of nanofluid. Li and Xuan [192] suggested the ultrasonic waves for increasing the stability of nanofluids in addition to surfactants. Peng et al. [193] defined and studied the important factors of the preparation of stable nanofluids. They showed that the dispersion method, volume fraction of nanoparticles, the viscosity of the base fluid, the value of pH, density of nanofluid, type of nanoparticles, and size of nanoparticles in conjunction with ultrasonic waves affect the stability of nanofluids.

The main purpose of all methods is to prevent particle clustering by changing the surface properties of particles, which results in a stable nanofluid. An ultrasonic bath, which is used widely by researchers [35], is a powerful instrument for breaking the agglomerations. A conclusion of researches, which has utilized an ultrasonic bath to prepare stable nanofluids, is presented Table 2.

The stability of an aqueous nanofluid directly depends on electro-kinetic properties. The high surface charge density of the nanoparticles may result in strong repulsive forces and consequently, bring up better dispersion of nanoparticles in suspensions [35].

In the isoelectric point (IEP), the concentration ions that play a role in zeta potential is zero. In the isoelectric point, surface charge density is equal to electron charge density and because of that, the zeta potential

is zero. The pH value has to be considered to attain the isoelectric point [206]. It has been observed that pH control makes a nanofluid to be stable for a long time [207]. By controlling the repulsive force between nanoparticles, the zeta potential is decreased to zero at a particular pH value at the isoelectric point and it is a negative problem for the stability of nanofluids [35]. The pH deviation of a prepared suspension from the isoelectric point increases the stability of colloidal particles and causes the changes in the thermal conductivity of the nanofluid [208]. Jorge et al. [209] investigated the MWCNT/water nanofluid at pH values of 2 and 5.5 and reported that the mentioned nanofluids were stable because of the deposition of amines on the MWCNT surface. Zareei et al. [210] evaluated the stability of Al_2O_3 /water nanofluid at various pH values and showed that the Al_2O_3 /water nanofluid had the highest stability at pH=4 while pH=10 showed less stability. Each type of nanoparticle became stably dispersed at its optimized pH value that leads to optimum thermal properties. At an optimum pH, the repulsive force between nanoparticles increases and prevents the sedimentations and agglomerations [211].

Among the various methods to evaluate the stability of nanofluids the most common techniques are: zeta potential, absorbency, stratification observing, sedimentation observing, and particle size-changing [212]. When almost all of the particles have high zeta potential values, there is no tendency for agglomeration and consequently, the suspension becomes stable [213]. In the zeta potential method, a Laser Doppler Velocimetry (LDV) records the movement of nanoparticles under an electrical field. Nowadays most of the investigations about the stability of nanofluids are done with the zeta potential method [181]. The acceptable values of zeta potential are shown in Table 3 [214]

2.3. Thermophysical properties of nanofluids

The main idea of the synthesis of nanofluids is to enhance the thermophysical behavior of the base fluids. Thermal properties of the working fluid play an essential role in the heat transfer rate of a thermal system. The working fluid commonly has weak thermal properties, therefore the improvements of these properties increase the efficiency of thermal devices, reduce costs, and results in more compact and miniaturized devices [20]. The properties of some of the base fluids that are utilized commonly in various investigations are presented in Table 4 [187, 215–218]. The dispersion of nanoparticles in the base fluid is one of the attractive methods in the enhancement of the fluid properties. Many factors affect the thermophysical properties of nanofluids that are presented in Fig. 2 [219]. Kolade et al. [220] investigated the effect of

Table 2.
Investigations of nanofluid stability

Authors	Publish year	Nanoparticles/Base fluid	Particle size(nm)	Fraction (vol% or wt%)	Sedimentation	surfactant
Patel et al. [194]	2005	Al_2O_3 /Water	11	0.8	-	-
Lee et al. [195]	2006	CuO/Water	25	0.3	-	-
Zhu et al. [189]	2007	Graphite/Water	20	0.5	-	PVP
Li et al. [188]	2008	Cu/Water	25	0.1	-	SDBS
Chen et al. [196]	2009	Titanate NT/EG	10*100	0.5-8	>2 months	-
Yu et al. [197]	2010	Fe_3O_4 /Kerosene	15	0.1-2	-	Oleic acid
Chandareskar [198]	2010	Al_2O_3 /Water	43	0.33-5	-	-
Aravind et al. [199]	2011	MWCNT/Water	-	0.005-0.03	-	-
Shanbedi et al. [200]	2012	MWCNT/Water	15*10000	0-1.5	>6 months	-
Shanbedi et al. [201]	2013	MWCNT/Water	15*10000	0-1	>6 months	GA
Amiri et al. [202]	2015	Graphene/Water	3.74*3000	0-0.1	1 month	SDBS
Mustafizur [203]	2016	SiO_2 /Methanol	5-15	0.005-0.05	24 hours	-
Cacua et al. [204]	2017	Al_2O_3 /Water	-	0.1-0.5	30 days	SDBS-CTAB
Krishnan et al. [205]	2019	MgO/Water-EG	-	0.05-0.6	20 days	-

Table 3.

The acceptable values of zeta potential [70]

Zeta potential (mv)	Stability
0	No stability or little stability
15	Some stability but settling lightly
30	Moderate stability
45	Good stability with settling possibility
60	Excellent stability

the particle fraction on the effective thermal conductivity of Al_2O_3 -water and MWCNT-water nanofluids and reported 6% and 10% enhancement at 2% and 0.2% fractions, respectively. Das et al. [221] reported that temperature increment results in higher thermal conductivity of nanofluids. Also, Shou et al. [222] indicated that an increase in thermal conductivity had a linear proportion with temperature. Chon et al. [223] studied the effect of nanoparticles size on the thermal conductivity of nanofluids for spherical nanoparticles with the size of 10–50 nm and showed that the thermal conductivity of nanofluids increased with a decrease in particles size.

2.3.1. Thermal conductivity

In the last decades, the thermal conductivity of the fluids containing nanoparticles has become a point of attraction for many researchers and various numerical and experimental studies have done about nanofluids [220]. The results of various studies show that the thermal conductivity of nanofluids improves by diverse factors like volume fraction, nanoparticle type and size, the thermal conductivity of nanoparticles and base fluid, temperature, viscosity, Brownian motion, pH value, and the quality of dispersion [224].

The Brownian movement of nanoparticles at nano-sized levels and molecular scales plays a key role in the thermal behavior of solid-fluid suspensions including nanofluids. The increases in thermal conductivity of nanofluids are related to local convections that caused by Brownian motions of nanoparticles [225].

Solid materials have generally higher thermal conductivities than fluids. Metals possess considerably high thermal conductivity, however, some types of advanced ceramics offer considerable thermal conductivities such as ZrB_2 , AlN , BeO , and TiB_2 [226–231]. Since the thermal conductivity of solid nanoparticles is very higher than fluids, it is expected that dispersing nanoparticles in a base fluid enhances the thermal conductivity and the heat transfer functions of the fluid. The approximate thermal conductivity of some materials and base fluids is shown in Fig. 3 and Fig. 4, respectively [211].

The experimental studies exhibited that nanofluids do not conform with general correlations and the thermal conductivity of nanofluids depends on many factors that some of them are still unknown. Jana et al. [232] studied various nanofluids and showed that the Cu-water nanofluid brings up to 74% enhancement in thermal conductivity. Xie et al. [233] investigated the effect of using CNT, CuO , and Al_2O_3 nanoparticles in a base fluid and showed that regardless of the type of the base fluid, Carbon nanotube suspensions demonstrated better thermal conductivity values in the same volume fractions [233]. Wang et al. [234] compared the diverse data for Al_2O_3 and CuO nanoparticles by considering water, vacuum pump fluid, engine oil, and ethylene glycol as base fluids and showed that the thermal conductivity of nanofluids increased with a decrease in nanoparticle size. Abareshi et al. [235] investigated the thermal conductivity of Fe_3O_4 -water nanofluid and highlighted that the thermal conductivity of nanofluids improved with increment in temperature due to the increases in the activity of molecules to transfer energy. Lai et al. [236] and Zhu et al. [237] claimed that the pH value is very effective on the thermal conductivity of suspensions. In Table 5 found., the thermal

Table 4.

Thermophysical properties of common base fluids that utilized in nanofluids [187, 215–218]

Base fluid	cp (J/kg.K)	k (W/m.K)	ρ (kg/m ³)	μ (N.s/m ²)
Distilled water	4184	0.599	998	1.00E-04
Ethylene Glycol	2383	0.25	1117	2.20E-02
Engine oil	1881	0.145	888	8.40E-01
Propylene glycol	4019	0.34	1036	4.20E-02
EG + water (X=0.5)	3473	0.316	1094	28.00E-04

conductivity enhancement reported by some researchers is presented.

Many studies reported the enhancement of thermal conductivity by utilizing and dispersing nanoparticles in the base fluid [220]. Although the researchers presented many models to predict the thermal conductivity of nanofluids, however, comparing the experimental data with theoretical models shows the need for more investigations to explain the abnormal improvements in the thermal conductivity of nanofluids.

Maxwell [251] for the first time presented a mathematical model to determine the thermal conductivity of a solid-fluid suspension by assuming spherical shape for all solid particles as follow:

$$k_{eff} = \frac{k_p + 2k_{bf} + 2(k_p - k_{bf})\phi}{k_p + 2k_{bf} - (k_p - k_{bf})\phi} k_{bf} \quad (1)$$

where ϕ is the volume fraction and k_{bf} and k_p are the thermal conductivity of the fluid and particles, respectively.

Researchers also developed various mathematical models by considering different parameters that affect thermal conductivity. Hamilton and Crosser [252] considered the shape of the particles and justified the Maxwell model as below:

$$k_{eff} = \frac{k_p + (n-1)k_{bf} + (n-1)(k_p - k_{bf})\phi}{k_p + (n-1)k_{bf} - (k_p - k_{bf})\phi} k_{bf} \quad (2)$$

where n is the shape factor given as

$$n = \frac{3}{\psi} \quad (3)$$

ψ is defined as the sphericity of the solid particles. A series of mathematical models considering the different involving factors are presented by several researchers. A conclusion of various presented models suggested by researchers is shown in Table 6.

2.3.2. Viscosity

The viscosity is a significant and important characteristic of all types of fluids that shows the resistance of a fluid flow against shear stress. Because of that, the viscosity has a great effect on the rheological and thermal behaviors of nanofluids as a special type of fluids. The viscosity affects the friction between the fluid molecules and the contact surface of nanoparticles and plays a key role in fluid flow and heat transfer phenomena. The pumping power and convective heat transfer rate are directly related to the value of viscosity [267].

The viscosity depends on various factors such as dispersing method, nanoparticle diameter, nanoparticle type, temperature, and nanoparticle concentration which the effect of concentration is more than other factors [268, 269]. Ghazvini et al. [270] showed that the viscosity of nanofluids increased by up to 20% in high nanoparticle concentrations. Ding et al. [271] investigated the viscosity of carbon nanotube-water nanofluid as a function of shear stress and indicated that the viscosity of

Table 5.

The overview of the result of some studies on the thermal conductivity of nanofluids

Authors	Publish year	Particle/Base fluid	Fraction (vol% or wt%)	Particle size (nm)	Additives	Enhancement (%)
Xuan & Li [192]	2000	Cu/water	2.5-7.5	100	Laurate salt	22-75
Xie et al. [238]	2002	Al ₂ O ₃ /water	1.8-5	60.4	-	7-21
Patel et al. [239]	2003	Ag/water	0.001	60-70	-	3% at 30°C 4% at 60°C
Das et al. [221]	2003	Al ₂ O ₃ /water	1-4	38.4	-	2-9% at 21°C 10-24% at 51°C
Wen & Ding [240]	2004	Al ₂ O ₃ /water	0.19-1.59	42	SDBS	1-10
Hong et al. [174]	2005	Fe/EG	0.2-0.55	10	-	13-18
Putnam et al. [241]	2006	Au/ethanol	0.01-0.07	4	Alkanthiolate	0.3-1.3
Lee et al. [195]	2006	CuO/water	0.03-0.3	25	-	4-12% at pH=3 2-7% at pH=6
Li et al. [188]	2008	Cu/water	0.02-1 wt%	25	SDBS	10.7
Godson et al. [242]	2010	Ag/water	0.3-0.9	60	-	10-30% (50 to 90°C)
Kole & Dey [243]	2010	Al ₂ O ₃ /water	0.001-0.035	50	Oleic acid	10.5%
Colla et al. [244]	2012	Fe ₃ O ₄ /water	5-20 wt%	67	-	0-7% at 10°C 1-10% at 30°C 5-11% at 50°C 3-15% at 70°C
Manna et al. [245]	2012	SiC/water	0.01-0.1	60	-	7.5-11.5%
Teng [246]	2013	Al ₂ O ₃ /water	0,0.5,1,3	20	Chitosan	1-9% decrease
Amiri et al. [202]	2015	Geraphene/water	0.025-0.1 wt%	3.74*3000	SDBS	Up to 26.2
Sinha et al. [247]	2017	ZnO/water	0.1-5	-	-	33
Micali et al. [248]	2018	CuO-water	2.5	-	-	Up to 18
Ranjbarzadeh et al. [249]	2019	SiO ₂ /water	0.1-3	-	-	Up to 38.2
Riahi et al. [250]	2020	Al ₂ O ₃ /water	0.7	9	-	8.6

nanofluids increases with increments in concentration on the one hand and also, decrements in temperature on the other hand. Zeinali Heris et al. [272] showed that the viscosity value of CuO-water nanofluid is greater than Al₂O₃-water nanofluid because of the bigger size of CuO nanoparticles.

Nguyen et al. [273] investigated the effect of temperature, concentration, and size of nanoparticles on the dynamic viscosity of Al₂O₃-water and CuO-water nanofluids. The results showed that the viscosity of prepared nanofluids was a function of temperature and volume fraction of nanoparticles.

A conclusion of experimental researches about the viscosity of nanofluids is presented in Table 7. Also, there are some mathematical correlations for predicting the effective viscosity of nanofluids. A summary of the significant viscosity correlations is presented in Table 8.

2.4. Convective heat transfer process in nanofluids

Using nanofluids in various devices is an effective method to reach high efficiencies in the cooling procedure. In the previous sections, the synthesis and some thermophysical properties of nanofluids have been explained, however, convective heat transfer needs many studies about the flow regime, heat transfer process, and other significant factors [295]. The convective heat transfer coefficient of nanofluids increases with increment in conductive heat transfer rate, intensification of turbulence, stopping the growth of the boundary layer, etc. [24]. A decrease in the thermal boundary layer can lead to the stimulation of the particles around the wall and migration of the particles toward the center of the duct and this subject will decrease the viscosity near the wall [296]. Numerous studies have been performed to investigate the convective heat transfer using nanofluids. A constant heat flux or constant wall tempera-

ture is usually considered as the boundary condition for studying the heat transfer of nanofluids [297].

By using nanofluids, complicated behaviors such as Brownian motion, rotation of the particles, and micro-displacements of nanoparticles emerge [297]. These mechanisms make it necessary to find new correlations to cover the convective heat transfer of the nanofluids.

Jung et al. [298] investigated the Al₂O₃-water nanofluid in a micro-channel with considering the laminar flow regime and showed a 32% increase in the convective heat transfer coefficient in comparison with used base fluids. Zeinali heris et al. [299] investigated the Cu-water nanofluids in a tube with a laminar flow regime at constant wall temperature condition as a boundary condition and indicated that with increases in volume fraction, the convective heat transfer coefficient values improved as 45% at 2% volume fraction. Faulkner et al. [300] investigated the convective heat transfer in a microchannel by utilizing CNT-water. The results showed that the convective heat transfer coefficient improves with an increase in volume fraction. Aravind et al [199] synthesized the CNT-water nanofluids at 0.005% and 0.03% volume fractions and showed that the convective heat transfer coefficient increases with an increase in Reynolds number and volume fraction. Naraki et al. [301] investigated the CuO-water nanofluid in a car radiator and presented an 8% enhancement in the heat transfer rate.

Several mathematical correlations are presented by researchers for predicting the Nusselt number of single-phase fluids in a tube at laminar and turbulent flow regimes. A conclusion of some correlations for the Nusselt number is shown in Table 9.

2.5. Future Challenges

As the researches about nanofluid progress over time, many chal-

Table 6.

