Enhanced Thermal Conductivity of Cooling Liquid Using Nano Material's

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Abstract

In present work alumina with grain size (50 nm) and titanium dioxide with grain size (20nm) are used to thermal conductivity is tested separately when mixed with water at different percent concentrations (0.05%, 0.1 %, 0.3%, and 0.5 W %), in order to investigate their effects on enhancement of heat transfer of pool boiling water and enhancement thermal conductivity of nanofluid.

The experimental results of thermal conductivity of water before and after adding of nanoparticles have been presented in this work. The results of a theoretical study of thermal conductivity of nanofluids with Al_2O_3 and TiO_2 nanoparticles are also presented and compared with the experimental results. Both results showed an increment of 1.5% -1.8% enhancements have been obtained when a small amount of nanoparticles is added to the pure water. The theoretical calculation is based on the mechanism of Brownian motion which is the reason for improvement of thermal conductivity.

Keywords : Heat transfer, nucleate pool boiling, Thermal conductivity, Al_2O_3 and TiO_2, Nanoparticle, Nanofluid, base fluid.

تحسين الموصلية الحرارية لسوائل التبريد باستخدام المواد النانوية

الخلاصة

في العمل الحالي أستخدم الألومينا Al_2O_3مع حجم حبيبي (50نانو متر) وثاني أكسيد التيتانيوم TiO_2. مع حجم حبيبي (20نانو متر) ويتم اختبار الموصلية الحرارية بشكل منفصل عند مزجه مع الماء في تراكيز مختلفة في المئة (0.05٪، 0.1 ٪، 0.3٪ و 0.5 ٪) نسبة وزنية، من أجل التحقق في آثارها على تعزيز نقل الحرارة من بركة الماء المغلي وتعزيز التوصيل الحراري للnanofluid.

في هذا العمل تم عرض النتائج التجريبية للتوصيل الحراري في الماء قبل وبعد إضافة الجسيمات متناهية الصغر. وعرض نتائج الدراسة النظرية للتوصيل الحراري لسوائل النانو مع جسيمات متناهية الصغر لAl_2O_3 وTiO_2، مع مقارنة النتائج للدراستين. وقد أظهرت النتائج الحصول على زيادة تحسن قدرها **1.5 - 1.8**٪ لسوائل TiO_2 وAl_2O_3 النانو على التوالي، عند إضافة كمية صغيرة من الجسيمات النانوية الى الماء النقي. وقد تمت دراسة آلية تستند إلى الحركة البراونية والتي هي السبب في حصول التحسن في الموصلية الحرارية.

الكلمات المرشدة: انتقال الحرارة،الغليان الحوضي التنوي، الموصلية الحرارية، الومينا، ثاني اوكسيد التيتانيوم ،الجسيمات المتناهية الصغر، سائل النانو، السائل كقاعدة .

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INTRODUCTION

The performance of any cooling or heating systems depends on some factors one of them is the heat transfer fluid which its heat transfer efficiency depends on its thermal properties (thermal conductivity (k) ,heat capacity (cp) ,viscosity (μ) and the thermal expansion coefficient and to improve these properties researchers work on this side by adding some materials to the base fluid and one of these material is the nonmaterial to be formed nanofluid by dispersing nanometer-sized particles (1-100 nm) or droplets into HTFs.

Heat transfer fluids (HTFs) have many industrial and civil applications, including in transport, energy supply, air-conditioning and electronic cooling, etc. Traditional HTFs, such as water, oils, glycols and fluorocarbons, however, have inherently poor performance due to their low thermal conductivities. Research and development activities are being carried out to improve the heat transport properties of fluids. Solid metallic materials, such as silver, copper and iron, and non-metallic materials, such as alumina, CuO, SiC and carbon nanotubes, have much higher thermal conductivities than HTFs. It is thus an innovative idea trying to enhance the thermal conductivity by adding solid particles into HTFs.[1]

Nanofluid

Nanofluids are a new class of nanotechnology-based heat-transfer fluids, engineered by dispersing and stably suspending nanoparticles (with dimensions on the order of (1-100 nm) in traditional heat-transfer fluids.

