**American Journal of Nano Research and Applications**
2016; 4(1): 1-5
Published online February 13, 2016 (http://www.sciencepublishinggroup.com/j/nano)
doi: 10.11648/j.nano.20160401.11

**Review Article**

# Heat Transfer Enhancement Using Nanofluids: A Review of the Recent Literature

**Mohammed Saad Kamel, Raheem Abed Syeal, Ayad Abdulameer Abdulhussein**

Department of Mechanical Techniques, Al-Nasiriyah Technical Institute, Southern Technical University, Thi-Qar, Iraq

**Email address:**
mr.mohd1986@yahoo.com (M. S. Kamel), raheemsyeal@gmail.com (R. A. Syeal), ayad_abdulameer@yahoo.com (A. A. Abdulhussein)

**To cite this article:**
Mohammed Saad Kamel, Raheem abed Syeal, Ayad Abdulameer Abdulhussein. Heat Transfer Enhancement Using Nanofluids: A Review of the Recent Literature. *American Journal of Nano Research and Applications.* Vol. 4, No. 1, 2016, pp. 1-5. doi: 10.11648/j.nano.20160401.11

**Abstract:** Nanofluids are a fluids containing nanometer-sized particles, called nanoparticles. These fluids are Suspension of nanoparticles in conventional fluids. Nanofluids have been the subject of intensive study worldwide since pioneering researchers recently discovered the anomalous thermal behavior of these fluids. The enhancement of heat transfer using nanofluids have been used as one of the passive heat transfer techniques in several heat transfer applications. It is considered to have great potential for heat transfer enhancement and are highly suited to application in heat transfer processes like microelectronics, fuel cells, pharmaceutical processes, and hybrid-powered engines, engine cooling/vehicle thermal management, domestic refrigerator, chiller, heat exchanger, and in boiler flue gas temperature reduction. This review covers the enhancement of heat transfer by using nanofluids and potential applications of nanofluids. This paper presents an updated review of the heat transfer applications of nanofluids to develop directions for future work because the literature in this area is spread over a wide range of disciplines, including heat transfer, material science, physics, chemical engineering and synthetic chemistry.

**Keywords:** Nanofluids, Nanoparticles, Enhancement of Heat Transfer, Friction Factor

## 1. Introduction

Nanofluids have attracted much attention recently because of their potential as high performance heat transfer fluids in electronic cooling and automotive. Performance of heat transfer equipment can be improved with studies related to a significant increase in heat flux and miniaturization. In many industrial applications such as power generation, microelectronics, heating processes, cooling processes and chemical processes, water, mineral oil and ethylene glycol are used as heat transfer fluid. Effectiveness and high compactness of heat exchangers are obstructed by the lower heat transfer properties of these common fluids as compared to most solids. It is obvious that solid particles having thermal conductivities several hundred times higher than these conventional fluids, as seen from *Figure 1.* To improve thermal conductivity of a fluid, suspension of ultrafine solid particles in the fluid can be a creative idea. Different types of particles (metallic, non-metallic and polymeric)can be added into fluids to form slurries. Due to the fact that sizes of these suspended particles are in the millimeter or even micrometer scale, some serious problems such as the clogging of flow channels, erosion of pipelines and an increase in pressure drop can occur. Moreover, they often suffer from rheological and instability problems. Especially, the particles tend to settle rapidly. For that reason, though the slurries have better thermal conductivities but they are not practical. [1].

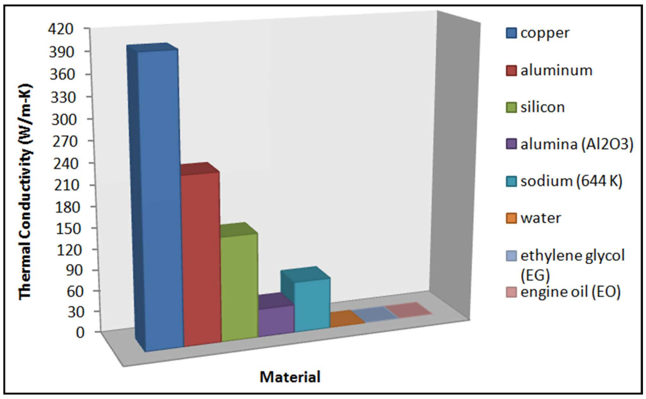


***Figure 1.*** *Thermal conductivities of various solids and liquids [2].*

The present review provides a comprehensive overview of the attractive research progress made in the area of nanofluids.