A conclusion of models proposed for thermal conductivity of nanofluids

Reference	Year	Correlation	Dependent Parameters
Maxwell et al [251]	1890	$k_{eff} = \frac{k_p + 2k_{bf} + 2(k_p - k_{bf})\phi}{k_p + 2k_{bf} - (k_p - k_{bf})\phi} k_{bf}$ $k_{eff} = \frac{1}{4}[(3\phi - 1)k_p + (2 - 3\phi)k_{bf}] + \frac{k_{bf}}{4}\sqrt{\Delta}$	Volume fraction
Bruggeman [253]	1937	$\Delta = \left[(3\phi - 1)^2 \left(\frac{k_p}{k_{bf}} \right) + (2 - 3\phi)^2 + 2(2 + 9\phi - 9\phi^2) \left(\frac{k_p}{k_{bf}} \right) \right]$	Volume fraction
Hamilton & Crosser [252]	1962	$k_{eff} = \frac{k_p + (n - 1)k_{bf} + (n - 1)(k_p - k_{bf})\phi}{k_p + (n - 1)k_{bf} - (k_p - k_{bf})\phi} k_{bf}$	Volume fraction Shape factor
Wasp [254]	1977	$k_{eff} = \frac{k_p + 2k_{bf} - 2(k_{bf} - k_p)\phi}{k_p + 2k_{bf} + (k_{bf} - k_p)\phi} k_{bf}$	Volume fraction
Lu and Lin [255]	1996	$k_{eff} = \left[1 + \frac{k_p}{k_{bf}}\phi + \frac{k_p - k_{bf}}{k_p + 2k_{bf}}\phi^2 \right] k_{bf}$	Volume fraction
Yu and Choi [256]	2003	$k_{eff} = \frac{k_{pe} + 2k_{bf} + 2(k_{pe} - k_{bf})(1 + \beta)^3\phi}{k_{pe} + 2k_{bf} - (k_{pe} - k_{bf})(1 + \beta)^3\phi} k_{bf}$ $k_{pe} = \frac{[2(1 - \gamma) + (1 + \beta)^3(1 + 2\gamma)]}{[-(1 - \gamma) + (1 + \beta)^3(1 + 2\gamma)]} k_p$	Interfacial layer Volume fraction
Nan [257]	2003	$\frac{k_{eff}}{k_{bf}} = \frac{3 + \phi(\frac{k_p}{k_{bf}})}{3 - 2\phi}$	Volume fraction
Wang et al [258]	2003	$k_{eff} = \frac{(1 - \phi) + 3\phi \int_0^\infty \frac{k_{cl}(r)n(r)}{k_{cl}(r) + 2k_{bf}} dr}{(1 - \phi) + 3\phi \int_0^\infty \frac{k_{bf}(r)n(r)}{k_{cl}(r) + 2k_{bf}} dr} k_{bf}$	Size effect Surface adsorption
Kumar et al [259]	2004	$k_{eff} = k_{bf} + c \frac{2k_b T}{\pi v d_p^2} \frac{\phi r_b}{k_{bf}(1 - \phi)r_p} k_{bf}$	Temperature, Density, Specific heat capacity, Viscosity, Radius of nanoparticle, Volume fraction
Xie et al [260]	2005	$k_{eff} = \left(1 + 3\Theta\phi_r + \frac{3\Theta^2\phi_r^2}{1 - \Theta\phi_r} \right) k_{bf}$ $\Theta = \frac{\beta_{lb}[(1 + \gamma^3) - \frac{\beta_{pl}}{\beta_{bl}}]}{(1 + \gamma)^3 + 2\beta_{pl}\beta_{bl}}$	Interfacial nanolayer Volume fraction
Prasher [261]	2005	$\frac{k_{eff}}{k_{bf}} = 1 + 64.7\phi^{0.746} \left(\frac{d_{bf}}{d_p} \right)^{0.369} \left(\frac{k_p}{k_{bf}} \right)^{0.7476} \times \text{Pr}^{0.9955} \times \text{Re}^{1.2321}$	Reynolds number Prandtl number Particle size Volume fraction
Murshed [262]	2006	$\frac{k_{eff}}{k_{bf}} = \frac{[1 + 0.27\phi^{1.3} \left(\frac{k_p}{k_{bf}} - 1 \right)] [1 + \frac{0.52\phi}{1 - \phi^{0.3}} \left(\frac{k_p}{k_{bf}} - 1 \right)]}{1 + \phi^{1.3} \left(\frac{k_p}{k_{bf}} - 1 \right) \left(\frac{0.52}{1 - \phi^{0.3}} + 0.27\phi^{0.3} + 0.27 \right)}$	Volume fraction

Continuation of Table 5

Reference	Year	Correlation	Dependent Parameters
Li [263]	2008	$k_{eff} = k_{static} + k_{Brownian}$ $k_{static} = \frac{k_p + 2k_{bf} + 2(k_p - k_{bf})\phi}{k_p + 2k_{bf} - (k_p - k_{bf})\phi} k_{bf}$ $k_{Brownian} = 50000\phi(\rho c_p)_{bf} \sqrt{\frac{k_b T}{\rho_p d_p}} g(T, \phi, d_p)$ $g(T, \phi, d_p) = (a + b \ln(d_p) + c \ln(\phi) + d \ln(\phi) \ln(d_p) + e \ln(d_p)^2) \ln(T) + (g + h \ln(d_p) + i \ln(\phi) + j \ln(\phi) \ln(d_p) + k \ln(d_p)^2)$	Brownian motion Particle diameter Temperature Volume fraction
Vajjha [264]	2010	$k_{eff} = \frac{k_p + 2k_{bf} - 2(k_{bf} - k_p)\phi}{k_p + 2k_{bf}(k_{bf} - k_p)\phi} k_{bf} + 5 \times 10^4 \beta \phi \rho_{bf} c_{pf} \sqrt{\frac{kT}{\rho_p d_p}} f(T, \phi)$	Temperature Nanoparticle type Volume fraction
Suganthi [265]	2014	$\frac{k_{eff}}{k_{bf}} = 1 + 7.926\phi$ $\frac{k_{eff}}{k_{bf}} = 1 + 8.195\phi$	Volume fraction
Gao [266]	2018	$\frac{k_{eff}}{k_{bf}} = \frac{\frac{3 + 2\eta^2\phi}{k_f} (\frac{2R_k}{L} + 13.4\sqrt{t})}{3 - \eta\phi}$	Thickness Length Thermal resistance Flatness ratio

Table 7.

A conclusion of experimental studies on the viscosity of nanofluids

Authors	Year	Particles/Base fluid	Fraction	Particle size(nm)	Additives	Viscosity increase
Godson et al. [242]	2010	Ag/water	0.3-0.9	20	-	6-23% at 50°C 10-35% at 70°C 20-43% at 90°C
Aravind [199]	2011	MWCNT/water	0.005-0.03	-	-	3-15% at 40°C 4-20% at 60°C 6-11% at 40°C 4-16% at 60°C
Colla et al. [244]	2012	Fe ₂ O ₃ /water	5-20 wt%	67	-	21-36% at 10°C 24-49% at 30°C 21-36% at 50°C 32-72% at 70°C
Syam Sundar et al. [274]	2013	Fe ₃ O ₄ /water	0.2-2	13	CTAB	6.3-108% at 20°C 1.8-107% at 40°C 10-196.6% at 60°C
Shanbedi et al. [275]	2015	MWCNT/water	0.1 wt%	10*30000	GA SDS CTAB	Temperature increase led to lower viscosity values
Chiam et al. [276]	2017	Al ₂ O ₃ /water+EG	0.2-1	-	-	Up to 50%
Yashawantha et al. [277]	2019	Graphite/EG	0.2, 0.8, 2	<50	-	58% decrease by increasing temperature (25°C-60°C)

lenges in nanofluid studies and applications still exist. Firstly, the synthesis of nanofluids must take lower costs on the one hand and give more stable nanofluids on the other hand. So, there is a critical need for more studies about the mechanisms and methods to earn information about the unique behavior of nanofluids and give more stable nanofluids that make them more commercial and applicable.

Secondly, many mathematical and experimental correlations are presented to predict the thermal and rheological properties of nanofluids. Some of them have properly validated, however, all mechanisms involved in the heat transfer of nanofluids are still unknown and unexplored. Considering optimal parameters for prospecting the behavior of nanofluids is very necessary to extract the maximum potential of nano-

fluids.

From the heat transfer aspect, nanofluids have developed in many heat transfer processes and instruments such as medical sciences, biomechanics, electronics, etc. [311]. Researchers are studying and investigating the various facets of the nanofluids to make nanofluids more reliable and marketable [312].

Nowadays, nanofluids are utilizing in heat transfer and other fields widely. However, this unique type of suspension is still under the investigation to be more applicable. Finding ways to give more stable and high-efficiency nanofluids will lead to a revolution in the heat transfer in industry and many other fields.

Table 8.

A conclusion of mathematical correlations for the viscosity of nanofluids

Authors	Year	Correlation	Dependent parameters
Einstein [278]	1906	$\mu_{eff} = (1 + 2.5\phi)\mu_{bf}$	Volume fraction
Robinson [279]	1949	$\mu_{eff} = \left(1 + \frac{c_p \phi}{1 - S_r \phi}\right) \mu$	Volume fraction Special heat capacity
Brinkman [279]	1952	$\mu_{eff} = \frac{\mu_f}{(1 - \phi)^{2.5}}$	Volume fraction
Eshelby [280]	1957	$\mu_{eff} = \left(1 + \frac{7.5(1 - \sigma)}{4 - 5\sigma} \phi\right) \mu_{bf}$ $\sigma = 0.333$	Volume fraction
Krieger [281]	1959	$\mu_{eff} = \mu_{bf} \left(1 - \frac{\phi}{\phi_m}\right)^{[\eta]\phi_m}$	Volume fraction Shear stress Particle packing
Frankel and Acrivos [282]	1967	$\mu_{eff} = 1.125 \left[\frac{\left(\frac{\phi}{\phi_m}\right)^{0.333}}{1 - \left(\frac{\phi}{\phi_m}\right)^{0.333}} \right] \mu_{bf}$	Volume fraction
Jeffrey et al [283]	1976	$\mu_{eff} = \mu_{bf} \left(3 + \frac{4}{3} \left(\frac{\phi r^2}{\ln\left(\frac{r}{\phi}\right)} \right) \right)$	Volume fraction
Graham [284]	1981	$\frac{\mu_{eff}}{\mu_{bf}} = 1 + 2.5\phi + \frac{4.5}{\left(\frac{h}{d_p}\right) \left(2 + \frac{h}{d_p}\right) \left(1 + \frac{h}{d_p}\right)^2}$	Particle diameter Inter-particle spacing
Chow [285]	1993	$\frac{\mu_{eff}}{\mu_{bf}} = \left[\exp\left(\frac{2.5\phi}{1 - \phi}\right) + \frac{A\phi^2}{1 - A\phi^2\phi_{max}} \right]$	Volume fraction
Pak and Cho [286]	1998	$\mu_{eff} = (108.2\phi^2 + 5.45\phi + 1)\mu_{bf}$	Volume fraction
Liu [287]	1999	$\frac{\mu_{eff}}{\mu_{bf}} = \left\{ \left(\frac{1 - \phi}{\phi_{max}}\right)^2 + \left(\frac{k_1 - 2}{\phi_{max}}\right)\phi + \left(\frac{k_2 - 6}{\phi_{max}^2}\right)\phi^2 \right\}$	Volume fraction
Noni [288]	2002	$\frac{\mu_{eff}}{\mu_{bf}} = \left(1 + b \left(\frac{\phi}{1 - \phi_m}\right)^n\right)$	Volume fraction Bidimensional forces
Orozco and Castillo [289]	2003	$\frac{\mu_{eff}}{\mu_{bf}} = 1 + 2.5\phi + 6.17\phi^2$	Volume fraction
Nguyen [290]	2007	$\frac{\mu_{eff}}{\mu_{bf}} = 0.904^{0.1483\phi}$	Volume fraction
Bobbo [291]	2012	$\frac{\mu_{eff}}{\mu_{bf}} = (1 + a\phi + b\phi^2)$	Volume fraction
Aberoumand [292]	2016	$\frac{\mu_{eff}}{\mu_{bf}} = 1.15 + 1.061\phi - 0.5442\phi^2 + 0.1181\phi^3$	Volume fraction
Karimipour [293]	2018	$\frac{\mu_{eff}}{\mu_{bf}} = 0.995246 - 0.000293119T.w + 0.125761w$	Weight fraction temperature
Esfe [294]	2019	$\mu_{eff} = 6.35 + 2.56\phi - 0.24T - 0.068\phi T + 0.905\phi^2 + 0.0027T^2$	Volume fraction temperature

Table 9.

A summary of correlations presented for Nusselt number

Author	Year	Correlation	Conditions
Dittus-Boelter [302]	1930	$Nu = 0.023 Re^{0.8} Pr^n$	Turbulent flow n=0.3 for cooling n=0.4 for heating 2500<Re<1.25×10 ⁵ 0.6<Pr<160
Hausen [303]	1943	$Nu = 3.66 + \frac{0.0668(d/L) Re Pr}{1 + 0.04[(d/L) Re Pr]^{2/3}}$	Laminar flow Const. wall temperature
Lyon [304]	1952	$Nu = 7 + 0.025(Re Pr)^{0.8}$	Const. heat flux
Lubarsky and Kaufman [305]	1955	$Nu = 0.625 Re^{0.4} Pr^{0.4}$	-
Churchill and Ugasi [306]	1972	$Nu^{10} = Nu_i^{10} + \left[\exp \left(\frac{2200 - (Re/365)}{Nu_e^2} + \frac{1}{Nu_i^2} \right) \right]^{-5}$	-
Notter-Sleicher [307]	1972	$Nu = 5 + 0.015 Re^{0.856} Pr^{0.347}$	0<Pr<10 ⁴ 10 ⁴ <Re<10 ⁵
Pak and Cho [286]	1998	$Nu = 0.021 Re^{0.8} Pr^{0.5}$	10 ⁴ <Re<10 ⁵ 6.54<Pr<12.33 0<φ<3%
Maiga et al. [308]	2004	$Nu = 0.086 Re^{0.55} Pr^{0.5}$ $Nu = 0.28 Re^{0.35} Pr^{0.36}$	Const. heat flux Const. wall temperature
Suresh et al. [309]	2012	$Nu = 0.031(Re Pr)^{0.68} (1 + \phi)^{95.73}$	Re<2300 0<φ<0.1%
Sundar et al. [310]	2012	$Nu = 0.02172 Re^{0.8} Pr^{0.5} (1 + \phi)^{0.5181}$	3000<Re<22000 3.72<Pr<6.5 0<φ<0.6%

3. Conclusion

Cooling performance is a major demand of many industries and because of that, the need for fluids with enhanced thermophysical properties and reliable stability is more vital than the past. The present review gives a piece of summarized information about the nanofluids and heat transfer phenomena in nanofluids and make nanofluids more understanding and displays the recent developments in nanofluids.

Many rheological and thermal properties of nanofluid have taken into account to make nanofluids more applicable. Although, the thermal conductivity, viscosity, stability, and heat transfer processes are reviewed in the present paper. Also, summarized experimental studies and mathematical correlations about the mentioned properties are brought in the present review. The parameters that affect the thermal behavior of nanofluids are particle size, volume and weight fraction, fluid type, nanoparticle type, temperature, viscosity, stability, and preparation method. Nanofluids have a huge potential to be used in many fields and industries but, there is more need for study on the hidden and unknown mechanisms of nanofluids to make them more applicable. Also, more investigations are needed to simplify the preparation methods and enhance the thermos-physical properties of nanofluids.

Conflict of interests

The Author(s) declare(s) that there is no conflict of interest.

REFERENCES

- [1] T. Gholizadeh, M. Vajdi, H. Rostamzadeh, A new trigeneration system for power, cooling, and freshwater production driven by a flash-binary geothermal heat source, *Renew. Energy*. 148 (2020) 31–43. doi:10.1016/j.renene.2019.11.154.

