Numerical Study of Heat Transfer Performance of Nanofluids

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ABSTRACT

In this review paper , the effects of different parameters such as nanoparticle volume concentration , nanoparticle size , Reynolds number , temperature and tube flatting with nanofluids are discussed in detail. Numerical results show that the addition of nanoparticle enhances the heat transfer and pressure loss of base fluid in all of the flat tubes at various Reynolds number and temperature .Both the relative average convective heat transfer coefficient and press drop can be enhanced by increasing nanoparticle volume concentration and decreasing nanoparticle size .

Keywords : Nanofluids , Heat transfer , Numerical

1. INTRODUCTION

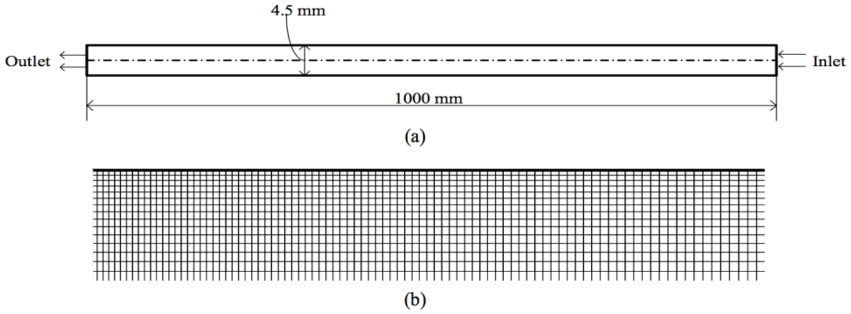
Fluids are essential for heat transfer in many engineering equipments . Although various techniques are applied to enhance the heat transfer , the low heat transfer performance of these conventional fluids obstructs the performance enhancement and the compactness of heat exchangers. The use of solid particles as an additive suspended into the base fluid is a technique for the heat transfer enhancement . The enhancement of thermal conductivity of conventional fluids by the suspension of solid particles, such as millimeter or micrometer sized particles , has been well known for more than 100 years . However , they have not been of interest for practical applications due to problems such as sedimentation , erosion , fouling and increased pressure drop of the flow channel .The recent advance in materials technology has made it possible to produce nanometer sizes particles that can overcome these problems. Innovative heat transfer fluids suspended by nanometer sized solid particles are called 'nanofluids' .These suspended nanoparticles can change the transport and thermal properties of the base fluid.

Study on forced convective heat transfer of non-newtonian nanofluids

Yurong et al. (2009) have reported a manuscript in field of heat transfer of nanofluids. This study mostly focused on forced convective heat transfer in non-newtonianfluids in laminar condition. The methodologies were both experimental and mathematical modelling. In the mathematical modelling, continuous single phase was supposed to fluids. The nanofluids were made by Titanate nanotubes as TNT/H_2O and Carbon nanotubes as CNT/H_2O by ultrasonic methods. The fluid was categorized based in particle size and the result for both newtonian and non-newtonian fluid was studied. Finally, the result shows that the heat transfer characteristic of nanofluids increase for both of fluids type, especially the non-newtonian one.

Dry TNT (Titanate nanotubes) nanoparticles and CNT (carbon nanotubes) nanoparticles were separately used to prepare nanofluids with distilled water . CNT have a hydrophobic surface , which is prone to aggregation and precipitation in water in the absence of a dispersant/surfactant . After many trials and error tests , sodium laurate (SL) , sodium dodecyl benzene sulfonate (SDBS) and gum Arabic (GA) were found to be able to stabilise carbon nanotubes for more than a month without visually observable sedimentation.

The geometrical configuration in this work was a tube which was 1000 mm long and 4.5 mm diameter and the other setup is 1834 mm long with a diameter of 4.0 mm as has been shown in Figure (1). In simulation configuration, there were 15 meshes in the radial direction with a size ratio of 1.1 from the center to the wall and also there were 800 meshes in the axial direction. In addition, in modelling, the single phase fluid was used to estimate the physical properties including thermal conductivity and viscosity. Finally, the uniform axial velocity and inlet temperature were specified as boundary condition. The simulation was done in Fluent®6.2 software. [1]

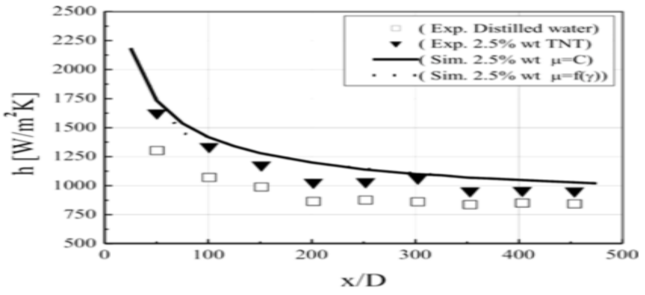


(a)