It also summarizes the experimental, theoretical, and computational developments in this field.

# 2. Preparation Methods for Nanofluids

Various methods have been tried to produce different kinds of nanoparticles and nanosuspensions. There are two primary methods to prepare nanofluids: A two-step method in which nanoparticles or nanotubes are first produced as a dry powder. The resulting nanoparticles are then dispersed into a fluid in a second step and Single-step nanofluid processing methods have also been developed and there are a novel methods also mentioned in this section.

### 2.1. Two-Step Method

This method is the most widely used for preparing nanofluids. Nanoparticles, nanofibers, nanotubes, or other nanomaterials used in this method are first produced as dry powders by chemical or physical methods. Then, the nano-sized powder will be dispersed into a fluid in the second processing step with the help of intensive magnetic force agitation, ultrasonic agitation, high-shear mixing, homogenizing, and ball milling. Two-step method is the most economic method to produce nanofluids in large scale, because nanopowder synthesis techniques have already been scaled up to industrial production levels. Due to the high surface area and surface activity, nanoparticles have the tendency to aggregate. The important technique to enhance the stability of nanoparticles in fluids is the use of surfactants. However, the functionality of the surfactants under high temperature is also a big concern, especially for high-temperature applications. Due to the difficulty in preparing stable nanofluids by two-step method, several advanced techniques are developed to produce nanofluids, including one-step method. In the following part, we will introduce single-step method.

### 2.2. One-Step Method

The nanoparticles may agglomerate during the drying storage, and transportation process, leading to difficulties in the following dispersion stage of two-step method. Consequently, the stability and thermal conductivity of nanofluid are not ideal. In addition, the production cost is high. To reduce the agglomeration of the nanoparticles, one-step methods have been developed. There are some ways for preparing nanofluids using this method including direct evaporation condensation [21, 22], chemical vapour condensation [23], and single-step chemical synthesis.

### 2.3. Other Novel Methods

Wei et al developed a continuous flow micro fluidic micro reactor to synthesize copper nanofluids. By this method, copper nanofluids can be continuously synthesized, and their microstructure and properties can be varied by adjusting parameters such as reactant concentration, flow rate, and additive. CuO nanofluids with high solid volume fraction (up to 10 vol%) can be synthesized through a novel precursor transformation method with the help of ultrasonic and microwave irradiation [24]. The precursor $Cu(OH)_2$ is completely transformed to CuO nanoparticle in water under microwave irradiation. The ammonium citrate prevents the growth and aggregation of nanoparticles, resulting in a stable CuO aqueous nanofluid with higher thermal conductivity than those prepared by other dispersing methods. Phase-transfer method is also a facile way to obtain monodisperse noble metal colloids [25]. Phase transfer method is also applied for preparing stable kerosene based $Fe_3O_4$ nanofluids. Oleic acid is successfully grafted onto the surface of $Fe_3O_4$ nanoparticles by chemisorbed mode, which lets $Fe_3O_4$ nanoparticles have good compatibility with kerosene [26]. In a water cyclohexane two-phase system, aqueous formaldehyde is transferred to cyclohexane phase via reaction with dodecylamine to form reductive intermediates in cyclohexane. The intermediates are capable of reducing silver or gold ions in aqueous solution to form dodecylamine-protected silver and gold nanoparticles in cyclohexane solution at room temperature. Feng et al. used the aqueous organic phase transfer method for preparing gold, silver, and platinum nanoparticles on the basis of the decrease of the PVP's solubility in water with the temperature increase [27].

# 3. Advantages of Nanofluids

Nanofluids cause drastic change in the properties of the base fluid so, the following benefits are expected to get on.

- Due to nano size particles, pressure drop is minimum.
- Higher thermal conductivity of nanoparticles will increase the heat transfer rate.
- Successful employment of nanofluid will lead to lighter and smaller heat exchanger.
- Heat transfer rate increases due to large surface area of the nanoparticles in the base fluid.
- Nanofluids are most suitable for rapid heating and cooling systems.
- Due to nano size particles, fluid is considered as integral fluid.
- Good mixture nanofluids will give better heat transfer.
- Microchannel cooling without clogging. Nanofluids are not only a better medium for heat transfer in general but they are also ideal for microchannel applications where high heat loads are needed.
- Cost and energy saving. Successful employment of nanofluids will result in significant energy and cost savings because heat exchange systems can be made smaller and lighter.