- [2] T. Gholizadeh, M. Vajdi, F. Mohammadkhani, Thermodynamic and thermoeconomic analysis of basic and modified power generation systems fueled by biogas, *Energy Convers. Manag.* 181 (2019) 463–475. doi:10.1016/j.enconman.2018.12.011.
- [3] T. Gholizadeh, M. Vajdi, H. Rostamzadeh, Freshwater and cooling production via integration of an ethane ejector expander transcritical refrigeration cycle and a humidification-dehumidification unit, *Desalination*. 477 (2020) 114259. doi:10.1016/j.desal.2019.114259.
- [4] T. Gholizadeh, M. Vajdi, H. Rostamzadeh, A new biogas-fueled bi-evaporator electricity/cooling cogeneration system: Exergoeconomic optimization, *Energy Convers. Manag.* 196 (2019) 1193–1207. doi:10.1016/j.enconman.2019.06.053.
- [5] F. Yekani, S. Abdi Aghdam, E. Sadegh Moghanlou, Experimental study of The Performance and exhaust gas emissions Response of A Spark Ignition Engine to Adding Natural Gas to Gasoline in CR=11., *Int. J. Ind. Math.* 11 (2019) 307–317.
- [6] T. Gholizadeh, M. Vajdi, H. Rostamzadeh, Energy and exergy evaluation of a new bi-evaporator electricity/cooling cogeneration system fueled by biogas, *J. Clean. Prod.* 233 (2019) 1494–1509. doi:10.1016/j.jclepro.2019.06.086.
- [7] T. Gholizadeh, M. Vajdi, H. Rostamzadeh, Exergoeconomic optimization of a new trigeneration system driven by biogas for power, cooling, and freshwater production, *Energy Convers. Manag.* 205 (2020) 112417. doi:10.1016/j.enconman.2019.112417.
- [8] S.M.F. Yekani S, Abdi Aghdam E, Performance Response of a Spark Ignition Engine to Adding Natural Gas to Gasoline on Lean-Burn Condition in 10 Compression Ratio., *Modares Mech. Eng.* 20 (2020) 1691–1699.
- [9] M. Namazizadeh, M. Talebian Gevari, M. Mojaddam, M. Vajdi, Optimization of the Splitter Blade Configuration and Geometry of a Centrifugal Pump Impeller using Design of Experiment, *J. Appl. Fluid Mech.* 13 (2020) 89–101. doi:10.29252/jafm.13.01.29856.
- [10] F.S. Moghanlou, A.S. Khorrami, E. Esmaeilzadeh, H. Aminfar, Experimental study on electrohydrodynamically induced heat transfer enhancement in a minichannel, *Exp. Therm. Fluid Sci.* 59 (2014) 24–31. doi:10.1016/j.expthermflusci.2014.07.019.
- [11] R.L. Webb, N.-H. Kim, principles enhanced heat transfer, CRC Press, 2005.
- [12] J.S. Moghanlou FS, Ghazanfari Jajin E, Vajdy Hokmabad M, On the Experimental and Numerical Droplet Generation in the Ordinary and Modified Micro

channels with Oval Obstacle, *Modares Mech. Eng.* 20 (2020).

- [13] Y. Sui, P.S. Lee, C.J. Teo, An experimental study of flow friction and heat transfer in wavy microchannels with rectangular cross section, *Int. J. Therm. Sci.* 50 (2011) 2473–2482. doi:10.1016/j.ijthermalsci.2011.06.017.
- [14] M. Shahedi Asl, M. Sakkaki, F. Sadegh Moghanlou, S. Parvizi, H. Baghbani-javid, A. Babapoor, Phase change materials as quenching media for heat treatment of 42CrMo4 steels, *J. Cent. South Univ.* (2020).
- [15] M. Fattahi, K. Vaferi, M. Vajdi, F. Sadegh Moghanlou, A. Sabahi Namini, M. Shahedi Asl, Aluminum nitride as an alternative ceramic for fabrication of micro-channel heat exchangers: A numerical study, *Ceram. Int.* 46 (2020) 11647–11657. doi:10.1016/j.ceramint.2020.01.195.
- [16] T. Dehghani, F. Sadegh Moghanlou, M. Vajdi, M. Shahedi Asl, M. Shokouhimehr, M. Mohammadi, Mixing enhancement through a micromixer using topology optimization, *Chem. Eng. Res. Des.* 161 (2020) 187–196. doi:10.1016/j.cherd.2020.07.008.
- [17] M. Namazizadeh, R. Haghighi khoshkhoo, F. Joda, Effect of Air Gap on thermohydraulic performance of finned tube bundles, *Therm. Sci. Eng. Prog.* 20 (2020) 100687. doi:10.1016/j.tsep.2020.100687.
- [18] M. Vajdi, M. Shahedi Asl, S. Nekahi, F. Sadegh Moghanlou, S. Jafaroghlinejad, M. Mohammadi, Numerical assessment of beryllium oxide as an alternative material for micro heat exchangers, *Ceram. Int.* 46 (2020) 19248–19255. doi:10.1016/j.ceramint.2020.04.263.
- [19] M. Vajdi, F. Sadegh Moghanlou, E. Ranjbarpour Niari, M. Shahedi Asl, M. Shokouhimehr, Heat transfer and pressure drop in a ZrB₂ microchannel heat sink: A numerical approach, *Ceram. Int.* 46 (2020) 1730–1735. doi:10.1016/j.ceramint.2019.09.146.
- [20] F. Sadegh Moghanlou, S. Noorzadeh, M. Ataei, M. Vajdi, M. Shahedi Asl, E. Esmailzadeh, Experimental investigation of heat transfer and pressure drop in a minichannel heat sink using Al₂O₃ and TiO₂–water nanofluids, *J. Brazilian Soc. Mech. Sci. Eng.* 42 (2020) 315. doi:10.1007/s40430-020-02403-5.
- [21] M.U. Sajid, H.M. Ali, Recent advances in application of nanofluids in heat transfer devices: A critical review, *Renew. Sustain. Energy Rev.* 103 (2019) 556–592. doi:10.1016/j.rser.2018.12.057.
- [22] J.A. Choi, S.U.S.; Eastman, No Title, in: *Enhancing Therm. Conduct. Fluids with Nanoparticles*, n.d.: pp. 99–106.
- [23] W.H. Choi, S. Siginer DA, *Developments and Applications of Non-Newtonian Flows*, 1995.
- [24] M. Ataei, F. Sadegh Moghanlou, S. Noorzadeh, M. Vajdi, M. Shahedi Asl, Heat transfer and flow characteristics of hybrid Al₂O₃/TiO₂–water nanofluid in a minichannel heat sink, *Heat Mass Transf.* 56 (2020) 2757–2767. doi:10.1007/s00231-020-02896-9.
- [25] S. Chakraborty, An investigation on the long-term stability of TiO₂ nanofluid, *Mater. Today Proc.* 11 (2019) 714–718. doi:10.1016/j.matpr.2019.03.032.
- [26] H. Zhang, S. Wang, Y. Lin, M. Feng, Q. Wu, Stability, thermal conductivity, and rheological properties of controlled reduced graphene oxide dispersed nanofluids, *Appl. Therm. Eng.* 119 (2017) 132–139. doi:10.1016/j.applthermaleng.2017.03.064.
- [27] W. Yu, D.M. France, S.U.S. Choi, J.L. Routbort, Review and assessment of nanofluid technology for transportation and other applications., Argonne, IL, 2007. doi:10.2172/919327.
- [28] C.G. Granqvist, R.A. Buhrman, J. Wyns, A.J. Sievers, Far-Infrared Absorption in Ultrafine Al Particles, *Phys. Rev. Lett.* 37 (1976) 625–629. doi:10.1103/PhysRevLett.37.625.
- [29] J.-H. Lee, K.S. Hwang, S.P. Jang, B.H. Lee, J.H. Kim, S.U.S. Choi, C.J. Choi, Effective viscosities and thermal conductivities of aqueous nanofluids containing low volume concentrations of Al₂O₃ nanoparticles, *Int. J. Heat Mass Transf.* 51 (2008) 2651–2656. doi:10.1016/j.ijheatmasstransfer.2007.10.026.
- [30] J.A. Eastman, S.U.S. Choi, S. Li, W. Yu, L.J. Thompson, Anomalous increase in effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles, *Appl. Phys. Lett.* 78 (2001) 718–720. doi:10.1063/1.1341218.
- [31] W. Yu, H. Xie, L. Chen, Y. Li, Investigation of thermal conductivity and viscosity of ethylene glycol based ZnO nanofluid, *Thermochim. Acta.* 491 (2009) 92–96. doi:10.1016/j.tca.2009.03.007.
- [32] Y. Hwang, J.K. Lee, C.H. Lee, Y.M. Jung, S.I. Cheong, C.G. Lee, B.C. Ku, S.P. Jang, Stability and thermal conductivity characteristics of nanofluids, *Thermochim. Acta.* 455 (2007) 70–74. doi:10.1016/j.tca.2006.11.036.
- [33] M.A. Khairul, K. Shah, E. Doroodchi, R. Azizian, B. Moghtaderi, Effects of surfactant on stability and thermo-physical properties of metal oxide nanofluids, *Int. J. Heat Mass Transf.* 98 (2016) 778–787. doi:10.1016/j.ijheatmasstransfer.2016.03.079.
- [34] V. Fuskale, R.M. Sarviya, Recent developments in Nanoparticles Synthesis, Preparation and Stability of Nanofluids, *Mater. Today Proc.* 4 (2017) 4049–4060. doi:10.1016/j.matpr.2017.02.307.
- [35] A. Ghadimi, R. Saidur, H.S.C. Metselaar, A review of nanofluid stability properties and characterization in stationary conditions, *Int. J. Heat Mass Transf.* 54 (2011) 4051–4068. doi:10.1016/j.ijheatmasstransfer.2011.04.014.
- [36] M. Sakkaki, F. Sadegh Moghanlou, M. Vajdi, M. Shahedi Asl, M. Mohammadi, M. Shokouhimehr, Numerical simulation of heat transfer during spark plasma sintering of zirconium diboride, *Ceram. Int.* 46 (2020) 4998–5007. doi:10.1016/j.ceramint.2019.10.240.
- [37] F. Sadegh Moghanlou, M. Vajdi, J. Sha, A. Motallebzadeh, M. Shokouhimehr, M. Shahedi Asl, A numerical approach to the heat transfer in monolithic and SiC reinforced HfB₂, ZrB₂ and TiB₂ ceramic cutting tools, *Ceram. Int.* (2019). doi:10.1016/j.ceramint.2019.05.095.
- [38] M. Vajdi, F. Sadegh Moghanlou, F. Sharifianjazi, M. Shahedi Asl, M. Shokouhimehr, A review on the Comsol Multiphysics studies of heat transfer in advanced ceramics, *J. Compos. Compd.* 2 (2020) 35–44. doi:10.29252/jcc.2.1.5.
- [39] M. Fattahi, M. Najafi Ershadi, M. Vajdi, F. Sadegh Moghanlou, A. Sabahi Namini, M. Shahedi Asl, On the simulation of spark plasma sintered TiB₂ ultra high temperature ceramics: A numerical approach, *Ceram. Int.* 46 (2020) 14787–14795. doi:10.1016/j.ceramint.2020.03.003.
- [40] F. Sadegh Moghanlou, M. Vajdi, A. Motallebzadeh, J. Sha, M. Shokouhimehr, M. Shahedi Asl, Numerical analyses of heat transfer and thermal stress in a ZrB₂ gas turbine stator blade, *Ceram. Int.* 45 (2019) 17742–17750. doi:10.1016/j.ceramint.2019.05.344.
- [41] S. Nekahi, K. Vaferi, M. Vajdi, F. Sadegh Moghanlou, M. Shahedi Asl, M. Shokouhimehr, A numerical approach to the heat transfer and thermal stress in a gas turbine stator blade made of HfB₂, *Ceram. Int.* (2019). doi:10.1016/j.ceramint.2019.08.112.
- [42] F. Sadegh Moghanlou, M. Vajdi, J. Sha, A. Motallebzadeh, M. Shokouhimehr, M. Shahedi Asl, A numerical approach to the heat transfer in monolithic and SiC reinforced HfB₂, ZrB₂ and TiB₂ ceramic cutting tools, *Ceram. Int.* 45 (2019) 15892–15897. doi:10.1016/j.ceramint.2019.05.095.
- [43] Z. Hajati, F. Sadegh Moghanlou, M. Vajdi, E. Razavi, S. Matin, Fluid Structure Interaction of blood flow around a vein valve, *BioImpacts.* (2020).
- [44] S. Mohammad Bagheri, M. Vajdi, F. Sadegh Moghanlou, M. Sakkaki, M. Mohammadi, M. Shokouhimehr, M. Shahedi Asl, Numerical modeling of heat transfer during spark plasma sintering of titanium carbide, *Ceram. Int.* 46 (2020) 7615–7624. doi:10.1016/j.ceramint.2019.11.262.
- [45] M. Sakkaki, F. Sadegh Moghanlou, M. Vajdi, F. Pishgar, M. Shokouhimehr, M. Shahedi Asl, The effect of thermal contact resistance on the temperature distribution in a WC made cutting tool, *Ceram. Int.* 45 (2019) 22196–22202. doi:10.1016/j.ceramint.2019.07.241.
- [46] K. Vaferi, M. Vajdi, S. Nekahi, S. Nekahi, F. Sadegh Moghanlou, M. Shahedi Asl, M. Mohammadi, Thermo-mechanical simulation of ultrahigh temperature ceramic composites as alternative materials for gas turbine stator blades, *Ceram. Int.* (2020). doi:10.1016/j.ceramint.2020.08.164.
- [47] M. Jaber Zamharir, M. Shahedi Asl, N. Pourmohammadi Vafa, M. Ghassemi Kakroudi, Significance of hot pressing parameters and reinforcement size on densification behavior of ZrB₂–25vol% SiC UHTCs, *Ceram. Int.* 41 (2015) 6439–6447. doi:10.1016/j.ceramint.2015.01.082.
- [48] M. Shahedi Asl, B. Nayeibi, M. Akhlaghi, Z. Ahmadi, S.A. Tayebifard, E. Salahi, M. Shokouhimehr, M. Mohammadi, A novel ZrB₂-based composite manufactured with Ti₃AlC₂ additive, *Ceram. Int.* (2020). doi:10.1016/j.ceramint.2020.08.193.
- [49] C. Xia, S.A. Delbari, Z. Ahmadi, M. Shahedi Asl, M. Ghassemi Kakroudi, Q. Van Le, A. Sabahi Namini, M. Mohammadi, M. Shokouhimehr, Electron microscopy study of ZrB₂–SiC–AlN composites: Hot-pressing vs. pressureless sintering, *Ceram. Int.* (2020). doi:10.1016/j.ceramint.2020.08.054.
- [50] Z. Ahmadi, M. Zakeri, A. Habibi-Yangjeh, M. Shahedi Asl, A novel ZrB₂–C₃N₄ composite with improved mechanical properties, *Ceram. Int.* 45 (2019) 21512–21519. doi:10.1016/j.ceramint.2019.07.144.
- [51] N. Pourmohammadi Vafa, B. Nayeibi, M. Shahedi Asl, M. Jaber Zamharir, M. Ghassemi Kakroudi, Reactive hot pressing of ZrB₂-based composites with changes in ZrO₂/SiC ratio and sintering conditions. Part II: Mechanical behavior, *Ceram. Int.* 42 (2016) 2724–2733. doi:10.1016/j.ceramint.2015.10.166.
- [52] Z. Ahmadi, B. Nayeibi, M. Shahedi Asl, M. Ghassemi Kakroudi, Fractographic characterization of hot pressed and pressureless sintered AlN-doped ZrB₂–SiC composites, *Mater. Charact.* 110 (2015) 77–85. doi:10.1016/j.matchar.2015.10.016.
- [53] C. Xia, M. Shahedi Asl, A. Sabahi Namini, Z. Ahmadi, S.A. Delbari, Q. Van Le, M. Shokouhimehr, M. Mohammadi, Enhanced fracture toughness of ZrB₂–SiCw ceramics with graphene nano-platelets, *Ceram. Int.* 46 (2020) 24906–24915. doi:10.1016/j.ceramint.2020.06.275.