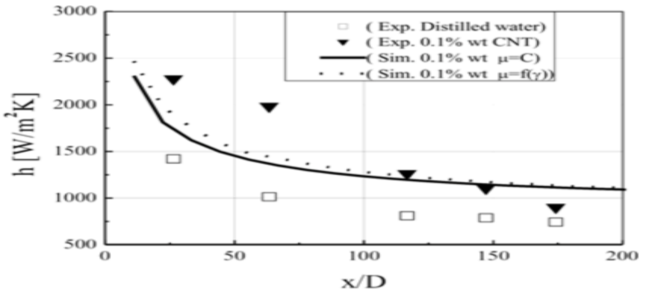
(b)

Figure 1: Schematic representation of the system for Case (a):numerical domain , (b) mesh

After initial test with pure water, an axial and radial velocity profile simulated. However, more attention attracted by thermal profile and axial profiles of the convective heat transfer coefficient. The temperature distribution of nanofluids has shown that for both nanofluids, the temperature increases gradually along both the radial direction from tube center to the wall and along the axial direction of the tube. However, the heat transfer coefficient increases from TNT/H_2O to CNT/H_2O as Figure (2). The result shows that the non-newtonian fluid presents bigger heat transfer coefficient from TNT/H_2O to CNT/H_2O. Also, The flow of nanofluids as a non-Newtonian fluid helps to explain the enhancement of nanofluids convective heat transfer to some degree.



(a) TNT/H_2O nanofluid (Case I)



(b) CNT/H_2O nanofluid (Case II)

Figure 2: The heat transfer coefficient for TNT and CNT nano fluid

Numerical study of forced convective heat transfer of Nanofluids: Comparison of different approaches

Lotfi et al. (2010) research aim’s to numerically study the forced convective heat transfer of nanofluids consists of Al2O3 nanoparticles in horizontal tubes. In this way, they introduced two-phase Eulerian model for the first time to study such a nanoflow field. Moreover, a single-phase model and two-phase mixture model were implemented to comparison. The result would be compared with single-phase model and two-phase mixture model formulations. Also, to gain more comparison the result of Dittus and Boelter model and also Gnielinski have calculated against the present work. The result shown that the mixture model is more precise although single-phase model and the two-phase Eulerian model underestimates the Nusselt number.

The result as has been shown in Figure (3) displays comparison of Nusselt numbers from the this numerical analysis for forced convection flow with the equations given by Dittus–Boelter and Gnielinski formulas. These data agree with the results published by Namburu. Finally, the result shows that the rate of thermal enhancement decreases with the increase of nanoparticles volume concentration and the mixture model is more precise than the other two models to explain this. [2]

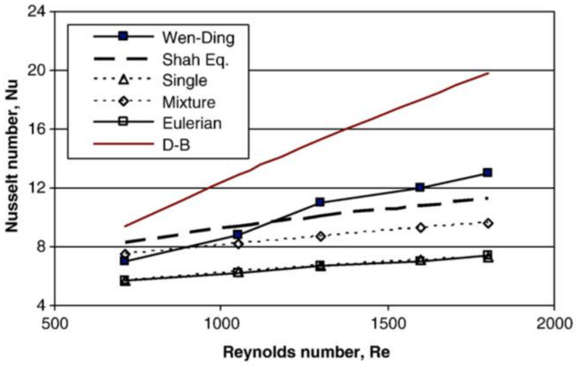


Figure 3: Dependence of Nusselt number on Reynolds number at Position P1 (x/D=63)

Forced convective heat transfer of nanofluids in microchannels

Jung et al. (2009) studied the forced convective heat transfer and friction factor of nanofluids in a microchannels profile. In this research, a microchannels with two localized heaters and five polysilicon temperature sensors were used to geometrical configuration in laminar regime. The material was Aluminum dioxide (Al_2O_3) with diameter of 170 nm as nanoparticles in water. The result showed that the convective heat transfer coefficient of nanofluids increases up to 32% compared to water at a volume fraction of 1.8. Moreover, The Nusselt number increases with Reynolds in laminar flow which turned out to be less than 0.5.

After test the heat transfer coefficient of micro tube in various Reynolds number from 5 to 300 in some cases, the change of heat transfer coefficient by Reynolds number were plotted as Figure (4-5)or various nanofluid concentrations and different microchannels.A this Figure shows, The result shows that the heat transfer coefficients of all nanofluids are greater than those of their base fluids i.e. pure water. In relatively small microchannel (with 50×50 lm^2), the heat transfer coefficients of both nanofluids and pure water at low Reynolds numbers are comparable to or higher than those obtained at high Reynolds number in relatively large microchannels. In all channels, the heat transfer coefficient increases by Raynolds number. However, the highest one is small microchanells with Reynolds number 100 in 1.8 concentration of nanofluids. Also, increasing nanofluid concentration results in more heat transfer coefficient.[3]