Nanofluids are prepared by suspending nano sized particles in conventional fluids and have higher thermal conductivity than the base fluids. [2]

Nanofluids have the following characteristics compared to the normal solid liquid suspensions:-

1. Higher heat transfer rate between the particles and fluids due to the high surface area of the particles
2. Better dispersion stability with predominant Brownian motion reduces particle clogging
3. Reduced pumping power as compared to base fluid to obtain equivalent heat transfer

These particles can be metallic (Cu, Au) or metal oxides (Al_2O_3,SiO_2, ZrO_2) carbon (Diamond, Nanotubes), glass or another material, and the base fluid being a typical heat-transfer fluid, such as water, light oils, ethylene glycol (radiator fluid) or a refrigerant. The base fluids alone have rather low thermal conductivities [3] Figure (1) shows photo of the various nanoparticles.

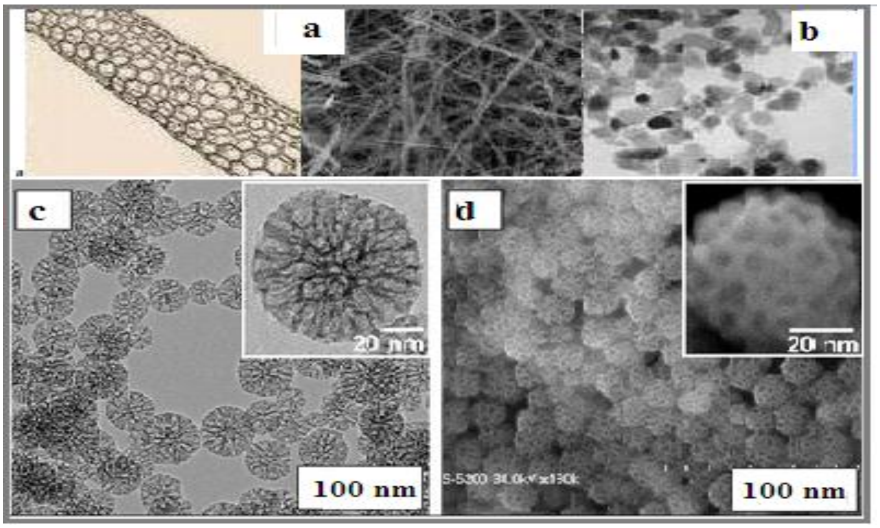


Figure (1) Photo of various nanoparticles: (a) Carbon nanotubes, (b)TiO_2 nanoparticles, (c) Silica nanoparticles in 80 nm (d) Silica nanoparticles in 45 nm. [4]

A Brief History of Nanofluids

Recent nanofluids (liquids) were first used by a group in Argonne National Laboratory USA [**5**] to describe liquid suspensions containing nanoparticles with thermal conductivities, on orders of magnitudes higher than the base liquids, and with sizes significantly smaller than 100 nm.

Li et al. [**6**] studied boiling of water-CuO nanofluids of different concentrations (0.05% and 0.2% by weight) on copper plate. They observed deterioration of heat transfer as compared to the base fluid and attributed this fact to the sedimentation of nanoparticles which leads to the changing of radius of cavity, contact angle, and superheat layer thickness.

You et al. [**7**] used nanoparticles materials with concentrations from (0.001) to (0.05 g/l),they studied nucleate boiling heat transfer coefficients for water-Al_2O_3 nanofluid while boiling on plate appeared to be the same as for base fluid at (0.001 g\l) but the change is very small at (0.05 g\l).

D. Wen and Y. Ding [**8**],have done an experimental investigation into the pool boiling heat transfer of aqueous based alumina nanofluids. Systematic experiments were carried out to formulate stable aqueous based nanofluids containing γ-alumina nanoparticles (primary particle size 10–50 nm), and to investigate their heat transfer behaviour under nucleate pool boiling conditions. The results show that alumina nanofluids can significantly enhance boiling heat transfer. The enhancement increases with increasing particle concentration and reaches ∼40% at a particle loading of 1.25% by weight.

Yang, B., and Han, Z. H.[**9**] "Thermal conductivity enhancement in water-in-FC72 nanoemulsion fluids" In this study, nanoemulsions of alcohol and polyalphaolefin (PAO) are spontaneously generated by self-assembly, and their thermal conductivity and viscosity are investigated experimentally. Alcohol and PAO have similar thermal conductivity values, so that the abnormal effects, such as particle Brownian motion, on thermal transport could be deducted in these alcohol/PAO nanoemulsion fluids. Both thermal conductivity and dynamic viscosity of the fluids are found to increase with alcohol droplet loading, as expected from classical theories. However, the measured conductivity increase is very moderate, e.g., a 2.3% increase for 9 vol%, in these fluids.