- [54] N.P. Vafa, M. Shahedi Asl, M. Jaber Zamharir, M. Ghassemi Kakroudi, Reactive hot pressing of ZrB₂-based composites with changes in ZrO₂/SiC ratio and sintering conditions. Part I: Densification behavior, *Ceram. Int.* 41 (2015) 8388–8396. doi:10.1016/j.ceramint.2015.03.033.
- [55] M.S. Asl, B. Nayeibi, Z. Ahmadi, M.J. Zamharir, M. Shokouhimehr, Effects of carbon additives on the properties of ZrB₂-based composites: A review, *Ceram. Int.* 44 (2018) 7334–7348. doi:10.1016/j.ceramint.2018.01.214.
- [56] B. Nayeibi, M. Shahedi Asl, M. Ghassemi Kakroudi, M. Shokouhimehr, Temperature dependence of microstructure evolution during hot pressing of ZrB₂-30 vol.% SiC composites, *Int. J. Refract. Met. Hard Mater.* 54 (2016) 7–13. doi:10.1016/j.ijrmhm.2015.06.017.
- [57] M. Shahedi Asl, Microstructure, hardness and fracture toughness of spark plasma sintered ZrB₂-SiC-Cf composites, *Ceram. Int.* 43 (2017) 15047–15052. doi:10.1016/j.ceramint.2017.08.030.
- [58] B. Nayeibi, N. Parvin, J. Aghazadeh Mohandesi, M. Shahedi Asl, Densification and toughening mechanisms in spark plasma sintered ZrB₂-based composites with zirconium and graphite additives, *Ceram. Int.* 46 (2020) 13685–13694. doi:10.1016/j.ceramint.2020.02.156.
- [59] M. Shahedi Asl, Y. Pazhouhanfar, A. Sabahi Namini, S. Shaddel, M. Fattahi, M. Mohammadi, Role of graphite nano-flakes on the characteristics of ZrB₂-based composites reinforced with SiC whiskers, *Diam. Relat. Mater.* 105 (2020) 107786. doi:10.1016/j.diamond.2020.107786.
- [60] T.P. Nguyen, M. Ghassemi Kakroudi, M. Shahedi Asl, Z. Ahmadi, A. Sabahi Namini, S.A. Delbari, Q. Van Le, M. Shokouhimehr, Influence of SiAlON addition on the microstructure development of hot-pressed ZrB₂-SiC composites, *Ceram. Int.* 46 (2020) 19209–19216. doi:10.1016/j.ceramint.2020.04.258.
- [61] M. Jaber Zamharir, M. Shahedi Asl, M. Ghassemi Kakroudi, N. Pourmohammadi Vafa, M. Jaber Zamharir, Significance of hot pressing parameters and reinforcement size on sinterability and mechanical properties of ZrB₂-25vol% SiC UHTCs, *Ceram. Int.* 41 (2015) 9628–9636. doi:10.1016/j.ceramint.2015.04.027.
- [62] B. Nayeibi, N. Parvin, J. Aghazadeh Mohandesi, M. Shahedi Asl, Effect of Zr and C co-addition on the characteristics of ZrB₂-based ceramics: Role of spark plasma sintering temperature, *Ceram. Int.* 46 (2020) 24975–24985. doi:10.1016/j.ceramint.2020.06.283.
- [63] M. Shahedi Asl, M.J. Zamharir, Z. Ahmadi, S. Parvizi, Effects of nano-graphite content on the characteristics of spark plasma sintered ZrB₂-SiC composites, *Mater. Sci. Eng. A.* 716 (2018) 99–106. doi:10.1016/j.msea.2018.01.038.
- [64] Y. Azizian-Kalandaragh, A.S. Namini, Z. Ahmadi, M. Shahedi Asl, Reinforcing effects of SiC whiskers and carbon nanoparticles in spark plasma sintered ZrB₂ matrix composites, *Ceram. Int.* 44 (2018) 19932–19938. doi:10.1016/j.ceramint.2018.07.258.
- [65] M. Shahedi Asl, B. Nayeibi, A. Motalebzadeh, M. Shokouhimehr, Nanoindentation and nanostructural characterization of ZrB₂-SiC composite doped with graphite nano-flakes, *Compos. Part B Eng.* 175 (2019) 107153. doi:10.1016/j.compositesb.2019.107153.
- [66] H. Istgaldi, B. Nayeibi, Z. Ahmadi, P. Shahi, M. Shahedi Asl, Characterization of ZrB₂-TiC composites reinforced with short carbon fibers, *Ceram. Int.* 46 (2020) 23155–23164. doi:10.1016/j.ceramint.2020.06.095.
- [67] M. Shahedi Asl, M. Ghassemi Kakroudi, F. Golestani-Fard, H. Nasiri, A Taguchi approach to the influence of hot pressing parameters and SiC content on the sinterability of ZrB₂-based composites, *Int. J. Refract. Met. Hard Mater.* 51 (2015) 81–90. doi:10.1016/j.ijrmhm.2015.03.002.
- [68] B. Mohammadpour, Z. Ahmadi, M. Shokouhimehr, M. Shahedi Asl, Spark plasma sintering of Al-doped ZrB₂-SiC composite, *Ceram. Int.* 45 (2019) 4262–4267. doi:10.1016/j.ceramint.2018.11.098.
- [69] V.-H. Nguyen, S.A. Delbari, Z. Ahmadi, M. Shahedi Asl, M. Ghassemi Kakroudi, Q. Van Le, A. Sabahi Namini, M. Mohammadi, M. Shokouhimehr, Electron microscopy characterization of porous ZrB₂-SiC-AlN composites prepared by pressureless sintering, *Ceram. Int.* 46 (2020) 25415–25423. doi:10.1016/j.ceramint.2020.07.011.
- [70] M. Shahedi Asl, B. Nayeibi, Z. Ahmadi, P. Pirmohammadi, M. Ghassemi Kakroudi, Fractographical characterization of hot pressed and pressureless sintered SiAlON-doped ZrB₂-SiC composites, *Mater. Charact.* 102 (2015) 137–145. doi:10.1016/j.matchar.2015.03.002.
- [71] M.S. Asl, M.G. Kakroudi, S. Noori, Hardness and toughness of hot pressed ZrB₂-SiC composites consolidated under relatively low pressure, *J. Alloys Compd.* 619 (2015) 481–487. doi:10.1016/j.jallcom.2014.09.006.
- [72] Z. Ahmadi, B. Nayeibi, M. Shahedi Asl, M. Ghassemi Kakroudi, I. Farahbakhsh, Sintering behavior of ZrB₂-SiC composites doped with Si₃N₄: A fractographical approach, *Ceram. Int.* 43 (2017) 9699–9708. doi:10.1016/j.ceramint.2017.04.144.
- [73] T.P. Nguyen, M. Shahedi Asl, S.A. Delbari, A. Sabahi Namini, Q. Van Le, M. Shokouhimehr, M. Mohammadi, Electron microscopy investigation of spark plasma sintered ZrO₂ added ZrB₂-SiC composite, *Ceram. Int.* 46 (2020) 19646–19649. doi:10.1016/j.ceramint.2020.04.292.
- [74] M. Shahedi Asl, F. Golmohammadi, M. Ghassemi Kakroudi, M. Shokouhimehr, Synergetic effects of SiC and Csf in ZrB₂-based ceramic composites. Part I: Densification behavior, *Ceram. Int.* 42 (2016) 4498–4506. doi:10.1016/j.ceramint.2015.11.139.
- [75] M. Shahedi Asl, M. Ghassemi Kakroudi, Fractographical assessment of densification mechanisms in hot pressed ZrB₂-SiC composites, *Ceram. Int.* 40 (2014) 15273–15281. doi:10.1016/j.ceramint.2014.07.023.
- [76] M. Khoeini, A. Nemati, M. Zakeri, M. Shahedi Asl, Pressureless sintering of ZrB₂ ceramics codoped with TiC and graphite, *Int. J. Refract. Met. Hard Mater.* 81 (2019) 189–195. doi:10.1016/j.ijrmhm.2019.02.026.
- [77] S. Parvizi, Z. Ahmadi, M.J. Zamharir, M. Shahedi Asl, Synergistic effects of graphite nano-flakes and submicron SiC particles on the characteristics of spark plasma sintered ZrB₂ nanocomposites, *Int. J. Refract. Met. Hard Mater.* 75 (2018) 10–17. doi:10.1016/j.ijrmhm.2018.03.017.
- [78] M. Shahedi Asl, M. Ghassemi Kakroudi, R. Abedi Kondolaji, H. Nasiri, Influence of graphite nano-flakes on densification and mechanical properties of hot-pressed ZrB₂-SiC composite, *Ceram. Int.* 41 (2015) 5843–5851. doi:10.1016/j.ceramint.2015.01.014.
- [79] E. Ghasali, M. Shahedi Asl, Microstructural development during spark plasma sintering of ZrB₂-SiC-Ti composite, *Ceram. Int.* 44 (2018) 18078–18083. doi:10.1016/j.ceramint.2018.07.011.
- [80] Y. Orooji, M.R. Derakhshandeh, E. Ghasali, M. Alizadeh, M. Shahedi Asl, T. Ebadzadeh, Effects of ZrB₂ reinforcement on microstructure and mechanical properties of a spark plasma sintered mullite-CNT composite, *Ceram. Int.* 45 (2019) 16015–16021. doi:10.1016/j.ceramint.2019.05.113.
- [81] B. Nayeibi, M.S. Asl, M.G. Kakroudi, I. Farahbakhsh, M. Shokouhimehr, Interfacial phenomena and formation of nano-particles in porous ZrB₂-40 vol% BaC UHTC, *Ceram. Int.* 42 (2016) 17009–17015. doi:10.1016/j.ceramint.2016.07.208.
- [82] F. Adibpur, S.A. Tayebifard, M. Zakeri, M. Shahedi Asl, Co-reinforcing of ZrB₂-SiC ceramics with optimized ZrC to Cf ratio, *Ceram. Int.* 46 (2020) 22661–22673. doi:10.1016/j.ceramint.2020.06.029.
- [83] N. Pourmohammadi Vafa, M. Ghassemi Kakroudi, M. Shahedi Asl, Advantages and disadvantages of graphite addition on the characteristics of hot-pressed ZrB₂-SiC composites, *Ceram. Int.* 46 (2020) 8561–8566. doi:10.1016/j.ceramint.2019.12.086.
- [84] H. Istgaldi, M. Shahedi Asl, P. Shahi, B. Nayeibi, Z. Ahmadi, Solid solution formation during spark plasma sintering of ZrB₂-TiC-graphite composites, *Ceram. Int.* 46 (2020) 2923–2930. doi:10.1016/j.ceramint.2019.09.287.
- [85] Y. Orooji, M. Alizadeh, E. Ghasali, M.R. Derakhshandeh, M. Alizadeh, M.S. Asl, T. Ebadzadeh, Co-reinforcing of mullite-TiN-CNT composites with ZrB₂ and TiB₂ compounds, *Ceram. Int.* 45 (2019) 20844–20854. doi:10.1016/j.ceramint.2019.07.072.
- [86] M. Shahedi Asl, A statistical approach towards processing optimization of ZrB₂-SiC-graphite nanocomposites. Part I: Relative density, *Ceram. Int.* 44 (2018) 6935–6939. doi:10.1016/j.ceramint.2018.01.122.
- [87] F. Adibpur, S.A. Tayebifard, M. Zakeri, M. Shahedi Asl, Spark plasma sintering of quadruplet ZrB₂-SiC-ZrC-Cf composites, *Ceram. Int.* 46 (2020) 156–164. doi:10.1016/j.ceramint.2019.08.243.
- [88] M. Shahedi Asl, B. Nayeibi, Z. Ahmadi, S. Parvizi, M. Shokouhimehr, A novel ZrB₂-VB₂-ZrC composite fabricated by reactive spark plasma sintering, *Mater. Sci. Eng. A.* 731 (2018) 131–139. doi:10.1016/j.msea.2018.06.008.
- [89] M. Shahedi Asl, Y. Azizian-Kalandaragh, Z. Ahmadi, A. Sabahi Namini, A. Motalebzadeh, Spark plasma sintering of ZrB₂-based composites co-reinforced with SiC whiskers and pulverized carbon fibers, *Int. J. Refract. Met. Hard Mater.* 83 (2019) 104989. doi:10.1016/j.ijrmhm.2019.104989.
- [90] V.-H. Nguyen, S.A. Delbari, M. Shahedi Asl, A. Sabahi Namini, M. Ghassemi Kakroudi, Y. Azizian-Kalandaragh, Q. Van Le, M. Mohammadi, M. Shokouhimehr, Role of hot-pressing temperature on densification and microstructure of ZrB₂-SiC ultrahigh temperature ceramics, *Int. J. Refract. Met. Hard Mater.* 93 (2020) 105355. doi:10.1016/j.ijrmhm.2020.105355.
- [91] M. Ghassemi Kakroudi, M. Dehghanzadeh Alvari, M. Shahedi Asl, N. Pourmohammadi Vafa, T. Rabizadeh, Hot pressing and oxidation behavior of ZrB₂-SiC-TaC composites, *Ceram. Int.* 46 (2020) 3725–3730. doi:10.1016/j.ceramint.2019.10.093.
- [92] B. Nayeibi, Z. Ahmadi, M. Shahedi Asl, S. Parvizi, M. Shokouhimehr, Influence of vanadium content on the characteristics of spark plasma sintered ZrB₂-SiC-V composites, *J. Alloys Compd.* 805 (2019) 725–732. doi:10.1016/j.jallcom.2019.07.117.
- [93] V.-H. Nguyen, S. Ali Delbari, Z. Ahmadi, M. Shahedi Asl, M. Ghassemi Kak-