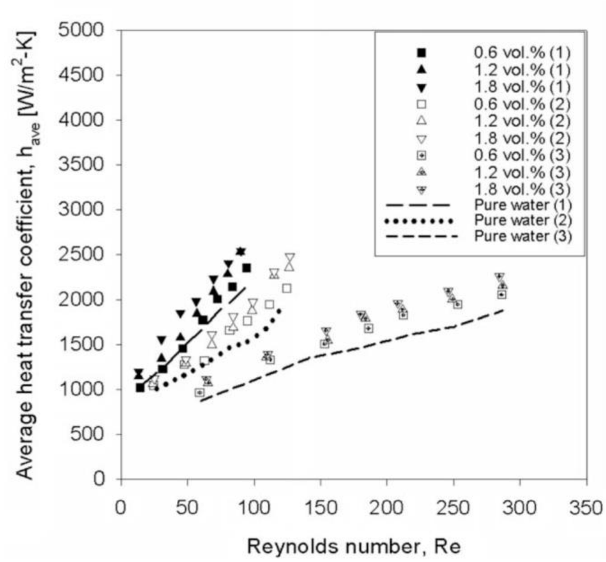


Figure4. Heat transfer coefficient versus Reynolds Number

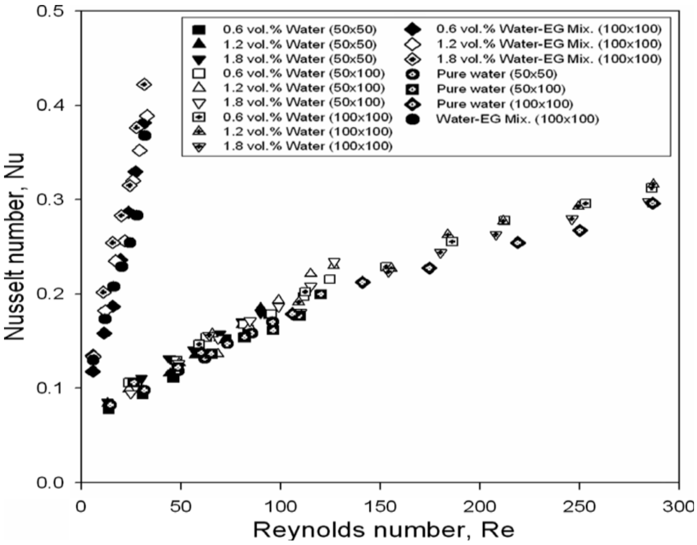


Figure 5: Dependence of Nusselt number on Reynolds number in different dimensions of microchannels of 50×50 μm^2 .50 ×100 μm^2 and 100×100 μm^2 for the water-based and the water and and ethylene glycol-based nanofluids as noted by mix.

Numerical investigations of laminar heat transfer and flow performance of Al_2O_3- water nanofluids in a flat tube

Zhao et al. (2016) studied the laminar heat transfer and flow performance of Al_2O_3 nanofluids in a flat tube numerically in three-dimension. To achieve this goal, a new model was developed for thermal conductivity and viscosity of nanofluids. In this research, the effects of parameters such as nanoparticle concentration, nanoparticle size, Reynolds number, temperature and tube flattening on the heat transfer performance are discussed in detail. The result showed that the heat transfer is enhanced by adding of nanoparticle. It is bolded when at smaller Reynolds number and higher temperature because of irreversibility. Moreover, nanoparticle concentration has a slight effect on the heat transfer performance between flat tubes and circular tube. [4]

The single-phase based numerical results show that Al_2O_3-water nanofluids have higher heat transfer coefficient and pressure drop than base fluid . Both the relative average convective heat transfer coefficient $\overline{h}_{nf}/\overline{h}_{bf}$ and press drop $\Delta P_{nf}/\Delta P_{bf}$ can be enhanced by increasing nanoparticle volume concentration and decreasing nanoparticle size . The heat transfer and press drop enhancements of nanofluids are more obvious at smaller Reynolds number and higher temperature .

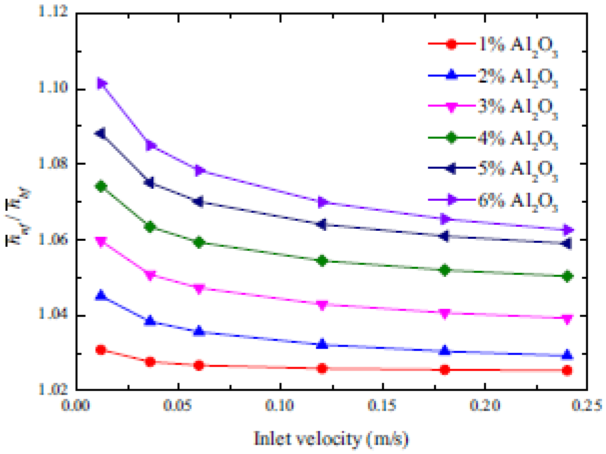


Figure 6. Variations of h_{nf}/h_{bf} with liquid inlet velocity for different nanoparticle volume concentration at T_{in} =293K and d_p=40nm.