# 4. Literature Survey in Recent Years

Many researcher tried to study the effect of nanoparticles on base fluids like water, ethylene glycol and oil and shows the enhancement that be get on because of the higher thermal conductivities for those fluids so there are some experimental and numerical studies have be done in recent years. *Table 1, 2 and 3* show some studies that presented in recent years.

***Table 1.*** *Some studies in 2013.*

| Authors | Type of investigation | Funding / results |
|---|---|---|
| C. Yang et. al [3] | Theoretical | It has been found that Nusselt number has optimal bulk mean nanoparticle volume fraction value for alumina water nanofluids, whereas it only increases monotonously with bulk mean nanoparticle volume fraction for titanium water nanofluids. |
| Y. Raja Sekhar et. al [4] | Experimental | The results found that The Nusselt number and friction factor increases with increase of particle concentration. But, friction factor decreases with increase of Reynolds number of flow where as the Nusselt number increases. Using nanofluid with a high heat exchange can help in reduce the size of the heat exchanger or without increasing the size of the heat exchanger efficiency of the system can be improved. Further, using twisted tapes and nanofluids in the pipe flows is advantageous since it is visible from the results that the energy gained with heat exchange is more than the energy spent on pumping power. It is clear from the results that heat transfer enhancement in a horizontal tube increases with Reynolds number of flow and nanoparticle concentration. |
| Adnan M. Hussein et. al [5] | Numerical | Data measured showed that thermal conductivity and viscosity increase with increasing the volume concentration of nanofluids with maximum deviation 19%and 6%, respectively. Simulation results concluded that the friction factor and Nusselt number increase with increasing the volume concentration. On the other hand, the flat tube enhances heat transfer and decreases pressure drop by 6% and −4%, respectively, as compared with circular tube. |
| Faris Mohammed Ali et. al [6] | Numerical | The results show that, the thermal conductivity and thermal diffusivity enhancement of nanofluids increases as the particle size increases. Thermal conductivity and thermal diffusivity enhancement of $Al_2O_3$ nanofluids was increase as the volume fraction concentration increases. This enhancement attributed to the many factors such as, ballistic energy, nature of heat transport in nanoparticle, and interfacial layer between solid/fluids. |
| S. Zeinali Heris et. al [7] | Experimental | Experiments show that considerable enhancement of heat transfer coefficient is achieved and this enhancement is up to 27.6% at 2.5% volume fraction of nanoparticles comparing to the base fluid (water), also it has been noticed that convective heat transfer coefficient increases with the increment of nanoparticles concentration in nanofluid especially at high flow rates. The decrement of wall temperature observed using nanofluid. |

***Table 2.*** *Some studies in 2014.*

| Authors | Type of investigation | Funding/ results |
|---|---|---|
| A. Azari et. al [8] | Experimental and numerical | Experimental and simulation results showed that the thermal performance of nanofluids is higher than that of the base fluid and the heat transfer enhancement increases with the particle volume concentration and Reynolds number. |
| Hassanain Ghani Hameed et. al [9] | Numerical | Results found The nanoparticles within the liquid enhance the thermal performance of the heat pipe by reducing the thermal resistance and temperature difference by 0.168 K/W and 5.06 K respectively. While increasing the maximum heat load and the capillary pressure by 96 W and 192.46 Pa respectively. All these results at input heat of 30 W and nanoparticles concentration of 5 Vol. %. The results of wall temperature distribution for the heat pipe have been compared with the previous study for the same problem and a good agreement has been achieved. |
| Mohamed H. Shedid [10] | Numerical | Results of numerical simulations are compared and showed an enhancement of Nusslet number as Peclet number grows with increasing concentration ratio of $Al_2O_3$ and $TiO_2$ nanoparticles. |
| Layth W. Ismael et. al [11] | Experimental | The experimental results emphasized the enhancement of the thermal conductivity due to the nanoparticles presence in the fluid greater than microfluids, also shown the effect of the particle size and concentration on the thermal conductivity. It has been recognized that the addition of highly conductive particles can significantly increase the thermal conductivity of heat – transfer fluids. Particles in the micro and nano – size range have attracted the most interest because of their enhanced stability against sedimentation and, as a result, reduction in potential for clogging a flow system. Furthermore the results showed that, the obtained thermal conductivities doubtlessly revealed that size and type particles was a key factor affecting conductive heat transport in suspensions. |
| HoomanYarmand et. al [12] | Numerical | The numerical results indicate that $SiO_2$-water has the highest Nusselt number compared to other nanofluids while it has the lowest heat transfer coefficient due to low thermal conductivity. The Nusselt number increases with the increase of the Reynolds number and the volume fraction of nanoparticles. |
| Adnan M. Hussein et. al [13] | Experimental | Results showed that the heat transfer in car radiator increases with increasing of nanofluid volume fraction by using $TiO_2$ and $SiO_2$ nanoparticles dispersed in water as a base fluid. |
| Sami D. Salman et. al [14] | Numerical | The results show that the heat transfer enhancement increases with an increase in the volume fraction of the CuO nanoparticle. |