Theoretical Calculation of nanofluid Thermal Conductivity

There are several mechanisms proposed to explain the thermal conductivity enhancement of nanofluids, such as Brownian motion of nanoparticles, clustering of nanoparticles and liquid layering around nanoparticles.

The thermal conductivity was affected by factors such as temperature and particle size. one of theoretical models have been proposed to explain the behavior of nanoparticles. Static

models . These model assume that the nanoparticles are stationary in the base fluid .model is the modified Maxwell theory of Hamilton and Crosser which gives the enhancement of thermal conductivity as:-[10]

$$\mathrm{Knf} = \frac{\mathrm{Kp+2Kf-2(Kp-Kf)\phi}}{\mathrm{Kp+2Kf-(Kp-Kf)\phi}}\mathrm{Kf} \qquad \ldots(1)$$

where

K_{nf}, K_p and K_f are the thermal conductivity of the nanofluid, nanoparticles and base fluid, respectively.$\boldsymbol{\phi}$ is the volume fraction of particles in the mixture, the formula of volume fraction $\boldsymbol{\phi} = \boldsymbol{\nu}$ can be written as

$$\boldsymbol{\nu} = \frac{\mathrm{Vp}}{(\mathrm{Vp+Vf})} \qquad \ldots (2)$$

volume of the base fluid that used in the present experimental equal 1.5 L and various concentration of Al_2O_3 and TiO_2 nanoparticles with (0.05%,0.1%.0.3%,0.5%) that dispersed in distilled water , and thermal conductivity of the base fluid equal 0.61 using equation (1 and 2) to calculate Knf of Al_2O_3 = 0.96 at 0.34 volume feaction and Knf of TiO_2= 0.80 at the same volume fraction .

Predicted Thermal Conductivity of Nanofluid

The thermal properties of nanofluids are predicted through conduction based models such as Eapen et al.[11]

$$\frac{\mathrm{Keff}}{\mathrm{Kf}} = 1 + \frac{\alpha+(n-1)-(n-1)(1-\alpha)\nu}{\alpha+(n-1)+\nu(1-\alpha)} \qquad \ldots(3)$$

$$\alpha = \frac{Kp}{Kf} \qquad \ldots(4)$$

where

K_p of Al_2O_3 =40 .K_p of TiO_2 =32, and n is the empirical shape factor and given by

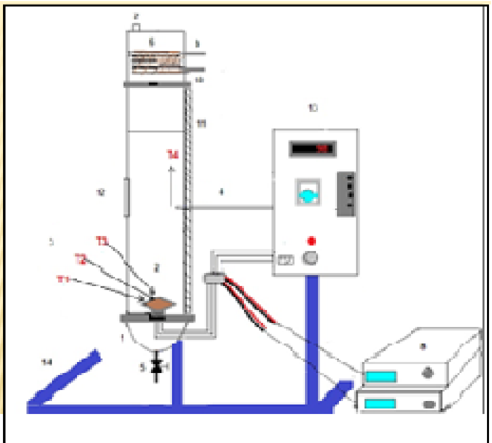
$$n = \frac{3}{\psi} \qquad \ldots (5)$$

where,

ψ is the sphericity, defined as the ratio of the surface area of sphere with volume equal to that of the particle to the surface area of the particle and n=3 and 6 for spheres and cylinders, respectively.[12]
from the spherical shape of Al_2O_3 particle, n=4 and from the semi spherical shape of TiO_2, n=5, by compensation the equations (4)and (5) in equation (3) , the K_{eff} of Al_2O_3 nanofluid equal 2.8 and K_{eff} of TiO_2 nanofluid equal 2.4 , at volume fraction as 0.34 .

Experimental Apparatus

A schematic diagram of the experimental apparatus is shown in figure (2) and a photograph of fig. (3). The experiments were carried out in saturated pool boiling of water under atmospheric pressure . There was a copper coil on top of the vessel to condense the vapor. A venting hole was drilled in the middle of the vessel lid to allow atmospheric operations. A glass window was designed on one side of the vessel for visual observations. The heating surface was submerged in fluid which was made of stainless steel grad 316.