- roudi, Q. Van Le, A. Sabahi Namini, M. Shokouhimehr, M. Mohammadi, W. Peng, TEM characterization of hot-pressed ZrB₂-SiC-AIN composites, *Results Phys.* 19 (2020) 103348. doi:10.1016/j.rinp.2020.103348.
- [94] Y. Pazhouhanfar, A. Sabahi Namini, S. Shaddel, Z. Ahmadi, M. Shahedi Asl, Combined role of SiC particles and SiC whiskers on the characteristics of spark plasma sintered ZrB₂ ceramics, *Ceram. Int.* 46 (2020) 5773–5778. doi:10.1016/j.ceramint.2019.11.027.
- [95] M. Ghassemi Kakroudi, N. Pourmohammadi Vafa, M. Shahedi Asl, M. Shokouhimehr, Effects of SiC content on thermal shock behavior and elastic modulus of cordierite–mullite composites, *Ceram. Int.* 46 (2020) 23780–23784. doi:10.1016/j.ceramint.2020.06.153.
- [96] Z. Balak, M. Shahedi Asl, M. Azizieh, H. Kafashan, R. Hayati, Effect of different additives and open porosity on fracture toughness of ZrB₂-SiC-based composites prepared by SPS, *Ceram. Int.* 43 (2017) 2209–2220. doi:10.1016/j.ceramint.2016.11.005.
- [97] M. Shahedi Asl, M. Ghassemi Kakroudi, B. Nayeibi, A fractographical approach to the sintering process in porous ZrB₂-B₄C binary composites, *Ceram. Int.* 41 (2015) 379–387. doi:10.1016/j.ceramint.2014.08.081.
- [98] M. Fattahi, Y. Azizian-Kalandaragh, S.A. Delbari, A. Sabahi Namini, Z. Ahmadi, M. Shahedi Asl, Nano-diamond reinforced ZrB₂-SiC composites, *Ceram. Int.* 46 (2020) 10172–10179. doi:10.1016/j.ceramint.2020.01.008.
- [99] M. Shahedi Asl, B. Nayeibi, M.G. Kakroudi, M. Shokouhimehr, Investigation of hot pressed ZrB₂-SiC-carbon black nanocomposite by scanning and transmission electron microscopy, *Ceram. Int.* 45 (2019) 16759–16764. doi:10.1016/j.ceramint.2019.05.211.
- [100] M. Shahedi Asl, B. Nayeibi, M. Shokouhimehr, TEM characterization of spark plasma sintered ZrB₂-SiC-graphene nanocomposite, *Ceram. Int.* 44 (2018) 15269–15273. doi:10.1016/j.ceramint.2018.05.170.
- [101] M. Shahedi Asl, M. Ghassemi Kakroudi, M. Rezvani, F. Golestani-Fard, Significance of hot pressing parameters on the microstructure and densification behavior of zirconium diboride, *Int. J. Refract. Met. Hard Mater.* 50 (2015) 140–145. doi:10.1016/j.jrmhm.2015.01.004.
- [102] M. Shahedi Asl, M. Ghassemi Kakroudi, B. Nayeibi, H. Nasiri, Taguchi analysis on the effect of hot pressing parameters on density and hardness of zirconium diboride, *Int. J. Refract. Met. Hard Mater.* 50 (2015) 313–320. doi:10.1016/j.jrmhm.2014.09.006.
- [103] A. Sabahi Namini, S.A.A. Dilawary, A. Motallebzadeh, M. Shahedi Asl, Effect of TiB₂ addition on the elevated temperature tribological behavior of spark plasma sintered Ti matrix composite, *Compos. Part B Eng.* 172 (2019) 271–280. doi:10.1016/j.compositesb.2019.05.073.
- [104] S.A. Delbari, A. Sabahi Namini, M. Shahedi Asl, Hybrid Ti matrix composites with TiB₂ and TiC compounds, *Mater. Today Commun.* 20 (2019) 100576. doi:10.1016/j.mtcomm.2019.100576.
- [105] Z. Ahmadi, B. Nayeibi, M. Shahedi Asl, I. Farahbakhsh, Z. Balak, Densification improvement of spark plasma sintered TiB₂-based composites with micron-, submicron- and nano-sized SiC particulates, *Ceram. Int.* 44 (2018) 11431–11437. doi:10.1016/j.ceramint.2018.03.202.
- [106] M. Shahedi Asl, Z. Ahmadi, S. Parvizi, Z. Balak, I. Farahbakhsh, Contribution of SiC particle size and spark plasma sintering conditions on grain growth and hardness of TiB₂ composites, *Ceram. Int.* 43 (2017) 13924–13931. doi:10.1016/j.ceramint.2017.07.121.
- [107] A. Sabahi Namini, Z. Ahmadi, A. Babapoor, M. Shokouhimehr, M. Shahedi Asl, Microstructure and thermomechanical characteristics of spark plasma sintered TiC ceramics doped with nano-sized WC, *Ceram. Int.* 45 (2019) 2153–2160. doi:10.1016/j.ceramint.2018.10.125.
- [108] Y. Orooji, E. Ghasali, M. Moradi, M.R. Derakhshandeh, M. Alizadeh, M.S. Asl, T. Ebadzadeh, Preparation of mullite-TiB₂-CNTs hybrid composite through spark plasma sintering, *Ceram. Int.* 45 (2019) 16288–16296. doi:10.1016/j.ceramint.2019.05.154.
- [109] M. Shahedi Asl, A. Sabahi Namini, M. Ghassemi Kakroudi, Influence of silicon carbide addition on the microstructural development of hot pressed zirconium and titanium diborides, *Ceram. Int.* 42 (2016) 5375–5381. doi:10.1016/j.ceramint.2015.12.072.
- [110] A. Sabahi Namini, S.N. Seyed Gogani, M. Shahedi Asl, K. Farhadi, M. Ghassemi Kakroudi, A. Mohammadzadeh, Microstructural development and mechanical properties of hot pressed SiC reinforced TiB₂ based composite, *Int. J. Refract. Met. Hard Mater.* 51 (2015) 169–179. doi:10.1016/j.jrmhm.2015.03.014.
- [111] M. Shahedi Asl, S.A. Delbari, F. Shayesteh, Z. Ahmadi, A. Motallebzadeh, Reactive spark plasma sintering of TiB₂-SiC-TiN novel composite, *Int. J. Refract. Met. Hard Mater.* 81 (2019) 119–126. doi:10.1016/j.jrmhm.2019.02.022.
- [112] Z. Hamidzadeh Mahaseni, M. Dashti Germi, Z. Ahmadi, M. Shahedi Asl, Microstructural investigation of spark plasma sintered TiB₂ ceramics with Si₃N₄ addition, *Ceram. Int.* 44 (2018) 13367–13372. doi:10.1016/j.ceramint.2018.04.171.
- [113] M. Dashti Germi, Z. Hamidzadeh Mahaseni, Z. Ahmadi, M. Shahedi Asl, Phase evolution during spark plasma sintering of novel Si₃N₄-doped TiB₂-SiC composite, *Mater. Charact.* 145 (2018) 225–232. doi:10.1016/j.matchar.2018.08.043.
- [114] A. Babapoor, M.S. Asl, Z. Ahmadi, A.S. Namini, Effects of spark plasma sintering temperature on densification, hardness and thermal conductivity of titanium carbide, *Ceram. Int.* 44 (2018) 14541–14546. doi:10.1016/j.ceramint.2018.05.071.
- [115] A. Sabahi Namini, A. Motallebzadeh, B. Nayeibi, M. Shahedi Asl, M. Azadbeh, Microstructure–mechanical properties correlation in spark plasma sintered Ti–4.8 wt.% TiB₂ composites, *Mater. Chem. Phys.* 223 (2019) 789–796. doi:10.1016/j.matchemphys.2018.11.057.
- [116] T.P. Nguyen, Z. Hamidzadeh Mahaseni, M. Dashti Germi, S.A. Delbari, Q. Van Le, Z. Ahmadi, M. Shokouhimehr, M. Shahedi Asl, A. Sabahi Namini, Densification behavior and microstructure development in TiB₂ ceramics doped with h-BN, *Ceram. Int.* 46 (2020) 18970–18975. doi:10.1016/j.ceramint.2020.04.223.
- [117] M. Fattahi, Y. Pazhouhanfar, S.A. Delbari, S. Shaddel, A. Sabahi Namini, M. Shahedi Asl, Influence of TiB₂ content on the properties of TiC–SiCw composites, *Ceram. Int.* 46 (2020) 7403–7412. doi:10.1016/j.ceramint.2019.11.236.
- [118] V.-H. Nguyen, S.A. Delbari, Z. Ahmadi, A. Sabahi Namini, Q. Van Le, M. Shokouhimehr, M. Shahedi Asl, M. Mohammadi, Effects of discrete and simultaneous addition of SiC and Si₃N₄ on microstructural development of TiB₂ ceramics, *Ceram. Int.* (2020). doi:10.1016/j.ceramint.2020.09.196.
- [119] V.-H. Nguyen, M. Shahedi Asl, Z. Hamidzadeh Mahaseni, M. Dashti Germi, S.A. Delbari, Q. Van Le, Z. Ahmadi, M. Shokouhimehr, A. Sabahi Namini, M. Mohammadi, Role of co-addition of BN and SiC on microstructure of TiB₂-based composites densified by SPS method, *Ceram. Int.* 46 (2020) 25341–25350. doi:10.1016/j.ceramint.2020.07.001.
- [120] T.P. Nguyen, S.A. Delbari, Y. Azizian-Kalandaragh, A. Babapoor, Q. Van Le, A. Sabahi Namini, M. Shokouhimehr, M. Shahedi Asl, Characteristics of quadruplet Ti–Mo–TiB₂-TiC composites prepared by spark plasma sintering, *Ceram. Int.* 46 (2020) 20885–20895. doi:10.1016/j.ceramint.2020.05.137.
- [121] Z. Ahmadi, Z.H. Mahaseni, M.D. Germi, M.S. Asl, Microstructure of spark plasma sintered TiB₂ and TiB₂-AlN ceramics, *Adv. Ceram. Prog.* 5 (2019) 36–40.
- [122] M. Fattahi, Y. Pazhouhanfar, S.A. Delbari, S. Shaddel, A. Sabahi Namini, M. Shahedi Asl, Strengthening of novel TiC–AlN ceramic with in-situ synthesized Ti₃Al intermetallic compound, *Ceram. Int.* 46 (2020) 14105–14113. doi:10.1016/j.ceramint.2020.02.213.
- [123] V.-H. Nguyen, S.A. Delbari, M. Shahedi Asl, Q. Van Le, H.W. Jang, M. Shokouhimehr, M. Mohammadi, A. Sabahi Namini, A novel TiC-based composite co-strengthened with AlN particulates and graphene nano-platelets, *Int. J. Refract. Met. Hard Mater.* 92 (2020) 105331. doi:10.1016/j.jrmhm.2020.105331.
- [124] B. Nayeibi, M. Mehrabian, M. Shahedi Asl, M. Shokouhimehr, Nanostructural approach to the thickening behavior and oxidation of calcium-stabilized aluminum foams, *Mater. Chem. Phys.* 220 (2018) 351–359. doi:10.1016/j.matchemphys.2018.09.017.
- [125] B. Nayeibi, A. Bahmani, M.S. Asl, A. Rasooli, M.G. Kakroudi, M. Shokouhimehr, Characteristics of dynamically formed oxide films in aluminum–calcium foamable alloys, *J. Alloys Compd.* 655 (2016) 433–441. doi:10.1016/j.jallcom.2015.09.200.
- [126] T.P. Nguyen, Y. Pazhouhanfar, S.A. Delbari, A. Sabahi Namini, A. Babapoor, Y. Mohammadpourderakhshi, S. Shaddel, Q. Van Le, M. Shokouhimehr, M. Shahedi Asl, Physical, mechanical and microstructural characterization of TiC–ZrN ceramics, *Ceram. Int.* 46 (2020) 22154–22163. doi:10.1016/j.ceramint.2020.05.292.
- [127] T.P. Nguyen, Y. Pazhouhanfar, S.A. Delbari, Q. Van Le, S. Shaddel, M. Pazhouhanfar, A. Sabahi Namini, M. Shokouhimehr, M. Shahedi Asl, Characterization of spark plasma sintered TiC ceramics reinforced with graphene nano-platelets, *Ceram. Int.* 46 (2020) 18742–18749. doi:10.1016/j.ceramint.2020.04.189.
- [128] M. Fattahi, S.A. Delbari, A. Babapoor, A. Sabahi Namini, M. Mohammadi, M. Shahedi Asl, Triplet carbide composites of TiC, WC, and SiC, *Ceram. Int.* 46 (2020) 9070–9078. doi:10.1016/j.ceramint.2019.12.155.
- [129] M. Shahedi Asl, Z. Ahmadi, A. Sabahi Namini, A. Babapoor, A. Motallebzadeh, Spark plasma sintering of TiC–SiCw ceramics, *Ceram. Int.* 45 (2019) 19808–19821. doi:10.1016/j.ceramint.2019.06.236.
- [130] M. Fattahi, S.A. Delbari, A. Sabahi Namini, Z. Ahmadi, M. Azadbeh, M. Shahedi Asl, Characterization of triplet Ti–TiB–TiC composites: Comparison of in-situ formation and ex-situ addition of TiC, *Ceram. Int.* 46 (2020) 11726–11734. doi:10.1016/j.ceramint.2020.01.204.
- [131] M. Fattahi, A. Babapoor, S.A. Delbari, Z. Ahmadi, A. Sabahi Namini, M. Shahedi Asl, Strengthening of TiC ceramics sintered by spark plasma via nano-graphite addition, *Ceram. Int.* 46 (2020) 12400–12408. doi:10.1016/j.ceramint.2020.01.291.
- [132] M. Fattahi, A. Mohammadzadeh, Y. Pazhouhanfar, S. Shaddel, M. Sha-