***Table 3.*** *Some studies in 2015.*

| Authors | Type of investigation | Funding/ results |
|---|---|---|
| Hsien-Hung Ting et. al [15] | Numerical | The numerical results show that the heat transfer coefficients and Nusselt numbers of $Al_2O_3$/water nanofluids increase with increases in the Peclet number as well as particle volume concentration. The heat transfer coefficient of nanofluids is increased by 25.5% at a particle volume concentration of 2.5% and a Peclet number of 7500 as compared with that of the base fluid (pure water). |
| Rabah Nebbati et. al [16] | Numerical | The results of thermal and hydrodynamic fields show that nanofluids can provoke an increase in the average and local Nusselt numbers, a decrease of bottom surface local temperature and a slight decrease of the shear stress on the wall, when compared to predictions using constant properties and nanoparticles free water. |
| Dr. Khalid Faisal Sultan [17] | Numerical | The numerical results show that as the solid volume fraction increases, the heat transfer is enhanced for all values of Rayleigh number. This enhancement is more significant at high Rayleigh number. The lowest heat transfer was obtained for $TiO_2$ (50 nm) due to domination of conduction and large nanoparticles. whereas Ag (20 nm), Cu (30 nm) – distilled water nanofluids has the highest heat transfer, respectively. |
| Dr. Khalid Faisal Sultan [18] | Experimental | The measured results show that silver with oil nanofluid gives maximum heat transfer enhancement compared with oxide zirconium nanofluid used. The presence of Ag and ZrOR2R nanoparticles attributes to the generation of strong nano convection current and better mixing also, The heat transfer coefficient and pressure drop is increased by using nanofluids (Ag + oil, $ZrO_2$ + oil) instead of the base fluid (oil). |
| Abdolbaqi Mohammed Khdher et. al [19] | Numerical | Results found that the heat transfer rates and wall shear stress increase with an increase of nanofluid volume concentration. In addition, the results of viscosity and thermal conductivity of the nanofluids show a significant increment with the increase of volume fractions. Therefore, optimal particle volume fraction is considered in enhancing the performance of nanofluid in an engineering system. |
| Bayram Sahin et. al [20] | Experimental | It was found that the particle volume concentrations higher than 1%vol. were not appropriate with respect to the heat transfer performance of the CuO-water nanofluid. No heat transfer enhancement was observed at Re = 4.000. The highest heat transfer enhancement was achieved at Re = 16.000 and $\Phi = 0.005$. |

# 5. Application of Nanofluids

Nanofluids can be used to improve heat transfer and energy efficiency in a variety of thermal systems. That's means can be used as a cooling fluids in many application and there are some common application:

1. Engine cooling
2. Nuclear cooling system
3. Cooling of electronic circuit
4. Refrigeration
5. Enhancement of heat transfer exchange
6. Thermal storage
7. Biomedical application
8. Cooling of microchips
9. In defense and space application
10. Transportation
11. Petroleum industry
12. Inkjet printing
13. Environmental remediation
14. Surface coating
15. Fuel additives
16. Lubricant