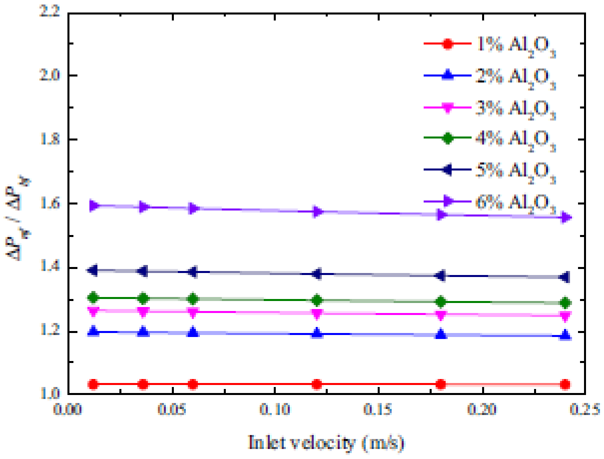


Figure 7. Variations of $\Delta P_{nf}/\Delta P_{bf}$ with liquid inlet velocity for different nanoparticle volume concentration at T_{in} =293K and d_p=40nm.

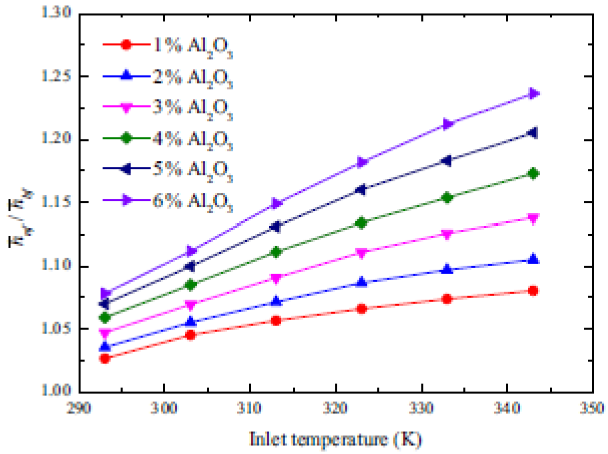


Figure 8. Variations of h_{nf}/h_{bf} with liquid inlet temperature for different nanoparticle volume concentration at V_{in} =0.06 m/s and d_p=40nm.

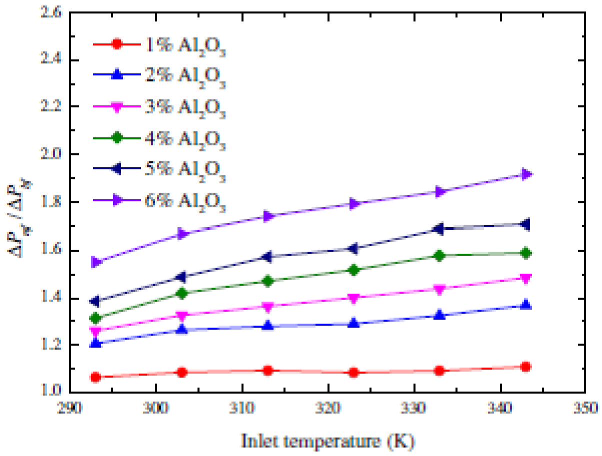


Figure 9.Variations of $\Delta P_{nf}/\Delta P_{bf}$ with liquid inlet temperature for different nanoparticle volume concentration at V_{in} =0.06 m/s and d_p=40nm.

Numerical Resizing Study of Al2O3 and CuO Nanofluids in the Flat Tubes of a Radiator

Elsebay et al. (2016) investigated resizing of Al2O3 and CuO nanofluids in the flat coolant tubes of an automobile radiator numerically to evaluate both thermal and flow performance. Therefore, various volume fraction of 1, 3, 5 and 7% of nanoparticles are studied at Reynolds number ranges from 250 to 1750. The validity of result was tested by data from the pervious literature and the well-known correlation. The result shows a significant reduction of the radiator volume and also there is a need to pumping power over increasing heat transfer performance. The result is plotted in Figure to express the effect of Al2O3 and CuO volume concentration on the predicted average heat transfer coefficient at different Reynolds numbers. From the figure, it is clear that the average heat transfer coefficient increased with both nanofluids concentration and Reynolds number. Also, the highest the average heat transfer coefficient was belong Al_2O_3 nanofluid with 3200 unit in Re=1800 and 0.07 concentration in comparison CuOnanofluid with 3000 unit in same condition. This is confirm that Al_2O_3 nanofluid could able introduce batter performance in comparison CuO in sample conditions. It is concluded that the heat transfer coefficient could reached 45 and 38% for Al_2O_3 and CuO, respectively.[5]