- hedhi Asl, A. Sabahi Namini, Influence of SPS temperature on the properties of TiC–SiCw composites, *Ceram. Int.* 46 (2020) 11735–11742. doi:10.1016/j.ceramint.2020.01.206.
- [133] V.-H. Nguyen, Y. Pazhouhanfar, S.A. Delbari, S. Shaddel, A. Babapoor, Y. Mohammadpourderakhshi, Q. Van Le, M. Shokouhimehr, M. Shahedi Asl, A. Sabahi Namini, Beneficial role of carbon black on the properties of TiC ceramics, *Ceram. Int.* 46 (2020) 23544–23555. doi:10.1016/j.ceramint.2020.06.125.
- [134] V.-H. Nguyen, S.A. Delbari, M. Shahedi Asl, Q. Van Le, M. Shokouhimehr, A. Sabahi Namini, M. Mohammadi, Microstructure–property correlation in nano-diamond and TiN added TiC-based ceramics, *Ceram. Int.* (2020). doi:10.1016/j.ceramint.2020.08.152.
- [135] V.-H. Nguyen, S.A. Delbari, A. Sabahi Namini, A. Babapoor, Q. Van Le, H.W. Jang, M. Shokouhimehr, M. Shahedi Asl, M. Mohammadi, Microstructural, mechanical and friction properties of nano-graphite and h-BN added TiC-based composites, *Ceram. Int.* (2020). doi:10.1016/j.ceramint.2020.08.068.
- [136] V.-H. Nguyen, S.A. Delbari, M. Shahedi Asl, Q. Van Le, H.W. Jang, M. Shokouhimehr, M. Mohammadi, A. Sabahi Namini, A novel spark plasma sintered TiC–ZrN–C composite with enhanced flexural strength, *Ceram. Int.* (2020). doi:10.1016/j.ceramint.2020.08.073.
- [137] K. Kasraee, S.A. Tayebifard, H. Roghani, M. Shahedi Asl, Preparation of B4C–SiC–HfB2 nanocomposite by mechanically activated combustion synthesis, *Ceram. Int.* 46 (2020) 12288–12295. doi:10.1016/j.ceramint.2020.01.279.
- [138] I. Farahbakhsh, Z. Ahmadi, M. Shahedi Asl, Densification, microstructure and mechanical properties of hot pressed ZrB₂–SiC ceramic doped with nano-sized carbon black, *Ceram. Int.* 43 (2017) 8411–8417. doi:10.1016/j.ceramint.2017.03.188.
- [139] M. Shahedi Asl, I. Farahbakhsh, B. Nayeibi, Characteristics of multi-walled carbon nanotube toughened ZrB₂–SiC ceramic composite prepared by hot pressing, *Ceram. Int.* 42 (2016) 1950–1958. doi:10.1016/j.ceramint.2015.09.165.
- [140] S.A. Delbari, B. Nayeibi, E. Ghasali, M. Shokouhimehr, M. Shahedi Asl, Spark plasma sintering of TiN ceramics codoped with SiC and CNT, *Ceram. Int.* 45 (2019) 3207–3216. doi:10.1016/j.ceramint.2018.10.223.
- [141] M. Shahedi Asl, M. Ghassemi Kakroudi, Characterization of hot-pressed graphene reinforced ZrB₂–SiC composite, *Mater. Sci. Eng. A.* 625 (2015) 385–392. doi:10.1016/j.msea.2014.12.028.
- [142] K. Farhadi, A. Sabahi Namini, M. Shahedi Asl, A. Mohammadzadeh, M. Ghassemi Kakroudi, Characterization of hot pressed SiC whisker reinforced TiB₂ based composites, *Int. J. Refract. Met. Hard Mater.* 61 (2016) 84–90. doi:10.1016/j.jrmhm.2016.08.004.
- [143] A. Sabahi Namini, M. Azadbeh, M. Shahedi Asl, Effect of TiB₂ content on the characteristics of spark plasma sintered Ti–TiBw composites, *Adv. Powder Technol.* 28 (2017) 1564–1572. doi:10.1016/j.apt.2017.03.028.
- [144] Z. Balak, M. Azizieh, H. Kafashan, M.S. Asl, Z. Ahmadi, Optimization of effective parameters on thermal shock resistance of ZrB₂–SiC-based composites prepared by SPS: Using Taguchi design, *Mater. Chem. Phys.* 196 (2017) 333–340. doi:10.1016/j.matchemphys.2017.04.062.
- [145] F. Sharifianjazi, M. Moradi, N. Parvin, A. Nemati, A. Jafari Rad, N. Sheysi, A. Abouchenari, A. Mohammadi, S. Karbasi, Z. Ahmadi, A. Esmailkhanian, M. Irani, A. Pakseresht, S. Sahmani, M. Shahedi Asl, Magnetic CoFe₂O₄ nanoparticles doped with metal ions: A review, *Ceram. Int.* 46 (2020) 18391–18412. doi:10.1016/j.ceramint.2020.04.202.
- [146] H. Jangara, K. Shayesteh, M. Shahedi Asl, Mathematical modeling of absorption accompanied by a non-elementary reversible chemical reaction, *Chem. Eng. Res. Des.* 157 (2020) 58–64. doi:10.1016/j.cherd.2020.02.030.
- [147] K. Asadi-Pakdel, R. Mehdiavaz Aghdam, M. Shahedi Asl, M.A. Faghihi Sani, Synthesis and morphology optimization of electrospun SiBNC nanofibers, *Ceram. Int.* 46 (2020) 6052–6059. doi:10.1016/j.ceramint.2019.11.063.
- [148] M. Akhlaghi, S.A. Tayebifard, E. Salahi, M. Shahedi Asl, Spark plasma sintering of TiAl–Ti₃AlC₂ composite, *Ceram. Int.* 44 (2018) 21759–21764. doi:10.1016/j.ceramint.2018.08.272.
- [149] S. Haji Amiri, M. Ghassemi Kakroudi, T. Rabizadeh, M. Shahedi Asl, Characterization of hot-pressed Ti₃SiC₂–SiC composites, *Int. J. Refract. Met. Hard Mater.* 90 (2020) 105232. doi:10.1016/j.jrmhm.2020.105232.
- [150] M. Shokouhimehr, M.S. Asl, B. Mazinani, Modulated large-pore mesoporous silica as an efficient base catalyst for the Henry reaction, *Res. Chem. Intermed.* 44 (2018) 1617–1626. doi:10.1007/s11164-017-3188-9.
- [151] A. Sabahi Namini, S.A. Delbari, B. Nayeibi, M. Shahedi Asl, S. Parvizi, Effect of B₄C content on sintering behavior, microstructure and mechanical properties of Ti-based composites fabricated via spark plasma sintering, *Mater. Chem. Phys.* 251 (2020) 123087. doi:10.1016/j.matchemphys.2020.123087.
- [152] A. Sabahi Namini, M. Shahedi Asl, S.A. Delbari, Influence of Sintering Temperature on Microstructure and Mechanical Properties of Ti–Mo–B₄C Composites, *Met. Mater. Int.* (2019). doi:10.1007/s12540-019-00469-y.
- [153] M. Akhlaghi, S.A. Tayebifard, E. Salahi, M. Shahedi Asl, G. Schmidt, Self-propagating high-temperature synthesis of Ti₃AlC₂ MAX phase from mechanically-activated Ti/Al/graphite powder mixture, *Ceram. Int.* 44 (2018) 9671–9678. doi:10.1016/j.ceramint.2018.02.195.
- [154] M. Fattahi, M. Shahedi Asl, S.A. Delbari, A. Sabahi Namini, Z. Ahmadi, M. Mohammadi, Role of nano-WC addition on microstructural, mechanical and thermal characteristics of TiC–SiC composites, *Int. J. Refract. Met. Hard Mater.* 90 (2020) 105248. doi:10.1016/j.jrmhm.2020.105248.
- [155] F. Sharifianjazi, M. Moradi, A. Abouchenari, A.H. Pakseresht, A. Esmailkhanian, M. Shokouhimehr, M. Shahedi Asl, Effects of Sr and Mg dopants on biological and mechanical properties of SiO₂–CaO–P₂O₅ bioactive glass, *Ceram. Int.* 46 (2020) 22674–22682. doi:10.1016/j.ceramint.2020.06.030.
- [156] K. Shayesteh, P. Abbasi, V. Vahid Fard, M. Shahedi Asl, Simultaneous Removal of Nickel and Cadmium During the Cold Purification of Zinc Sulfate Solution, *Arab. J. Sci. Eng.* 45 (2020) 587–598. doi:10.1007/s13369-019-04320-9.
- [157] S.A. Delbari, A. Sabahi Namini, M. Azadbeh, Z. Ahmadi, V.-H. Nguyen, Q. Van Le, M. Shokouhimehr, M. Shahedi Asl, M. Mohammadi, Post hot rolling of spark plasma sintered Ti–Mo–B₄C composites, *Mater. Sci. Eng. A.* 799 (2021) 140214. doi:10.1016/j.msea.2020.140214.
- [158] M. Shahedi Asl, S.A. Delbari, M. Azadbeh, A. Sabahi Namini, M. Mehrabian, V.-H. Nguyen, Q. Van Le, M. Shokouhimehr, M. Mohammadi, Nanoindentational and conventional mechanical properties of spark plasma sintered Ti–Mo alloys, *J. Mater. Res. Technol.* 9 (2020) 10647–10658. doi:10.1016/j.jmrt.2020.07.066.
- [159] H. Roghani, S.A. Tayebifard, K. Kasraee, M. Shahedi Asl, Volume combustion synthesis of B₄C–SiC nanocomposites in tubular and spark plasma furnaces, *Ceram. Int.* (2020). doi:10.1016/j.ceramint.2020.08.060.
- [160] Y. Azizian-Kalandaragh, J. Farazin, Ş. Altindal, M. Shahedi Asl, G. Pirgholi-Givi, S.A. Delbari, A. Sabahi Namini, Electrical and dielectric properties of Al/(PVP: Zn–TeO₂)/p–Si heterojunction structures using current–voltage (I–V) and impedance-frequency (Z–f) measurements, *Appl. Phys. A.* 126 (2020) 635. doi:10.1007/s00339-020-03804-y.
- [161] S. Asadzadeh-Khaneghah, A. Habibi-Yangjeh, M. Shahedi Asl, Z. Ahmadi, S. Ghosh, Synthesis of novel ternary g-C₃N₄/SiC/C-Dots photocatalysts and their visible-light-induced activities in removal of various contaminants, *J. Photochem. Photobiol. A Chem.* 392 (2020) 112431. doi:10.1016/j.jphotochem.2020.112431.
- [162] F. Sharifianjazi, A.H. Pakseresht, M. Shahedi Asl, A. Esmailkhanian, H. Nargesi khoramabadi, H.W. Jang, M. Shokouhimehr, Hydroxyapatite Consolidated by Zirconia: Applications for Dental Implant, *J. Compos. Compd.* 2 (2020) 26–34. doi:10.29252/jcc.2.1.4.
- [163] H. Salimkhani, P. Palmeh, A.B. Khiabani, E. Hashemi, S. Matinpour, H. Salimkhani, M.S. Asl, Electrophoretic deposition of spherical carbonyl iron particles on carbon fibers as a microwave absorbent composite, *Surfaces and Interfaces.* 5 (2016) 1–7. doi:10.1016/j.surfin.2016.09.004.
- [164] P. Mohammadzadeh Jahani, Simultaneous Detection of Morphine and Diclofenac Using Graphene Nanoribbon Modified Screen-Printed Electrode, *Int. J. Electrochem. Sci.* (2020) 9037–9048. doi:10.20964/2020.09.14.
- [165] V. Sridhara, L.N. Satapathy, Effect of Nanoparticles on Thermal Properties Enhancement in Different Oils – A Review, *Crit. Rev. Solid State Mater. Sci.* 40 (2015) 399–424. doi:10.1080/10408436.2015.1068159.
- [166] X. Li, C. Zou, X. Lei, W. Li, Stability and enhanced thermal conductivity of ethylene glycol-based SiC nanofluids, *Int. J. Heat Mass Transf.* 89 (2015) 613–619. doi:10.1016/j.ijheatmasstransfer.2015.05.096.
- [167] Y. Hwang, J.-K. Lee, J.-K. Lee, Y.-M. Jeong, S. Cheong, Y.-C. Ahn, S.H. Kim, Production and dispersion stability of nanoparticles in nanofluids, *Powder Technol.* 186 (2008) 145–153. doi:10.1016/j.powtec.2007.11.020.
- [168] W. Yu, D.M. France, J.L. Routbort, S.U.S. Choi, Review and Comparison of Nanofluid Thermal Conductivity and Heat Transfer Enhancements, *Heat Transf. Eng.* 29 (2008) 432–460. doi:10.1080/01457630701850851.
- [169] Q.B. Romano, J. M., Parker, J. C., & Ford, Application opportunities for nanoparticles made from the condensation of physical vapors, *Advances in Powder Metallurgy and Particulate Materials*, 1997.
- [170] P. Garg, J.L. Alvarado, C. Marsh, T.A. Carlson, D.A. Kessler, K. Annamalai, An experimental study on the effect of ultrasonication on viscosity and heat transfer performance of multi-wall carbon nanotube-based aqueous nanofluids, *Int. J. Heat Mass Transf.* 52 (2009) 5090–5101. doi:10.1016/j.ijheatmasstransfer.2009.04.029.
- [171] A. Nasiri, M. Shariaty-Niasar, A. Rashidi, A. Amrollahi, R. Khodafarin, Effect of dispersion method on thermal conductivity and stability of nanofluid, *Exp. Therm. Fluid Sci.* 35 (2011) 717–723. doi:10.1016/j.expthermflsci.2011.01.006.
- [172] S.S. Sonawane, R.S. Khedkar, K.L. Wasewar, Effect of sonication time on enhancement of effective thermal conductivity of nano TiO₂–water, ethylene glycol, and paraffin oil nanofluids and models comparisons, *J. Exp. Nanosci.* 10

- (2015) 310–322. doi:10.1080/17458080.2013.832421.
- [173] B. Buonomo, O. Manca, L. Marinelli, S. Nardini, Effect of temperature and sonication time on nanofluid thermal conductivity measurements by nano-flash method, *Appl. Therm. Eng.* 91 (2015) 181–190. doi:10.1016/j.applthermaleng.2015.07.077.
- [174] T.-K. Hong, H.-S. Yang, C.J. Choi, Study of the enhanced thermal conductivity of Fe nanofluids, *J. Appl. Phys.* 97 (2005) 064311. doi:10.1063/1.1861145.
- [175] M.-S. Liu, M.C.-C. Lin, C.Y. Tsai, C.-C. Wang, Enhancement of thermal conductivity with Cu for nanofluids using chemical reduction method, *Int. J. Heat Mass Transf.* 49 (2006) 3028–3033. doi:10.1016/j.ijheatmasstransfer.2006.02.012.
- [176] G. Paul, S. Sarkar, T. Pal, P.K. Das, I. Manna, Concentration and size dependence of nano-silver dispersed water based nanofluids, *J. Colloid Interface Sci.* 371 (2012) 20–27. doi:10.1016/j.jcis.2011.11.057.
- [177] E. De Robertis, E.H.H. Cosme, R.S. Neves, A.Y. Kuznetsov, A.P.C. Campos, S.M. Landi, C.A. Achete, Application of the modulated temperature differential scanning calorimetry technique for the determination of the specific heat of copper nanofluids, *Appl. Therm. Eng.* 41 (2012) 10–17. doi:10.1016/j.applthermaleng.2012.01.003.
- [178] S.U.S. Choi, Z.G. Zhang, W. Yu, F.E. Lockwood, E.A. Grulke, Anomalous thermal conductivity enhancement in nanotube suspensions, *Appl. Phys. Lett.* 79 (2001) 2252–2254. doi:10.1063/1.1408272.
- [179] S.M.S. Murshed, K.C. Leong, C. Yang, Enhanced thermal conductivity of TiO₂—water based nanofluids, *Int. J. Therm. Sci.* 44 (2005) 367–373. doi:10.1016/j.ijthermalsci.2004.12.005.
- [180] M.E. Meibodi, M. Vafaie-Sefti, A.M. Rashidi, A. Amrollahi, M. Tabasi, H.S. Kalal, The role of different parameters on the stability and thermal conductivity of carbon nanotube/water nanofluids, *Int. Commun. Heat Mass Transf.* 37 (2010) 319–323. doi:10.1016/j.icheatmasstransfer.2009.10.004.
- [181] S.W. Lee, S.D. Park, S. Kang, I.C. Bang, J.H. Kim, Investigation of viscosity and thermal conductivity of SiC nanofluids for heat transfer applications, *Int. J. Heat Mass Transf.* 54 (2011) 433–438. doi:10.1016/j.ijheatmasstransfer.2010.09.026.
- [182] P.K. Singh, P.V. Harikrishna, T. Sundararajan, S.K. Das, Experimental and numerical investigation into the hydrodynamics of nanofluids in microchannels, *Exp. Therm. Fluid Sci.* 42 (2012) 174–186. doi:10.1016/j.expthermfluidsci.2012.05.004.
- [183] S.A. Fazeli, S.M. Hosseini Hashemi, H. Zirakzadeh, M. Ashjaee, Experimental and numerical investigation of heat transfer in a miniature heat sink utilizing silica nanofluid, *Superlattices Microstruct.* 51 (2012) 247–264. doi:10.1016/j.spmi.2011.11.017.
- [184] Z.T. Tabari, S.Z. Heris, Heat Transfer Performance of Milk Pasteurization Plate Heat Exchangers Using MWCNT/Water Nanofluid, *J. Dispers. Sci. Technol.* 36 (2015) 196–204. doi:10.1080/01932691.2014.894917.
- [185] R. Choudhary, S. Subudhi, Aspect ratio dependence of turbulent natural convection in Al₂O₃/water nanofluids, *Appl. Therm. Eng.* 108 (2016) 1095–1104. doi:10.1016/j.applthermaleng.2016.08.016.
- [186] V. Irani, A. Maleki, A. Tavasoli, CO₂ absorption enhancement in graphene-oxide/MDEA nanofluid, *J. Environ. Chem. Eng.* 7 (2019) 102782. doi:10.1016/j.jece.2018.11.027.
- [187] W. Rashmi, A.F. Ismail, I. Sopyan, A.T. Jameel, F. Yusof, M. Khalid, N.M. Mubarak, Stability and thermal conductivity enhancement of carbon nanotube nanofluid using gum arabic, *J. Exp. Nanosci.* 6 (2011) 567–579. doi:10.1080/17458080.2010.487229.
- [188] X.F. Li, D.S. Zhu, X.J. Wang, N. Wang, J.W. Gao, H. Li, Thermal conductivity enhancement dependent pH and chemical surfactant for Cu-H₂O nanofluids, *Thermochim. Acta.* 469 (2008) 98–103. doi:10.1016/j.tca.2008.01.008.
- [189] H. Zhu, C. Zhang, Y. Tang, J. Wang, B. Ren, Y. Yin, Preparation and thermal conductivity of suspensions of graphite nanoparticles, *Carbon N. Y.* 45 (2007) 226–228. doi:10.1016/j.carbon.2006.07.005.
- [190] M.J. Assael, I.N. Metaxa, J. Arvanitidis, D. Christofilos, C. Lioutas, Thermal Conductivity Enhancement in Aqueous Suspensions of Carbon Multi-Walled and Double-Walled Nanotubes in the Presence of Two Different Dispersants, *Int. J. Thermophys.* 26 (2005) 647–664. doi:10.1007/s10765-005-5569-3.
- [191] L. Jiang, L. Gao, J. Sun, Production of aqueous colloidal dispersions of carbon nanotubes, *J. Colloid Interface Sci.* 260 (2003) 89–94. doi:10.1016/S0021-9797(02)00176-5.
- [192] Y. Xuan, Q. Li, Heat transfer enhancement of nanofluids, *Int. J. Heat Fluid Flow.* 21 (2000) 58–64. doi:10.1016/S0142-727X(99)00067-3.
- [193] X. Peng, X. F., Yu, X. L., Xia, L. F., & Zhong, Influence factors on suspension stability of nanofluids, *Journal-Zhejiang Univ. Eng. Sci.* 41 (2007) 577.
- [194] H.E. Patel, K.B. Anoop, T. Sundararajan, S.K. Das, A MICRO-CONVECTION MODEL FOR THERMAL CONDUCTIVITY OF NANOFLUIDS, in: *Nanoscale*, Begell House Inc., 2006. doi:10.1615/IHTC13.p8.240.
- [195] D. Lee, J.-W. Kim, B.G. Kim, A New Parameter to Control Heat Transport in Nanofluids: Surface Charge State of the Particle in Suspension, *J. Phys. Chem. B.* 110 (2006) 4323–4328. doi:10.1021/jp057225m.
- [196] H. Chen, Y. Ding, A. Lapkin, Rheological behaviour of nanofluids containing tube / rod-like nanoparticles, *Powder Technol.* 194 (2009) 132–141. doi:10.1016/j.powtec.2009.03.038.
- [197] W. Yu, H. Xie, L. Chen, Y. Li, Enhancement of thermal conductivity of kerosene-based Fe₃O₄ nanofluids prepared via phase-transfer method, *Colloids Surfaces A Physicochem. Eng. Asp.* 355 (2010) 109–113. doi:10.1016/j.colsurfa.2009.11.044.
- [198] M. Chandrasekar, S. Suresh, A. Chandra Bose, Experimental studies on heat transfer and friction factor characteristics of Al₂O₃/water nanofluid in a circular pipe under laminar flow with wire coil inserts, *Exp. Therm. Fluid Sci.* 34 (2010) 122–130. doi:10.1016/j.expthermfluidsci.2009.10.001.
- [199] S.S.J. Aravind, P. Baskar, T.T. Baby, R.K. Sabareesh, S. Das, S. Ramaprabhu, Investigation of Structural Stability, Dispersion, Viscosity, and Conductive Heat Transfer Properties of Functionalized Carbon Nanotube Based Nanofluids, *J. Phys. Chem. C.* 115 (2011) 16737–16744. doi:10.1021/jp201672p.
- [200] M. Shanbedi, S.Z. Heris, M. Baniadam, A. Amiri, M. Maghrebi, Investigation of Heat-Transfer Characterization of EDA-MWCNT/DI-Water Nanofluid in a Two-Phase Closed Thermosyphon, *Ind. Eng. Chem. Res.* 51 (2012) 1423–1428. doi:10.1021/ie202110g.
- [201] M. Shanbedi, S. Zeinali Heris, M. Baniadam, A. Amiri, The Effect of Multi-Walled Carbon Nanotube/Water Nanofluid on Thermal Performance of a Two-Phase Closed Thermosyphon, *Exp. Heat Transf.* 26 (2013) 26–40. doi:10.1080/08916152.2011.631078.
- [202] A. Amiri, R. Sadri, M. Shanbedi, G. Ahmadi, B.T. Chew, S.N. Kazi, M. Dahari, Performance dependence of thermosyphon on the functionalization approaches: An experimental study on thermo-physical properties of graphene nanoplatelet-based water nanofluids, *Energy Convers. Manag.* 92 (2015) 322–330. doi:10.1016/j.enconman.2014.12.051.
- [203] R.M. Mostafizur, A.R. Abdul Aziz, R. Saidur, M.H.U. Bhuiyan, Investigation on stability and viscosity of SiO₂-CH₃OH (methanol) nanofluids, *Int. Commun. Heat Mass Transf.* 72 (2016) 16–22. doi:10.1016/j.icheatmasstransfer.2016.01.001.
- [204] K. Cacua, R. Buitrago-Sierra, B. Herrera, F. Chejne, E. Pabón, Influence of different parameters and their coupled effects on the stability of alumina nanofluids by a fractional factorial design approach, *Adv. Powder Technol.* 28 (2017) 2581–2588. doi:10.1016/j.appt.2017.07.009.
- [205] S.J.K. S., P.K. Nagarajan, Influence of stability and particle shape effects for an entropy generation based optimized selection of magnesia nanofluid for convective heat flow applications, *Appl. Surf. Sci.* 489 (2019) 560–575. doi:10.1016/j.apsusc.2019.06.038.
- [206] H. Chang, C.S. Jwo, P.S. Fan, S.H. Pai, Process optimization and material properties for nanofluid manufacturing, *Int. J. Adv. Manuf. Technol.* 34 (2007) 300–306. doi:10.1007/s00170-006-0597-0.
- [207] Y. He, Y. Jin, H. Chen, Y. Ding, D. Cang, H. Lu, Heat transfer and flow behaviour of aqueous suspensions of TiO₂ nanoparticles (nanofluids) flowing upward through a vertical pipe, *Int. J. Heat Mass Transf.* 50 (2007) 2272–2281. doi:10.1016/j.ijheatmasstransfer.2006.10.024.
- [208] K.B. Hadjov, Modified self-consistent scheme to predict the thermal conductivity of nanofluids, *Int. J. Therm. Sci.* 48 (2009) 2249–2254. doi:10.1016/j.ijthermalsci.2009.05.008.
- [209] L. Jorge, S. Coulombe, P.-L. Girard-Lauriault, Tetraethylenepentamine and (3-aminopropyl)triethoxysilane adsorbed on multi-walled carbon nanotubes for stable water and ethanol nanofluids, *Thin Solid Films.* 682 (2019) 50–56. doi:10.1016/j.tsf.2019.05.007.
- [210] M. Zareei, H. Yoozbashizadeh, H.R. Madaah Hosseini, Investigating the effects of pH, surfactant and ionic strength on the stability of alumina/water nanofluids using DLVO theory, *J. Therm. Anal. Calorim.* 135 (2019) 1185–1196. doi:10.1007/s10973-018-7620-1.
- [211] B. Baktavatchalam, K. Habib, R. Saidur, B.B. Saha, K. Irshad, Comprehensive study on nanofluid and ionanofluid for heat transfer enhancement: A review on current and future perspective, *J. Mol. Liq.* 305 (2020) 112787. doi:10.1016/j.molliq.2020.112787.
- [212] L. Yang, Y. Hu, Toward TiO₂ Nanofluids—Part I: Preparation and Properties, *Nanoscale Res. Lett.* 12 (2017) 417. doi:10.1186/s11671-017-2184-8.
- [213] J.D. Clogston, A.K. Patri, Zeta Potential Measurement, in: 2011: pp. 63–70. doi:10.1007/978-1-60327-198-1_6.
- [214] L. Vandsburger, Synthesis and covalent surface modification of carbon nanotubes for preparation of stabilized nanofluid suspensions, *M.Eng., Montr. McGill*