# 6. Conclusion

The present papers gives a review about the enhancement of heat transfer by using nanofluids by many authors that preformed an experimental and numerical investigations related to heat transfer enhancement using nanofluids. So, we need to understanding the fundamentals of heat transfer and wall friction from this review because has a significant importance for developing nanofluids for a wide range of heat transfer applications and we can concluded the following:

1. Heat transfer rate is directly proportional to the Reynolds number and peclet number of Nanofluid.
2. Increasing volume Concentration of nanoparticles increases the pressure drop of Nanofluids.
3. Spherical shaped nanoparticles increases the heat transfer rate of Nanofluids compared with other shaped nanoparticles.
4. The fine grade of Nanoparticles increases the heat transfer rate but it's having poor stability.
5. Increasing size of nanoparticales (diameter of NP) led to decreasing in heat transfer because area per unit volume decreases.

# References

[1] A. S. Dalkilic et.al ' Forced Convective Heat Transfer of Nanofluids - A Review of the Recent Literature' Current Nanoscience, 2012, 8, 949-969.

[2] Xiang-Qi Wang et.al 'A review on nanofluids - part i: theoretical and numerical investigations' 'Brazilian Journal of Chemical Engineering' Vol. 25, No. 04, pp. 613 - 630, October - December, 2008.

[3] C. Yang, W. Li, A. Nakayama, 'Convective heat transfer of Nanofluids in a concentric annulus' 'International Journal of Thermal Sciences' 71 (2013) 249-257.

[4] Y. Raja Sekhara, K. V. Sharmab, R. Thundil Karupparaja, C. Chiranjeevia 'Heat Transfer Enhancement with Al2O3 Nanofluids and Twisted Tapes in a Pipe for Solar Thermal Applications' 'International Conference On DESIGN AND MANUFACTURING, IConDM 2013'Procedia Engineering 64 ( 2013 ) 1474 – 1484.

[5] Adnan M. Hussein, K. V. Sharma, R. A. Bakar, and K. Kadirgama.'The Effect of Nanofluid Volume Concentration on Heat Transfer and Friction Factor inside a Horizontal Tube' Hindawi Publishing Corporation 'Journal of Nanomaterials' Volume 2013, Article ID 859563, 12 pages.

[6] Faris Mohammed Ali, W. Mahmood Mat Yunus and Zainal Abidin Talib "Study of the effect of particles size and volume fraction concentration on the thermal conductivity and thermal diffusivity of Al2O3 nanofluids"'International Journal of Physical Sciences' Vol. 8(28), pp. 1442-1457, 30 July, 2013.

[7] S. ZeinaliHeris, Taofik H. Nassan, S. H. Noie, H. Sardarabadi, M. Sardarabadi "Laminar convective heat transfer of Al2O3/water nanofluid through square cross-sectional duct" 'International Journal of Heat and Fluid Flow' 2013.

[8] A. Azari, M. Kalbasi and M. Rahimi "CFD AND EXPERIMENTAL INVESTIGATION ON THE HEAT TRANSFER CHARACTERISTICS OF ALUMINA NANOFLUIDS UNDER THE LAMINAR FLOW REGIME" 'Brazilian Journal of Chemical Engineering' Vol. 31, No. 02, pp. 469 - 481, April-June, 2014

[9] Hassanain Ghani Hameed, Proof. Dr. Abudl-Muhsin A. Rageb "NUMERICAL SIMULATION OF THERMAL PERFORMANCE OF CONSTANT CONDUCTANCE CYLINDRICAL HEAT PIPE USING NANOFLUID" Al-Qadisiya Journal For Engineering Sciences, Vol. 7, No. 4, 2014.

[10] Mohamed H. Shedid" Computational Heat Transfer for Nanofluids through an Annular Tube" "Proceedings of the International Conference on Heat Transfer and Fluid Flow" Prague, Czech Republic, August 11-12, 2014.

[11] Layth W. Ismael, Dr. Khalid Faisal. Sultan" A comparative Study on the Thermal Conductivity of Micro and Nano fluids by Using Silver and Zirconium Oxide" Al-Qadisiya Journal For Engineering Sciences, Vol. 7, No. 2, 2014.