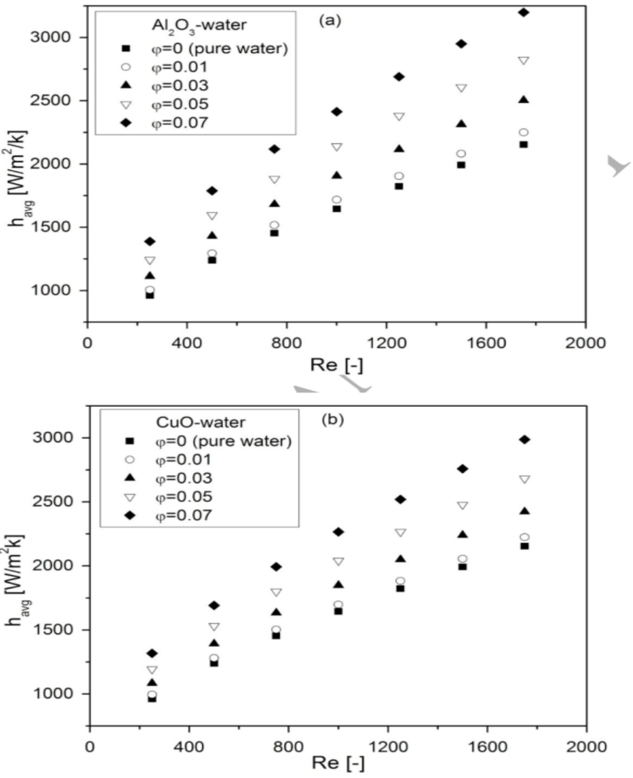
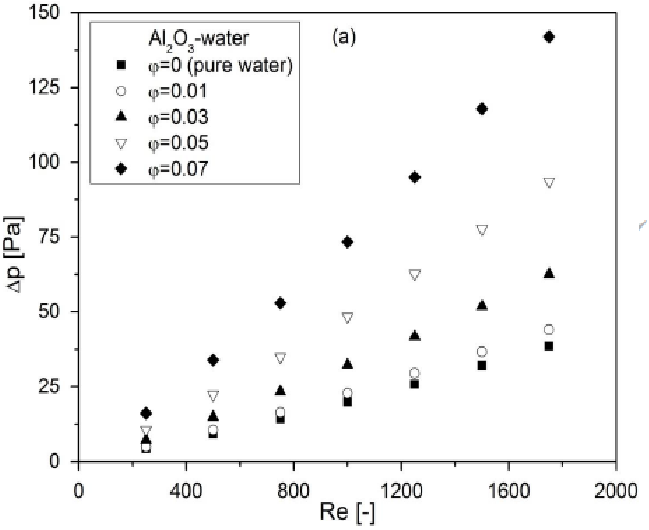


Figure 10. Variations of the average heat transfer coefficient with reynolds number for different nanoparticles volume concentrations of (a) Al$_2$O$_3$ (b) CuO



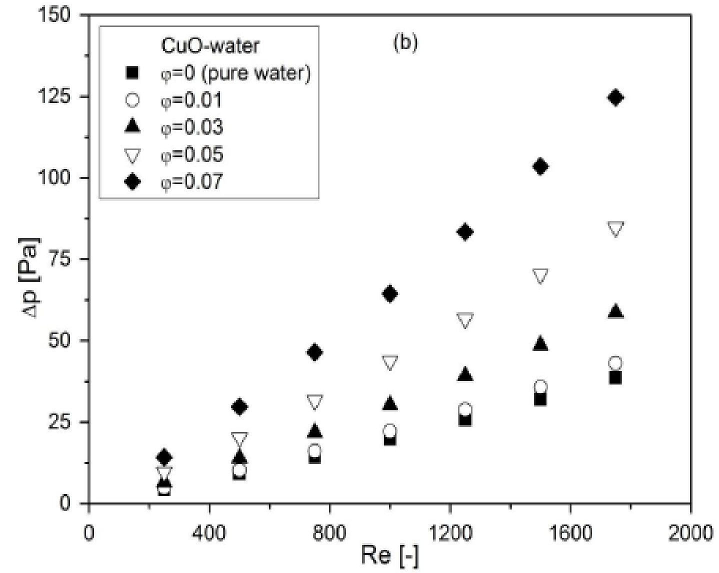


Figure11. Variations of pressure drop with Reynolds number at different nanoparticles volume concentrations of (a) Al_2O_3 (b) CuO.