Univ. (2009) 1–73.

- [215] F. Mashali, E.M. Languri, J. Davidson, D. Kerns, W. Johnson, K. Nawaz, G. Cunningham, Thermo-physical properties of diamond nanofluids: A review, *Int. J. Heat Mass Transf.* 129 (2019) 1123–1135. doi:10.1016/j.jheatmasstransfer.2018.10.033.
- [216] I. Zakaria, W.A.N.W. Mohamed, A.M.I. Bin Mamat, R. Saidur, W.H. Azmi, R. Mamat, S.F.A. Talib, Experimental Investigation of Al_2O_3 - Water Ethylene Glycol Mixture Nanofluid Thermal Behaviour in a Single Cooling Plate for PEM Fuel Cell Application, *Energy Procedia*. 79 (2015) 252–258. doi:10.1016/j.egypro.2015.11.474.
- [217] T. Sun, A.S. Teja, Density, Viscosity and Thermal Conductivity of Aqueous Solutions of Propylene Glycol, Dipropylene Glycol, and Tripropylene Glycol between 290 K and 460 K, *J. Chem. Eng. Data*. 49 (2004) 1311–1317. doi:10.1021/je049960h.
- [218] N.G. Tsierkezos, I.E. Molinou, Thermodynamic Properties of Water + Ethylene Glycol at 283.15, 293.15, 303.15, and 313.15 K, *J. Chem. Eng. Data*. 43 (1998) 989–993. doi:10.1021/je9800914.
- [219] M. Hosseinzadeh, A. Salari, M. Sardarabadi, M. Passandideh-Fard, Optimization and parametric analysis of a nanofluid based photovoltaic thermal system: 3D numerical model with experimental validation, *Energy Convers. Manag.* 160 (2018) 93–108. doi:10.1016/j.enconman.2018.01.006.
- [220] B. Kolade, K.E. Goodson, J.K. Eaton, Convective Performance of Nanofluids in a Laminar Thermally Developing Tube Flow, *J. Heat Transfer*. 131 (2009). doi:10.1115/1.3013831.
- [221] S.K. Das, N. Putra, P. Thiesen, W. Roetzel, Temperature Dependence of Thermal Conductivity Enhancement for Nanofluids, *J. Heat Transfer*. 125 (2003) 567–574. doi:10.1115/1.1571080.
- [222] Q. Shou, R. Chen, S. Su, Experimental research on thermal conductivity of metal-oxide nanofluids, *Appl. Mech. Mater.* 148–149 (2012) 587–590. doi:10.4028/www.scientific.net/AMM.148-149.587.
- [223] C.H. Chon, K.D. Kihm, S.P. Lee, S.U.S. Choi, Empirical correlation finding the role of temperature and particle size for nanofluid (Al_2O_3) thermal conductivity enhancement, *Appl. Phys. Lett.* 87 (2005) 153107. doi:10.1063/1.2093936.
- [224] Y. Li, J. Zhou, S. Tung, E. Schneider, S. Xi, A review on development of nanofluid preparation and characterization, *Powder Technol.* 196 (2009) 89–101. doi:10.1016/j.powtec.2009.07.025.
- [225] A.S. Dalkılıç, G. Yalçın, B.O. Küçükyıldırım, S. Öztuna, A. Akdoğan Eker, C. Jumholkul, S. Nakkaew, S. Wongwises, Experimental study on the thermal conductivity of water-based CNT- SiO_2 hybrid nanofluids, *Int. Commun. Heat Mass Transf.* 99 (2018) 18–25. doi:10.1016/j.icheatmasstransfer.2018.10.002.
- [226] K. Vaferi, S. Nekahi, M. Vajdi, F. Sadegh Moghanlou, M. Shokouhimehr, A. Motalebzadeh, J. Sha, M. Shahedi Asl, Heat transfer, thermal stress and failure analyses in a TiB_2 gas turbine stator blade, *Ceram. Int.* 45 (2019). doi:10.1016/j.ceramint.2019.06.184.
- [227] M. Vajdi, F. Sadegh Moghanlou, Z. Ahmadi, A. Motalebzadeh, M. Shahedi Asl, Thermal diffusivity and microstructure of spark plasma sintered TiB_2SiC Ti composite, *Ceram. Int.* 45 (2019) 8333–8344. doi:10.1016/j.ceramint.2019.01.141.
- [228] S. Nekahi, M. Vajdi, F. Sadegh Moghanlou, K. Vaferi, A. Motalebzadeh, M. Özen, U. Aydemir, J. Sha, M. Shahedi Asl, TiB_2 - SiC -based ceramics as alternative efficient micro heat exchangers, *Ceram. Int.* 45 (2019) 19060–19067. doi:10.1016/j.ceramint.2019.06.150.
- [229] S. Nekahi, F. Sadegh Moghanlou, M. Vajdi, Z. Ahmadi, A. Motalebzadeh, M. Shahedi Asl, Microstructural, thermal and mechanical characterization of TiB_2 - SiC composites doped with short carbon fibers, *Int. J. Refract. Met. Hard Mater.* 82 (2019) 129–135. doi:10.1016/j.jrmm.2019.04.005.
- [230] M. Vajdi, F. Sadegh Moghanlou, S. Nekahi, Z. Ahmadi, A. Motalebzadeh, H. Jafarzadeh, M. Shahedi Asl, Role of graphene nano-platelets on thermal conductivity and microstructure of TiB_2 - SiC ceramics, *Ceram. Int.* 46 (2020) 21775–21783. doi:10.1016/j.ceramint.2020.05.289.
- [231] F. Sadegh Moghanlou, S. Nekahi, M. Vajdi, Z. Ahmadi, A. Motalebzadeh, A. Shokouhimehr, M. Shokouhimehr, S. Jafaroghlinejad, M. Shahedi Asl, Effects of graphite nano-flakes on thermal and microstructural properties of TiB_2 - SiC composites, *Ceram. Int.* 46 (2020) 11622–11630. doi:10.1016/j.ceramint.2020.01.192.
- [232] S. Jana, A. Salehi-Khojin, W.-H. Zhong, Enhancement of fluid thermal conductivity by the addition of single and hybrid nano-additives, *Thermochim. Acta*. 462 (2007) 45–55. doi:10.1016/j.tca.2007.06.009.
- [233] H. Xie, H. Lee, W. Youn, M. Choi, Nanofluids containing multiwalled carbon nanotubes and their enhanced thermal conductivities, *J. Appl. Phys.* 94 (2003) 4967. doi:10.1063/1.1613374.
- [234] X. Wang, X. Xu, S.U.S. Choi, Thermal Conductivity of Nanoparticle - Fluid Mixture, *J. Thermophys. Heat Transf.* 13 (1999) 474–480. doi:10.2514/2.6486.
- [235] M. Abareshi, E.K. Goharshadi, S. Mojtaba Zebarjad, H. Khandan Fada-fan, A. Youssefi, Fabrication, characterization and measurement of thermal conductivity of Fe_3O_4 nanofluids, *J. Magn. Magn. Mater.* 322 (2010) 3895–3901. doi:10.1016/j.jmmm.2010.08.016.
- [236] W.Y. Lai, S. Vinod, P.E. Phelan, R. Prasher, Convective Heat Transfer for Water-Based Alumina Nanofluids in a Single 1.02-mm Tube, *J. Heat Transfer*. 131 (2009). doi:10.1115/1.3133886.
- [237] D. Zhu, X. Li, N. Wang, X. Wang, J. Gao, H. Li, Dispersion behavior and thermal conductivity characteristics of Al_2O_3 - H_2O nanofluids, *Curr. Appl. Phys.* 9 (2009) 131–139. doi:10.1016/j.cap.2007.12.008.
- [238] H. Xie, J. Wang, T. Xi, Y. Liu, F. Ai, Q. Wu, Thermal conductivity enhancement of suspensions containing nanosized alumina particles, *J. Appl. Phys.* 91 (2002) 4568–4572. doi:10.1063/1.1454184.
- [239] H.E. Patel, S.K. Das, T. Sundararajan, A. Sreekumaran Nair, B. George, T. Pradeep, Thermal conductivities of naked and monolayer protected metal nanoparticle based nanofluids: Manifestation of anomalous enhancement and chemical effects, *Appl. Phys. Lett.* 83 (2003) 2931–2933. doi:10.1063/1.1602578.
- [240] D. Wen, Y. Ding, Experimental investigation into convective heat transfer of nanofluids at the entrance region under laminar flow conditions, *Int. J. Heat Mass Transf.* 47 (2004) 5181–5188. doi:10.1016/j.jheatmasstransfer.2004.07.012.
- [241] S.A. Putnam, D.G. Cahill, P. V. Braun, Z. Ge, R.G. Shimmin, Thermal conductivity of nanoparticle suspensions, *J. Appl. Phys.* 99 (2006) 084308. doi:10.1063/1.2189933.
- [242] L. Godson, B. Raja, D.M. Lal, S. Wongwises, Experimental Investigation on the Thermal Conductivity and Viscosity of Silver-Deionized Water Nanofluid, *Exp. Heat Transf.* 23 (2010) 317–332. doi:10.1080/08916150903564796.
- [243] M. Kole, T.K. Dey, Thermal conductivity and viscosity of Al_2O_3 nanofluid based on car engine coolant, *J. Phys. D. Appl. Phys.* 43 (2010) 315501. doi:10.1088/0022-3727/43/31/315501.
- [244] L. Colla, L. Fedele, M. Scattolini, S. Bobbo, Water-Based Fe_3O_4 Nanofluid Characterization: Thermal Conductivity and Viscosity Measurements and Correlation, *Adv. Mech. Eng.* 4 (2012) 674947. doi:10.1155/2012/674947.
- [245] O. MANNA, S.K. SINGH, G. PAUL, Enhanced thermal conductivity of nano- SiC dispersed water based nanofluid, *Bull. Mater. Sci.* 35 (2012) 707–712. doi:10.1007/s12034-012-0366-7.
- [246] T.-P. Teng, Thermal conductivity and phase-change properties of aqueous alumina nanofluid, *Energy Convers. Manag.* 67 (2013) 369–375. doi:10.1016/j.enconman.2012.12.004.
- [247] M.K. Sinha, R. Madhakar, S. Ghosh, P.V. Rao, Application of eco-friendly nanofluids during grinding of Inconel 718 through small quantity lubrication, *J. Clean. Prod.* 141 (2017) 1359–1375. doi:10.1016/j.jclepro.2016.09.212.
- [248] F. Micali, M. Milanese, G. Colangelo, A. de Risi, Experimental investigation on 4-strokes biodiesel engine cooling system based on nanofluid, *Renew. Energy*. 125 (2018) 319–326. doi:10.1016/j.renene.2018.02.110.
- [249] R. Ranjbarzadeh, A. Moradikazerouni, R. Bakhtiari, A. Asadi, M. Afrand, An experimental study on stability and thermal conductivity of water/silica nanofluid: Eco-friendly production of nanoparticles, *J. Clean. Prod.* 206 (2019) 1089–1100. doi:10.1016/j.jclepro.2018.09.205.
- [250] A. Riahi, S. Khamlich, M. Balghouthi, T. Khamliche, T.B. Doyle, W. Dimassi, A. Guizani, M. Maaza, Study of thermal conductivity of synthesized Al_2O_3 -water nanofluid by pulsed laser ablation in liquid, *J. Mol. Liq.* 304 (2020) 112694. doi:10.1016/j.molliq.2020.112694.
- [251] J.C. Maxwell, The Scientific Papers of James Clerk Maxwell, Cambridge University Press, Cambridge, 1890. doi:10.1017/CBO9780511698095.
- [252] R.L. Hamilton, O.K. Crosser, Thermal Conductivity of Heterogeneous Two-Component Systems, *Ind. Eng. Chem. Fundam.* 1 (1962) 187–191. doi:10.1021/i160003a005.
- [253] D.A.G. Bruggeman, Berechnung verschiedener physikalischer Konstanten von heterogenen Substanzen. III. Die elastischen Konstanten der quasiisotropen Mischkörper aus isotropen Substanzen, *Ann. Phys.* 421 (1937) 160–178. doi:10.1002/andp.19374210205.
- [254] R.L.G. E.J. Wasp, J.P. Kenny, Solid-liquid flow: Slurry pipeline transportation. [pumps, valves, mechanical equipment, economicS], Ser. Bulk Mater. Handl.; (United States). 1:4 (1977) 1.
- [255] S. Lu, H. Lin, Effective conductivity of composites containing aligned spheroidal inclusions of finite conductivity, *J. Appl. Phys.* 79 (1996) 6761–6769. doi:10.1063/1.361498.
- [256] W. Yu, S.U.S. Choi, The role of interfacial layers in the enhanced thermal conductivity of nanofluids: A renovated Hamilton-Crosser model, *J. Nanoparticle Res.* 6 (2004) 355–361. doi:10.1007/s11051-004-2601-7.
- [257] C.-W. Nan, Z. Shi, Y. Lin, A simple model for thermal conductivity of carbon nanotube-based composites, *Chem. Phys. Lett.* 375 (2003) 666–669. doi:10.1016/S0009-2614(03)00956-4.