1	Boiling vessel	9	Condenser water input
2	Heating element	10	Condenser water output
3	Thermocouples on heating surface element	11	Thermal Insulation
4	Thermocouples in the Bull	12	Observation Window
5	Discharge valve	13	Digital temperature reader
6	Condenser	14	Stand
7	Vent		
8	Voltmeter and Ammeter		

Figure (2) Schematic diagram of the experimental system

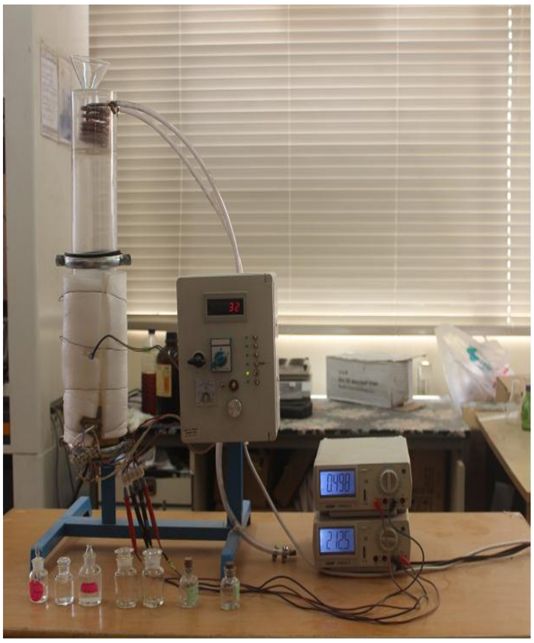


Figure (3) General view of the experimental system

To prepare the nanofluid, it is necessary to disperse the dry nanoparticles uniformly into the whole base fluid. Al_2O_3 and TiO_2 are used as nanoparticles, Alumina nanoparticles (Al_2O_3 alpha/gamma), of spherical form with diameter 50 nm and Titanium Oxide Nanopowder/ NanoparticlesTiO_2 (anatase / rutile), with diameter 20 nm. While distilled water was used as a base fluid. To prepare nanofluids, nanoparticles were dispersed in pure water. Different concentrations were used in the experiment. The amounts of nanoparticles required and base fluid are mixed together by magnetic stirrer for 4 hours and in ultrasonic path for 1 hour to ensure that there are no significant, agglomerated particles inside the boiling vessel.

Experimental work

1- Measuring the thermal conductivity of the base fluid (without nonmaterial's)

2- Measuring the thermal conductivity of the nanofluids after different concentrations of Al_2O_3 and TiO_2 nanoparticles are adding.

Characterization analysis of nanoparticles

Figures (4and 5) show the nanoparticles of Al_2O_3 and TiO_2 in the powder state, by SEM (scanning electron microscopy).The nanoparticles form loose agglomerates of micrometer size. As is well-known, nanoparticles have a strong tendency to agglomerate due to relatively strong van der Waals attraction between particles in dry and wet environments, and the result of particles agglomerate forms particle in micrometer size.

- Preparation the nanofluid as weight concentrations at (0.05, 0.1, 0.3, and 0.5) of Al_2O_3 and TiO_2 nanoparticles and the base fluid (distilled water). Figures (6 and 7) display photographs of the tested water-Al_2O_3 and water-TiO_2 nanofluids.
- For nanofluid must work several stepes:
- The nanoparticles and distilled water were mixed in a flask using a magnetic stirrer for 4 hours and then it is immersed in an ultrasonic bath for 1 hour to suspend nanoparticles in the base fluid and break down the agglomerates formed.

Figures(8 and 9) show Atomic Force Microscope images of – Al_2O_3 and TiO_2 nanofluids.

- SEM (Scanning Electron Microscope) was used too, after nanoparticles were dispersed in distilled water, to be sure it is well dispersed before nanofluids used in boiling experiment. Figures (10 and 11) show the A_{l2O3} and Ti_{O2} nanoparticles are very dispersed in base fluid (distilled water). And then nanofluid will be ready for use in the experiment.