Numerical simulation and sensitivity analysis of effective parameters on heat transfer and homogeneity of Al2O3 nanofluid in a channel using DPM and RSM

Shirvan et al. (2016) have done a 2-D numerical simulation heat transfer and homogeneity of Al_2O_3 nanofluid in a channel using DPM and RSM and finite volume method (FVM). In this research a sensitivity analysis of convective heat transfer is also done using the Discrete Phase Model (DPM) along with determination of the nanoparticles concentration distribution. Three parameters were included the Reynolds number from 250 to 650, nanoparticles volume fraction from 0.01 to 0.05, and nanoparticles diameter 40 nm to 100 nm. Moreover, the Response Surface Methodology (RSM) was used to study the effective parameters analysis. Finally the result showed that the Nusselt number increases with Reynolds number and nanoparticles volume fraction and decreases withnanoparticlesdiameter. In addition, it is found that the sensitivity of the mean total Nusselt number is more than nanoparticles concentration ratio to Reynolds number, nanoparticles volume fraction and nanoparticles diameter parameters. he top and bottom walls of the channel are assumed to be adiabatic except for a part of the bottom wall which is under a niform heat flux q'' . [6]

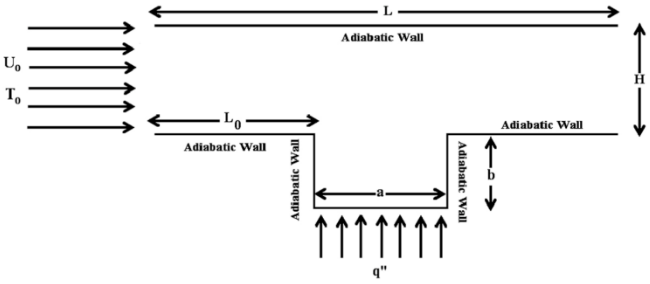


Figure 12. The Schematic of the channel.

Numerical simulations have been carried out to study the effects of the three parameters , the Reynolds number , nanoparticles volume fraction and the nanoparticles diameter , on the heat transfer performance and nanoparticles distribution inside the channel . The mean total Nusselt number and the nanofluid homogeneity have been calculated and the residual diagrams have been obtained in order to define the optimum conditions for a better heat transfer and nanofluid homogeneity . Finally , using the sensitivity analysis , the effects of the above mentioned effective parameters on the mentioned functions have been studied. The obtained results of the numerical study have been summerized as the following :

The sensitivity analysis for Nu$_{mt}$.

Re	*Φ*	*d*	Sensitivity		
			$\frac{\partial Nu_{mt}}{\partial Re}$	$\frac{\partial Nu_{mt}}{\partial \phi}$	$\frac{\partial Nu_{mt}}{\partial dp}$
−1	−1	−1	15.45	17.97	−7.63
0	−1	−1	15.45	26.31	−12.79
+1	−1	−1	15.45	36.65	−17.95

The sensitivity analysis for C.

Re	*Φ*	*d*	Sensitivity		
			$\frac{\partial C}{\partial Re}$	$\frac{\partial C}{\partial \phi}$	$\frac{\partial C}{\partial dp}$
−1	−1	−1	−3.5383	0.1266	0.1572
0	−1	−1	−1.1473	0.0444	0.2502
+1	−1	−1	1.2437	−0.0387	0.3432

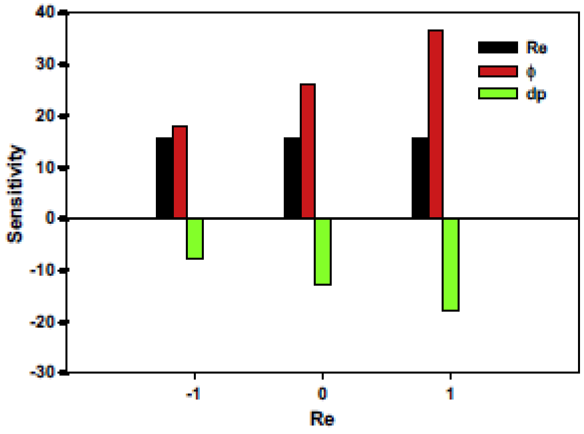


Figure13.The sensivity analysis results of the Nu$_{mt}$ (Ø and dp in level -1) .

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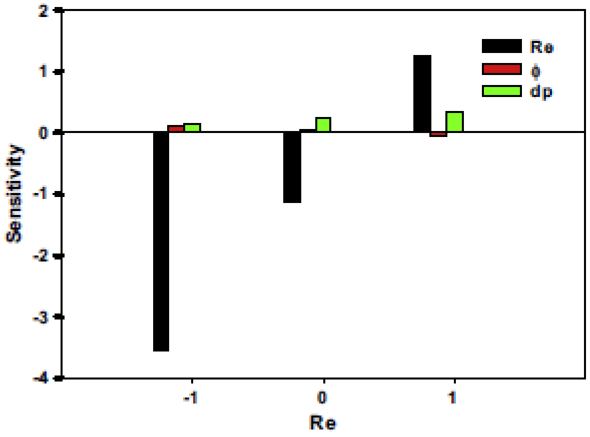


Figure14.The sensivity analysis results of the C (Ø and dp in level -1) .