- [258] B.-X. Wang, L.-P. Zhou, X.-F. Peng, A fractal model for predicting the effective thermal conductivity of liquid with suspension of nanoparticles, *Int. J. Heat Mass Transf.* 46 (2003) 2665–2672. doi:10.1016/S0017-9310(03)00016-4.
- [259] S.K. Kumar, D. H., Patel, H. E., Kumar, V. R., Sundararajan, T., Pradeep, T., & Das, Model for heat conduction in nanofluids, *Phys. Rev. Lett.* 93 (2004) 144301.
- [260] H. Xie, M. Fujii, X. Zhang, Effect of interfacial nanolayer on the effective thermal conductivity of nanoparticle-fluid mixture, *Int. J. Heat Mass Transf.* 48 (2005) 2926–2932. doi:10.1016/j.ijheatmasstransfer.2004.10.040.
- [261] P.E.P. R. Prasher, P. Bhattacharya, Thermal conductivity of nanoscale colloidal solutions (nanofluids), *Phys. Rev. Lett.* 94 (2005) 25901.
- [262] S.M.S. Murshed, K.C. Leong, C. Yang, A model for predicting the effective thermal conductivity of nanoparticle-fluid suspensions, *Int. J. Nanosci.* 05 (2006) 23–33. doi:10.1142/S0219581X06004127.
- [263] J. Li, Computational Analysis of Nanofluid Flow in Microchannels with Applications to Micro-heat Sinks and Bio-MEMS., (2008) 207. doi:10.1017/CBO9781107415324.004.
- [264] R.S. Vajjha, D.K. Das, D.P. Kulkarni, Development of new correlations for convective heat transfer and friction factor in turbulent regime for nanofluids, *Int. J. Heat Mass Transf.* 53 (2010) 4607–4618. doi:10.1016/j.ijheatmasstransfer.2010.06.032.
- [265] K.S. Suganthi, V. Leela Vinodhan, K.S. Rajan, Heat transfer performance and transport properties of ZnO–ethylene glycol and ZnO–ethylene glycol–water nanofluid coolants, *Appl. Energy*. 135 (2014) 548–559. doi:10.1016/j.apenergy.2014.09.023.
- [266] Y. Gao, H. Wang, A.P. Sasmito, A.S. Mujumdar, Measurement and modeling of thermal conductivity of graphene nanoplatelet water and ethylene glycol base nanofluids, *Int. J. Heat Mass Transf.* 123 (2018) 97–109. doi:10.1016/j.ijheatmasstransfer.2018.02.089.
- [267] R. Prasher, D. Song, J. Wang, P. Phelan, Measurements of nanofluid viscosity and its implications for thermal applications, *Appl. Phys. Lett.* 89 (2006) 133108. doi:10.1063/1.2356113.
- [268] E.W. Woolard, A. Einstein, R. Furth, A.D. Cowper, Investigations on the Theory of the Brownian Movement., Dover Publications, Inc, 1956.
- [269] S.M.S. Murshed, P. Estellé, A state of the art review on viscosity of nanofluids, *Renew. Sustain. Energy Rev.* 76 (2017) 1134–1152. doi:10.1016/j.rser.2017.03.113.
- [270] M. Ghazvini, M.A. Akhavan-Behabadi, E. Rasouli, M. Raisee, Heat Transfer Properties of Nanodiamond–Engine Oil Nanofluid in Laminar Flow, *Heat Transf. Eng.* 33 (2012) 525–532. doi:10.1080/01457632.2012.624858.
- [271] Y. Ding, H. Alias, D. Wen, R.A. Williams, Heat transfer of aqueous suspensions of carbon nanotubes (CNT nanofluids), *Int. J. Heat Mass Transf.* 49 (2006) 240–250. doi:10.1016/j.ijheatmasstransfer.2005.07.009.
- [272] S. Zeinali Heris, S.G. Etemad, M. Nasr Esfahany, Experimental investigation of oxide nanofluids laminar flow convective heat transfer, *Int. Commun. Heat Mass Transf.* 33 (2006) 529–535. doi:10.1016/j.icheatmasstransfer.2006.01.005.
- [273] C.T. Nguyen, F. Desgranges, N. Galanis, G. Roy, T. Maré, S. Boucher, H. Angue Mintsa, Viscosity data for Al₂O₃–water nanofluid—hysteresis: is heat transfer enhancement using nanofluids reliable?, *Int. J. Therm. Sci.* 47 (2008) 103–111. doi:10.1016/j.jthermalsci.2007.01.033.
- [274] L. Syam Sundar, M.K. Singh, A.C.M. Sousa, Investigation of thermal conductivity and viscosity of Fe₃O₄ nanofluid for heat transfer applications, *Int. Commun. Heat Mass Transf.* 44 (2013) 7–14. doi:10.1016/j.icheatmasstransfer.2013.02.014.
- [275] M. Shanbedi, S. Zeinali Heris, A. Maskooki, Experimental investigation of stability and thermophysical properties of carbon nanotubes suspension in the presence of different surfactants, *J. Therm. Anal. Calorim.* 120 (2015) 1193–1201. doi:10.1007/s10973-015-4404-8.
- [276] H.W. Chiam, W.H. Azmi, N.A. Usri, R. Mamat, N.M. Adam, Thermal conductivity and viscosity of Al₂O₃ nanofluids for different based ratio of water and ethylene glycol mixture, *Exp. Therm. Fluid Sci.* 81 (2017) 420–429. doi:10.1016/j.expthermflusci.2016.09.013.
- [277] K.M. Yashawantha, A. Asif, G. Ravindra Babu, M.K. Ramis, Rheological Behavior and Thermal Conductivity of Graphite–Ethylene Glycol Nanofluid, *J. Test. Eval.* 49 (2021) 20190255. doi:10.1520/JTE20190255.
- [278] A. Ajith, Eine neue bestimmung der moleküldimensionen, *Ann. Phys.* 324 (1906) 289–306.
- [279] H.C. Brinkman, The Viscosity of Concentrated Suspensions and Solutions, *J. Chem. Phys.* 20 (1952) 571–571. doi:10.1063/1.1700493.
- [280] J.D. Eshelby, The determination of the elastic field of an ellipsoidal inclusion, and related problems, *Proc. R. Soc. London. Ser. A. Math. Phys. Sci.* 241 (1957) 376–396. doi:10.1098/rspa.1957.0133.
- [281] I.M. Krieger, T.J. Dougherty, A Mechanism for Non-Newtonian Flow in Suspensions of Rigid Spheres, *Trans. Soc. Rheol.* 3 (1959) 137–152. doi:10.1122/1.548848.
- [282] N.A. Frankel, A. Acrivos, On the viscosity of a concentrated suspension of solid spheres, *Chem. Eng. Sci.* 22 (1967) 847–853. doi:10.1016/0009-2509(67)80149-0.
- [283] D.J. Jeffrey, A. Acrivos, The rheological properties of suspensions of rigid particles, *AIChE J.* 22 (1976) 417–432. doi:10.1002/aic.690220303.
- [284] A.L. Graham, On the viscosity of suspensions of solid spheres, *Appl. Sci. Res.* 37 (1981) 275–286. doi:10.1007/BF00951252.
- [285] T.S. Chow, Viscosities of concentrated dispersions, *Phys. Rev. E.* 48 (1993) 1977–1983. doi:10.1103/PhysRevE.48.1977.
- [286] B.C. Pak, Y.I. Cho, Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles, *Exp. Heat Transf.* 11 (1998) 151–170. doi:10.1080/08916159808946559.
- [287] S. Liu, Particle dispersion for suspension flow, *Chem. Eng. Sci.* 54 (1999) 873–891. doi:10.1016/S0009-2509(98)00309-1.
- [288] A. De Noni Jr, D.E. Garcia, D. Hotza, A modified model for the viscosity of ceramic suspensions, *Ceram. Int.* 28 (2002) 731–735. doi:10.1016/S0272-8842(02)00035-4.
- [289] L.A. Dávalos Orozco, L.F. del Castillo, Hydrodynamic Behavior of Suspensions of Polar Particles, *Encycl. Surf. Colloid Sci.* Third Ed. (2016) 3070–3091. doi:10.1081/e-esccs3-120021916.
- [290] C.T. Nguyen, F. Desgranges, G. Roy, N. Galanis, T. Maré, S. Boucher, H. Angue Mintsa, Temperature and particle-size dependent viscosity data for water-based nanofluids – Hysteresis phenomenon, *Int. J. Heat Fluid Flow.* 28 (2007) 1492–1506. doi:10.1016/j.ijheatfluidflow.2007.02.004.
- [291] S. Bobbo, L. Fedele, A. Benetti, L. Colla, M. Fabrizio, C. Pagura, S. Barison, Viscosity of water based SWCNH and TiO₂ nanofluids, *Exp. Therm. Fluid Sci.* 36 (2012) 65–71. doi:10.1016/j.expthermflusci.2011.08.004.
- [292] S. Aberoumand, A. Jafarimoghaddam, M. Moravej, H. Aberoumand, K. Javaherdeh, Experimental study on the rheological behavior of silver-heat transfer oil nanofluid and suggesting two empirical based correlations for thermal conductivity and viscosity of oil based nanofluids, *Appl. Therm. Eng.* 101 (2016) 362–372. doi:10.1016/j.applthermaleng.2016.01.148.
- [293] A. Karimipour, S. Ghasemi, M.H.K. Darvanjooghi, A. Abdollahi, A new correlation for estimating the thermal conductivity and dynamic viscosity of CuO/liquid paraffin nanofluid using neural network method, *Int. Commun. Heat Mass Transf.* 92 (2018) 90–99. doi:10.1016/j.icheatmasstransfer.2018.02.002.
- [294] M. Hemmat Esfe, H. Rahimi Raki, M.R. Sarmasti Emami, M. Afrand, Viscosity and rheological properties of antifreeze based nanofluid containing hybrid nano-powders of MWCNTs and TiO₂ under different temperature conditions, *Powder Technol.* 342 (2019) 808–816. doi:10.1016/j.powtec.2018.10.032.
- [295] A. Kumar, S. Subudhi, Preparation, characterization and heat transfer analysis of nanofluids used for engine cooling, *Appl. Therm. Eng.* 160 (2019) 114092. doi:10.1016/j.applthermaleng.2019.114092.
- [296] B. Farajollahi, S.G. Etemad, M. Hojjat, Heat transfer of nanofluids in a shell and tube heat exchanger, *Int. J. Heat Mass Transf.* 53 (2010) 12–17. doi:10.1016/j.ijheatmasstransfer.2009.10.019.
- [297] D. Wen, Y. Ding, Formulation of nanofluids for natural convective heat transfer applications, *Int. J. Heat Fluid Flow.* 26 (2005) 855–864. doi:10.1016/j.ijheatfluidflow.2005.10.005.
- [298] J.-Y. Jung, H.-S. Oh, H.-Y. Kwak, Forced Convective Heat Transfer of Nanofluids in Microchannels, in: *Heat Transf. Vol. 3, ASME*, 2006: pp. 327–332. doi:10.1115/IMECE2006-13851.
- [299] S.Z. Heris, S.G. Etemad, M.N. Esfahany, Convective Heat Transfer of a Cu/Water Nanofluid Flowing Through a Circular Tube, *Exp. Heat Transf.* 22 (2009) 217–227. doi:10.1080/08916150902950145.
- [300] D.J. Faulkner, D.R. Rector, J.J. Davidson, R. Shekariz, Enhanced Heat Transfer Through the Use of Nanofluids in Forced Convection, in: *Heat Transf. Vol. 3, ASME*, 2004: pp. 219–224. doi:10.1115/IMECE2004-62147.
- [301] M. Naraki, S.M. Peyghambarzadeh, S.H. Hashemabadi, Y. Vermahmoudi, Parametric study of overall heat transfer coefficient of CuO/water nanofluids in a car radiator, *Int. J. Therm. Sci.* 66 (2013) 82–90. doi:10.1016/j.jthermalsci.2012.11.013.
- [302] F.W. Dittus, L.M.K. Boelter, Heat transfer in automobile radiators of the tubular type, *Int. Commun. Heat Mass Transf.* 12 (1985) 3–22. doi:10.1016/0735-1933(85)90003-X.
- [303] H. Hausen, Darstellung des Wärmeüberganges in Rohren durch verallgemeinerte Potenzbeziehungen, *Z. VDI Beih. Verfahrenstech.* 4 (1943) 91–98.
- [304] D.L. V. Lyon, R. N., & Katz, *Liquid-Metals Handbook*, US Gov. Print. Off. 733 (1954).

- [305] S. Lubarsky, Bernard; Kaufman, Review of Experimental Investigations of Liquid-Metal Heat Transfer, *Natl. Advis. Comm. Aeronaut.* (1956) 1–33.
- [306] S.W. Churchill, R. Usagi, A general expression for the correlation of rates of transfer and other phenomena, *AIChE J.* 18 (1972) 1121–1128. doi:10.1002/aic.690180606.
- [307] R.H. Notter, C.A. Sleicher, A solution to the turbulent Graetz problem-III Fully developed and entry region heat transfer rates, *Chem. Eng. Sci.* 27 (1972) 2073–2093. doi:10.1016/0009-2509(72)87065-9.
- [308] S.E.B. Maïga, C.T. Nguyen, N. Galanis, G. Roy, Heat transfer behaviours of nanofluids in a uniformly heated tube, *Superlattices Microstruct.* 35 (2004) 543–557. doi:10.1016/j.spmi.2003.09.012.
- [309] S. Suresh, K.P. Venkataraj, P. Selvakumar, M. Chandrasekar, Effect of Al_2O_3 -Cu/water hybrid nanofluid in heat transfer, *Exp. Therm. Fluid Sci.* 38 (2012) 54–60. doi:10.1016/j.expthermflusci.2011.11.007.
- [310] L. Syam Sundar, M.T. Naik, K. V. Sharma, M.K. Singh, T.C. Siva Reddy, Experimental investigation of forced convection heat transfer and friction factor in a tube with Fe_3O_4 magnetic nanofluid, *Exp. Therm. Fluid Sci.* 37 (2012) 65–71. doi:10.1016/j.expthermflusci.2011.10.004.
- [311] K. Raj, R. Moskowitz, Commercial applications of ferrofluids, *J. Magn. Magn. Mater.* 85 (1990) 233–245. doi:10.1016/0304-8853(90)90058-X.
- [312] K. V. Wong, O. De Leon, Applications of nanofluids: Current and future, *Adv. Mech. Eng.* 2010 (2010). doi:10.1155/2010/519659.