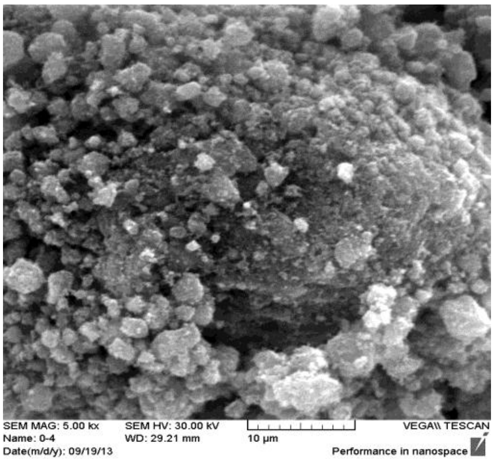


Figure (4) SEM image of Al_2O_3 powder powder state

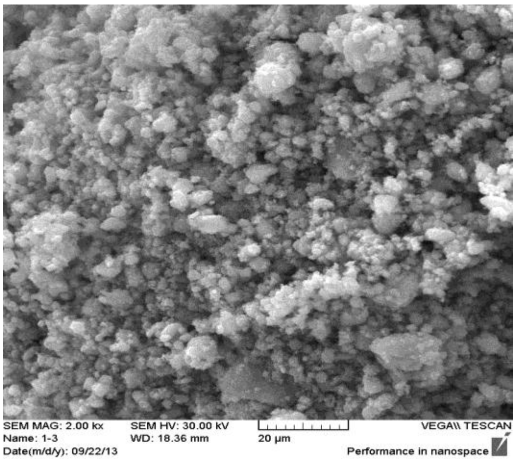


Figure (5) SEM image of TiO_2 powder state

Figure (6) Photographs of the water-Al_2O_3 nano fluid preparation

Figure (7) Photographs of the water TiO2 nanofluids preparation

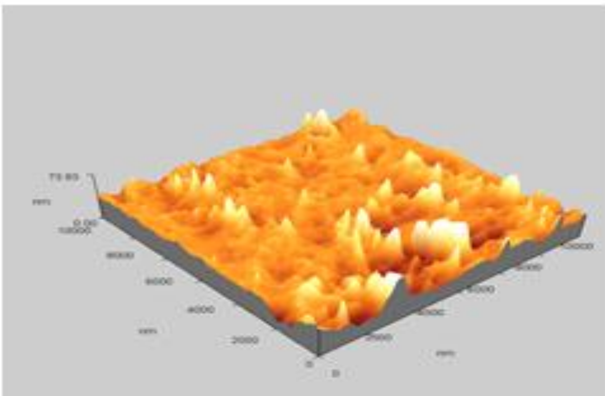


Figure (8) AFM of 0.5%Al_2O_3 nanoparticle in water (nanofluid).

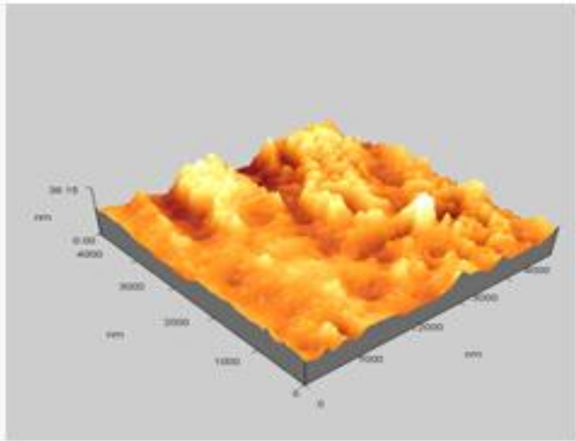


Figure (9) AFM of 0.5%TiO_2 nanoparticle in water (nanofluid).