Numerical study of heat transfer performance of nanofluids in a heat exchanger

Garoosi et al. (2016) have done a numerical study of natural convection heat transfer performance of nanofluids in a heat exchanger. The geometrical configuration was some tubes with constant temperature conditions are given for hot (T_h) and cold (T_c) pipes. Moreover, the parameters were Rayleigh number, temperature of the nanofluid, diameter and type of the nanoparticles. Also, some design parameters including internal and external cooling and heating on the flow field, temperature distributions and the heat transfer rate were studied. The result indicated that the Nusselt number increases with the nanoparticle volume fraction. Although, heat transfer rate increases with average temperature of the nanofluid.

The geometry of the present problem is shown in Fig 15. it consists of a two-dimensional heat exchanger with two curved walls and multiple hot and cold pipes inside. Walls of the enclosure are thermally insulated while hot (T_h) and cold (T_c) pipes are kept at different and constant temperatures ($T_h \rangle\ T_c$) . The shape of the hot and cold pipes is elliptic with dimensionless minor and major axes of R_1 and R_2 , respectively (see Fig 15)In addition, there are three different nanoparticles including Al_2O_3, CuO, and TiO_2. The condition was assumed laminar and steady with incompressible nanofluid with concentration of nanoparticles lower than the 0.05. The thermo-physical properties of the base-fluid and nanoparticles are assumed to be constant except for the density variation, which is approximated by the Boussinesq model. as it has been shown in Figure (16)the result showed that there is an optimum volume fraction of nanoparticles where the heat transfer rate within the enclosure has a maximum value. Also, the heat transfer increases by decreasing the size of the nanoparticles. Cu nanoparticle has reflect higher the Nusselt number and then were Al_2O_3 and TiO_2, respectively. But most important thing was that the Nusselt number severely increased by Rayleigh number.[7]

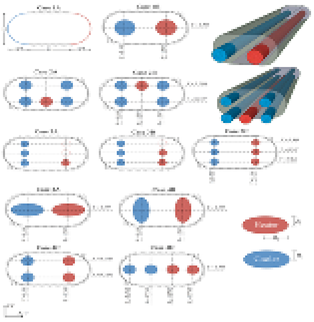
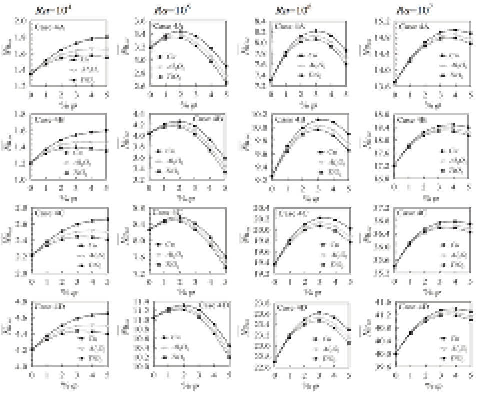


Figure 15. Schematic of the problem (heat exchanger) and the coordinate system . Location of the hot and cold pipes for each case is shown by dashed line.



- **Figure 16. the he effects of the volume fraction and type of nanoparticles on total Nusselt number at different Ra for case 4A to 4D. (● Cu , ∇Al_2O_3 , ■ $T_I O_2$) . d_p =25nm . T_{av} =309 K.**

Investigating performance improvement of solar collectors by using nanofluids

This paper presents an overview of recent studies in the performance of solar collector , especially direct solar absorption collector by using nanofluid as the working fluid .Despite the great effect of nanoparticles on changing optical properties of fluid, nanofluids have little considerable effect on performance of typical (non-direct) solar collector due to changing the optical properties of basefluid such as transmittance and extinction coefficient ; but there is significant effect on optical properties of direct absorb solar collector .

According to the literatures , water is the best absorber in direct absorption solar collector due to its strong solar absorption , but it is not high enough (only 13% of the incoming energy) .suspension nanoparticles can improve the optical properties of basefluid, which are dependent on particle size , particle shape , the optical properties of the particles and basefluid. Extinction coefficient is a function of the particle diameter and wavelength of the light. Nanofluid with small diameter suspended nanoparticle has higher extinction coefficient compared with conventional basefluid therefore has more capability to absorb the energy from incident light in a solar collector .

Particle concentration , temperature , size , dispersion , and stability are the most effective parameters to increase the thermal conductivity of nanofluid . Thermal conductivity of metallic nanofluid is more than non-metallic nanofluid, while metalic nanofluids are less absorptive .The effect of surface to volume ration in thermal conductivity is more than surface size of nanoparticles.The most important way to decrease the speed of nanoparticle sedimentation is to decrease the size of nanoparticle.[8]

The use of nanofluids for enhancing the thermal performance of stationary solar collectors : A review

Nanofluid , an advanced type of fluid containing small quantity of nanoparticles (usually less than 100 nm) , has been proven to provide more efficient heat transfer compared to conventional fluids , The dispersion of a small amount of solid nanoparticles in conventional fluids such as water or ethylene glycol changes their thermal conductivity remarkably .Recently , nanofluid has been used as a heat transfer fluid to enhance the performance of solar collector devices.