[12] Hooman Yarmand, Samira Gharehkhani, Salim Newaz Kazi, Emad Sadeghinezhad, and Mohammad Reza Safaei " Numerical Investigation of Heat Transfer Enhancement in a Rectangular Heated Pipe for Turbulent Nanofluid" Hindawi Publishing Corporation, Scientific World Journal. Volume 2014, Article ID 369593, 9 pages.

[13] Adnan M. Hussein , R. A. Bakar, K. Kadirgama, K. V. Sharma" Heat transfer augmentation of a car radiator using nanofluids " Heat and Mass Transfer journal, November 2014, Volume 50, Issue 11, pp 1553-1561.

[14] Sami D. Salman, Abdul Amir H. Kadhum, Mohd S. Takriff, and Abu Bakar Mohamad "Heat Transfer Enhancement of Laminar Nanofluids Flow in a Circular Tube Fitted with Parabolic-Cut Twisted Tape Inserts" Hindawi Publishing Corporation, Scientific World Journal Volume 2014, Article ID 543231, 7 pages.

[15] Hsien-Hung Ting and Shuhn-Shyurng Hou" Investigation of Laminar Convective Heat Transfer for Al2O3-Water Nanofluids Flowing through a Square Cross-Section Duct with a Constant Heat Flux" Materials 2015, 8, 5321-5335.

[16] Rabah Nebbati, Mahfoud Kadj" Study of forced convection of a nanofluid used as a heat carrier in a microchannel heat sink" "International Conference on Technologies and Materials for Renewable Energy, Environment and Sustainability, TMREES15", 2015.

[17] Khalid Faisal Sultan "Numerical Solution of Heat Transfer and Flow of Nanofluids in Annulus With Fins Attached on the Inner Cylinder" Journal of Babylon University/Engineering Sciences/ No.(2) / Vol.(23): 2015.

[18] Dr. Khalid Faisal Sultan "Augmentation of Heat Transfer Through Heat Exchanger With and Without Fins by Using Nano fluids" Journal of Engineering and Development, Vol. 19. No. 4, July 2015, ISSN 1813- 7822.

[19] Abdolbaqi Mohammed Khdher, Rizalman Mamat, Nor Azwadi Che Sidik "The Effects of Turbulent Nanofluids and Secondary Flow on the Heat Transfer through a Straight Channel" Recent Advances in Mathematical and Computational Methods, 2015.

[20] Bayram Sahin, Eyuphan Manay and Eda Feyza Akyurek " An Experimental Study on Heat Transfer and Pressure Drop of CuO-Water Nanofluid" Hindawi Publishing Corporation, Journal of Nanomaterials, Volume 2015, Article ID 790839, 10 pages.

[21] J. A. Eastman, U. S. Choi, S. Li, L. J. Thompson, S. Lee, Proceedings of the Materials Research Symposium(Nanophase and Nanocomposite Materials II), 1997.

[22] J. A. Eastman, S. U. S. Choi, S. Li, G. Soyez, L. J. Thompson, R. J. DiMelfi, J. Metastab. Nanocryst. 2(1998) 629.

[23] V. V. Srdic, M. Winterer, A. Mller, G. Miehe, H. Hahn, J. Am. Ceram. Soc. 84 (2001) 277.

[24] H. T. Zhu, C. Y. Zhang, Y. M. Tang, and J. X. Wang, "Novel synthesis and thermal conductivity of CuO nanofluid," Journal of Physical Chemistry C, vol. 111, no. 4, pp. 1646–1650, 2007.

[25] Y. Chen and X. Wang, "Novel phase-transfer preparation of monodisperse silver and gold nanoparticles at room temperature," Materials Letters, vol. 62, no. 15, pp. 2215– 2218, 2008.

[26] W. Yu, H. Xie, L. Chen, and Y. Li, "Enhancement of thermal conductivity of kerosene-based Fe3O4 nanofluids prepared via phase-transfer method," Colloids and Surfaces A, vol. 355, no. 1–3, pp. 109–113, 2010.

[27] X. Feng, H. Ma, S. Huang et al., "Aqueous-organic phasetransfer of highly stable gold, silver, and platinum nanoparticles and new route for fabrication of gold nanofilms at the oil/water interface and on solid supports," Journal of Physical Chemistry B, vol. 110, no. 25, pp. 12311–12317, 2006.