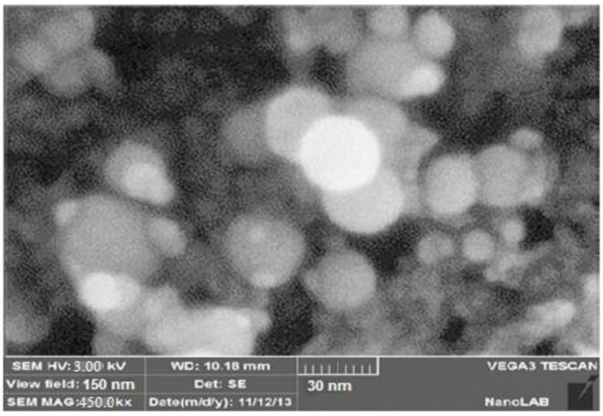


Figure (10) SEM image of Al_2O_3 nanoparticle dispersion in water

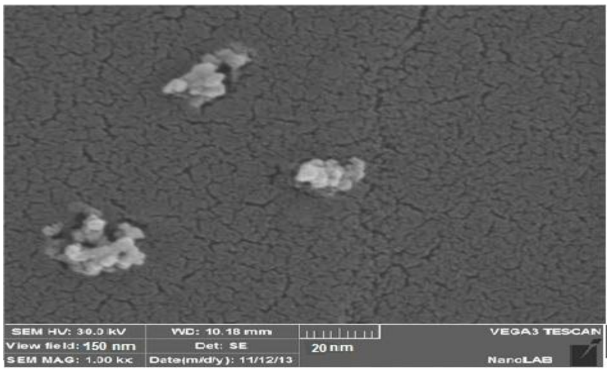


Figure (11) SEM image of TiO_2 nanoparticle dispersion in water

Results and Discussions

Effect of Nanoparticle Concentrations

Distilled water has thermal conductivity about 0.61W\m.K, this value change after added nanoparticles. When measuring the thermal conductivity of nanofluid ,as we not in the tables (1and 2) .The value of experimental thermal conductivity and data of theoretical calculation of nanofluids is increased, after it is added and these increase continue whene increase concentration from of Al_2O and TiO_2 nanoparticles, and found the enhancement increase linearly proportional to the volume fraction. The value of the thermal conductivity of Al_2O_3 and TiO_2 nanofluid approximately about 1.78 and 1.62 respectively, at 0.34 volume fraction, due to the thermal conductivity of these nanoparticles , these behavior show clearly in Figures (10 and 11) special scanning electron microscopy of samples were observed better dispersed nanoparticles, in base fluid ,and show in Figures (12 and 13) increase the volume fraction with increase nanoparticles concentration. the Brownian motion of nanoparticles may be one of the main reasons responsible for the increase of nanofluid thermal conductivity. When a particle immersed in a fluid, it moves randomly due to the interaction between the particle and its surrounding fluid molecules due to increase in thermal conductivity of nanofluid and the large surface area of their nanoparticles gives large area of heat transport, the large surface area of nanoparticles per unit volume allows for more heat transfer between solids particles and base fluids. These result agreement with result of Wei, Y., and Huaqing, X.[13]

Comparsion between Expermintal and Predicted Data

A more traditional plot of experimental thermal conductivity against thermal conductivity predict, is shown in Figures (14and 15),were plot together with the prediction by the Eapen et al. model [11].

Comparisons between the experimental data and the Eapen et al.model show that the correlation can potentially predict the performance with an appropriate volume fraction factor,Kp(thermal conductivity of particles),Kf(thermal conductivity of fluid) and empirical shape factor of nanoparticles .

These figures show the pure water results match the traditional Eapen et al. model, and show the significant enhancement in thermal conductivity, with increased volume fraction .

Optimum Nanofluids for Thermal Conductivity

When the two nanofluids of $Al_2O_3$and TiO_2-water having highly thermal conductivity ,the markedly different behavior of thermal conductivity performance for $Al_2O_3$and TiO_2 nanofluid can be seen from figures (16 and 17) which give a typical enhancement plot quantifying the extent of thermal conductivity of two nanofluids that used.

These figures show a maximum enhancement is (1.8%) for 0.34 % volume fraction of Al_2O_3 nanofluid while the enhancement ratio is (1.5 %) for TiO_2 at the same volume fraction, and in both nanofluids,The enhancement ratio increases with increased nanoparticles concentration. .

Although Al_2O_3 and TiO_2 have the same properties, in terms of the smaller particle size, the greater the surface area, the better the particle activity and phase stability. The reasons for Al_2O_3 nanoparticle gave more enhancement than TiO_2 nanoparticle, are: ultrafine Al_2O_3 high hardness, easy dispersion and strong permeability in distillated water which results in stable form so that the dispersion is in the form of solid balls free movement while the titanium oxide nanoparticle dispersion in water is in the thin film.

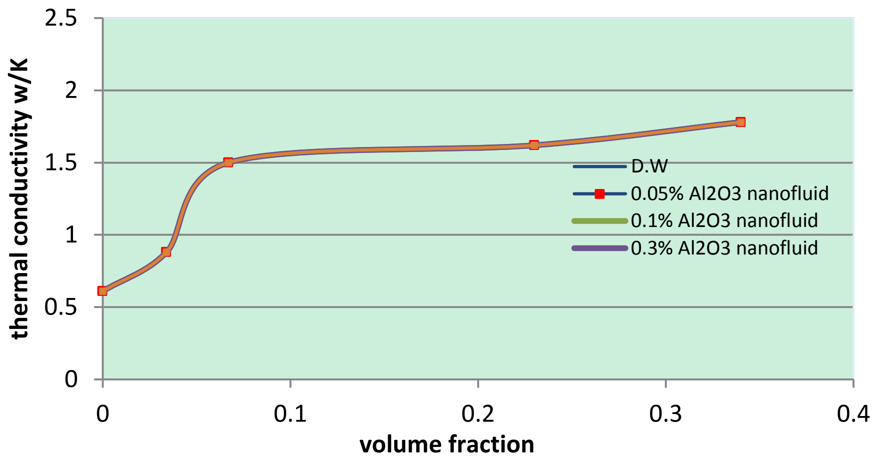


Figure (12) Thermal conductivity enhancement of Al_2O_3 nano fluid with variation Volume fraction at different concentrations