Solar energy collectors are mediums , generally designed to collect and absorb solar radiation .The absorbed solar radiation is converted into heat by these collector devices which is eventually transferred to the working fluid of a system , usually water or air . Basically , there are two types of solar collector : stationary and sun tracking or concentrating solar collector .

Flat plate solar collector (FPSC) , direct absorption solar collector (DASC) and evacuated tube solar collector (ETSC) are the most common and widely use stationary solar collectors .[9]

a. Flat-plate solar collector (FPSC) using nanofluids

Flat-plate slar collectors have been in service for the last 30 years , without significant changes in their design and operating principles .In addition , flat plate solar collectors are the most production solar heater , but have relatively low thermal efficiency and outlet temperatures .However , since their installation/production is less complicated and their suitability to collect low temperature solar thermal energy , this type of solar collector remains one of the chosen system for homes and industrials applications.

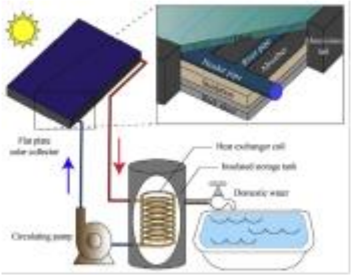


Fig 17. Flat plate solar collector

b.Evacuated Solar collector (ETSC) using nanofluids

Solar collectors with evacuated tubes have many advantages compared to flat-plate collectors. In this model , The evacuated U-tube solar collector , as shown in Fig , is a novel model for solar thermal system. Based on this novel method , revealed that the annual CO_2 and SO_2 emission could be reduced by 600 kg and 5.3 kg respectively , when 50 of this type of solar collector were employed.

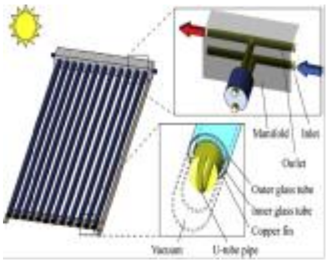


Fig 18 . Evacuated U-tube solar collector

C.Direct absorption solar collector (DASC) using nanofluids

In this system , Solar irradiance is first absorbed at the outer surface of a plate or tube and then transferred to a working fluid through conduction and convection heat transfer .Conductance and convection resistance between the absorbing surface and working fluid result in large heat loss and result in an inefficient system .

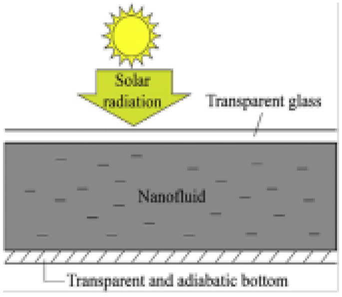


Fig 19. direct absorption solar collector (Dasc) .

Heat Transfer augmentation in a tube using nanofluids under constant heat flux boundary condition : A review

This paper presents a comprehensive review on forced convection heat transfer characteristics by using different nanoparticles (metals and their oxides) based upon the numerical and experimental investigations with constant heat flux boundary condition . Most of the studies show an enhancement in the heat transfer coefficient and pressure drop when compared with the base fluids . It is also observed that the heat transfer coefficient and the nusselt number increases significantly with the increase in concentration of the nanoparticles and as well as the Reynolds number . Further using nanofluid of high concentration cannot always suit best for the experiments.Thus , it is recommended that the nanofluids used in different volume fractions and concentrations must be checked to find appropriate volume fractions , Because use of nanofluids above a certain limit may impose difficulties such as agglomeration and hence rate of heat transfer enhancement may decreases Hybrid nanofluids are a comparatively new class of nanofluids which have drawn attention to various researchers .[10]

Conclusions :

Nanofluid , an advanced type of fluid containing small quantity of nanoparticles (usually less than 100 nm) , has been proven to provide more efficient heat transfer compared to conventional fluids. The following conclusions are made :

- Thermal conductivity increased with increasing temperature and volume concentraton.
- The thermal conductivity of nanofluids is sort of thermal dependent parameter , especially for CNT/H_2O nanofluid.
- Addition of nanoparticles into the base liquid enhances the thermal conduction especially in the entrance region of the tube.
- The convective heat transfer coefficient and the Nusselt number of nanofluids increase with the Reynolds number and the volume fraction of nanoparticles under turbulent flow.
- Compared with the circular tube , flat tube has a higher surface-to-cross-sectional flow area ratio , which can be used to enhance the heat transfer rate and increase the compactness of heat exchange devices.
- By increasing the Rayleigh number , avarage temperature of the nanofluid and thermal conductivity of the nanoparticles , the heat transfer rate and optimal particle loading (Φ_{opt}) enhances.
- By decreasing the size of the nanoparticles , the heat transfer rate and optimal particle loading (Φ_{opt}) enhances.
- The presence of nanoparticles in base fluid enhances solar absorption and heat transport in the collector .
- The collector efficiency was enhanced around two times by increasing the Reynolds number and solid volume fraction .

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