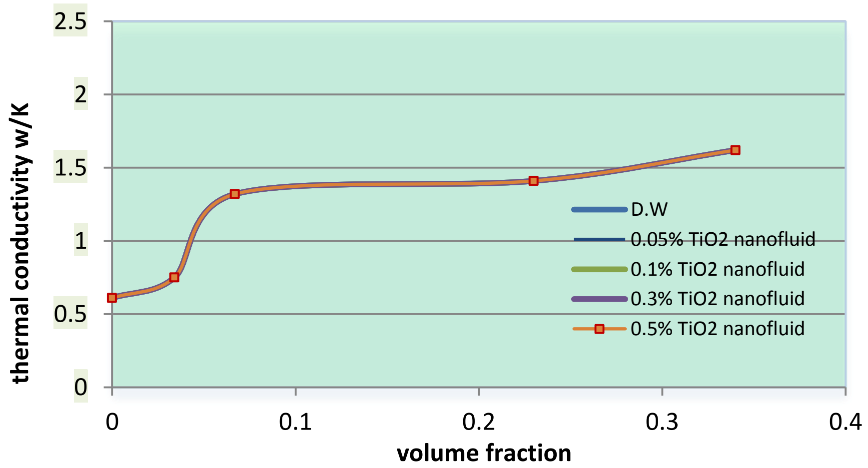


Figure (13) Thermal conductivity enhancement of TiO_2 nanofluid with variation Volume fraction at different concentrations

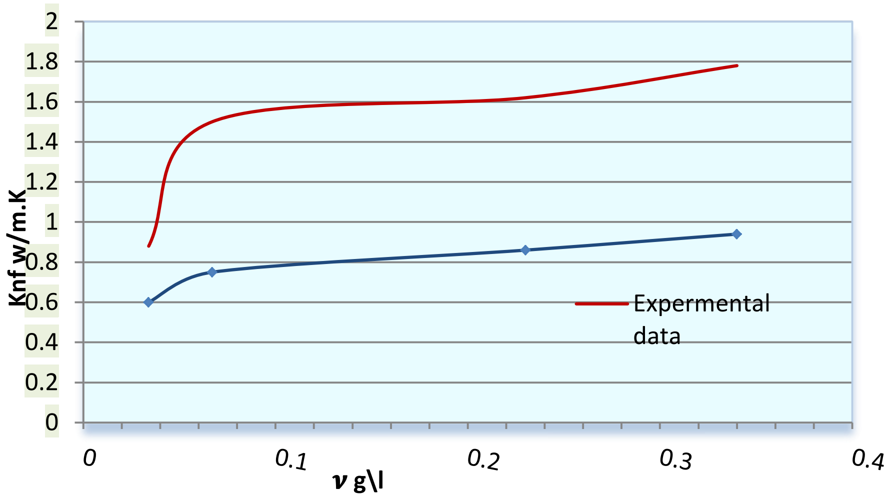


Figure (14) Comparison Thermal conductivity values of the Maxwell model with experimental data of Al_2O_3 nanofluid

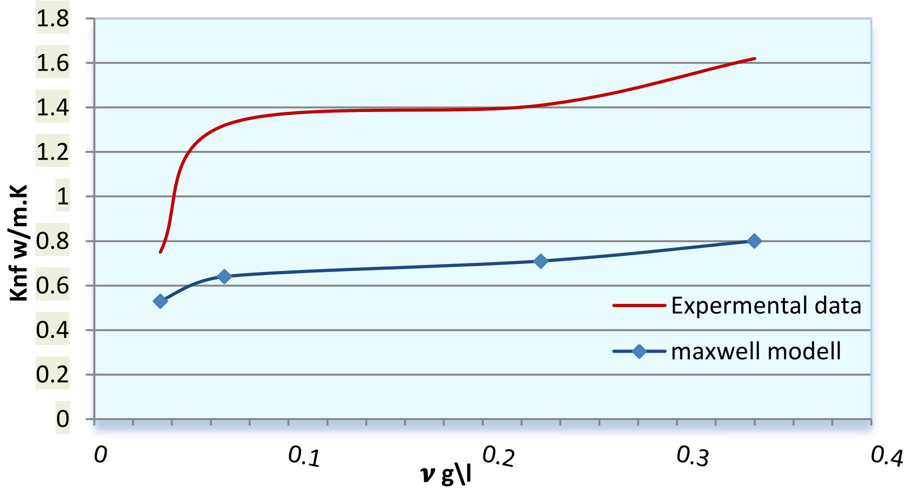


Figure (15) Comparison Thermal conductivity values of the Maxwell model with experimental data of TiO_2 nanofluid

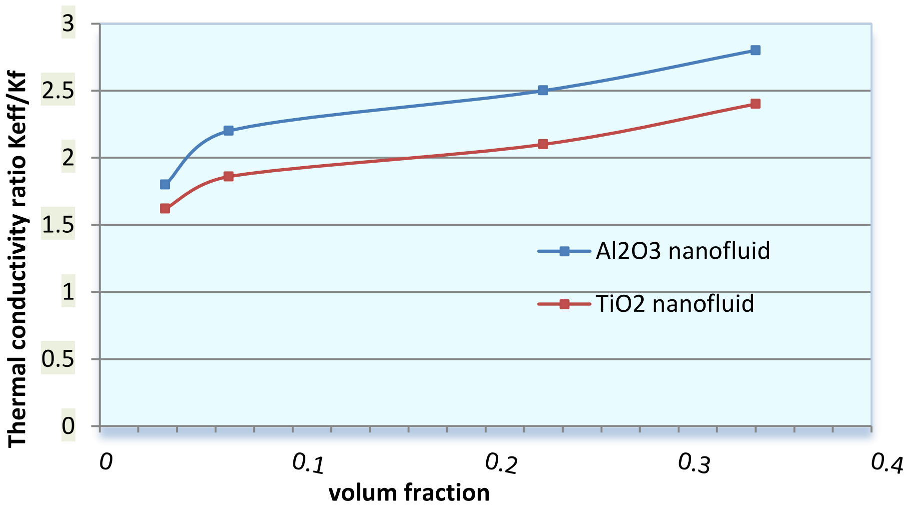


Figure (16) Comparison of the effective thermal conductivity for Al_2O_3 and TiO_2 nanofluids with respect to volume fraction.

Table (1) Value of thermal conductivity (K=w\m.K) enhancement of Al_2O_3 nanofluid.

Particle volume fraction	Base fluid	K of pure water	K_{NF} experimental	K_{NF} Theoretically	K_{NF} effective
0.034	Water	0.61	0.88	0.6	1.8
0.067			1.5	0.75	2.2
0.23			1.62	0.86	2.5
0.34			1.78	0.94	2.8

Table (2) Value of thermal conductivity (K=w\m.K) enhancement of Ti O_2 nanofluid.

Particle volume fraction	Base fluid	K of pure water	K_{NF} experimental	K_{NF} Theoretically	K_{NF} effective
0.034	Water	0.61	0.75	0.53	1.62
0.067			1.32	0.64	1.86
0.23			1.41	0.71	2.1
0.34			1.62	0.8	2.4

Conclusions

1. The value of thermal conductivity dramatically increases, with presence of nanoparticles, higher thermal conductivity is reported compared to pure water.
2. Thermal conductivity increasing with increasing particle volume fraction.
3. To get better value of thermal conductivity for nanofluid must be dispersing nanoparticles very well in base fluid.
4. Effective thermal conductivity depends not only the volume fraction and shape but also on the thermal conductivity of the particles and base fluid.
5. The best value of thermal conductivity of nanofluids is generally, when using Al_2O_3 nanofluid, compared to that of TiO_2 nanofluid and pure water.

Nomenclatures

A	area, m^2
C	concentration [v/v]
I	current, A
K	Thermal conductivity, w\m.k
q	Heat amount, W
q"	Heat flux W/m^2
T	Temperature, K
V	Voltage, V
ΔT_{sa}	Wall superheat or temperature difference $[T_s - T_{sat}]$ K

Subscripts

b	bulk
l	liquid
S	Surface temperature
v	vapor

Abbreviation

HTFs	Heat Transfer Fluids
	nm nanometer
	Nf Nanofluid
	CHF Critical Heat Flux

Greek symbols

ν	Kinematic viscosity m^2/s
μ	Dynamic viscosity g/m.s
ρ	Density kg/m^3

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