IJERST

International Journal of Engineering Research and Science & Technology

ISSN : 2319-5991
Vol. 3, No. 4
November 2014

www.ijerst.com

Email: editorijerst@gmail.com or editor@ijerst.com

Int. J. Engg. Res. & Sci. & Tech. 2014

International Journal of Engineering Research and Science & Technology

ISSN 2319-5991 www.ijerst.com
Vol. 3, No. 4, November 2014

Research Paper

ENHANCEMENT OF EFFECTIVENESS OF HEAT EXCHANGER BY USING OXIDE NANO FLUIDS: A REVIEW OF THE SCIENCE AND APPLICATIONS

Rakesh Kumar[1]*

**Corresponding Author: Rakesh Kumar* ✉ *rakesh056891@gmail.com*

Heat exchange is an important unit operation that contributes to efficiency and safety of many processes. Nano fluids are suspensions of Nanoparticles in liquids that show noteworthy upgrade of their thermal properties. The Reynolds number, convective heat transfer coefficient, specific heat, thermal conductivity are the essential parameters controlling the heat exchange of the fluid. The aim of this review is to outline later advancements in exploration on the dependability of nanofluids, upgrade of overall heat transfer using nanofluids in heat exchanger.

Keywords: Nano fluids, Nanoparticles, Heat transfer, Heat transfer Coefficient, Thermal Conductivity, LMTD

INTRODUCTION

Nano fluids are colloidal dilute dispersion of nanoparticles (generally less than 5% in volume) such as metals, oxides, carbides, or carbon nanotubes in conventional coolants or base fluids such as water, ethylene glycol, and oil (Applied Mechanics, 2013). Nanofluids are a relatively new class of fluids which consist of a base fluid with nano-sized particles (1-100 nm) suspended within them. It is introduced by Choi (1995) (Conference: Korea-US, 1998). Nanofluids are suspensions containing particles that are altogether smaller than 100 nm (Wen and Ding, 2004; Wen Dongsheng and Ding Yulong, 2004), and having thermal conductivity of extents higher than the base fluids. Due to novel properties of nanofluid it can be broadly utilized for different heat exchange applications of designing including, automotive and air conditioning cooling, sun based and power plant cooling, cooling of transformer oil, enhancing diesel generator productivity, in Nuclear reactor and defense and space as reported by Xiang and Arun (2008). The heat transfer coefficients of nanofluids are much superior to base fluid. The principle reason of heat exchange upgrade of nanofluids is: the suspended nanoparticles build the thermal conductivity of the fluids, and the chaotic movement of ultrafine particles enhance the fluctuation and turbulence of the fluids to accelerate heat exchange in the process (Daung thong suk and Wongwises, 2007). Effectiveness of the heat exchanger is the function of thermal conductivity and convective

---

[1] Department of Material Science and Nanotechnology, Deen Bandhu Chhotu Ram University of Science And Technology Sonipat, Haryana.

heat transfer coefficient of the fluid. The convective heat transfer coefficient of nanofluids depends on the thermal conductivity, density, specific heat, and viscosity of the nanofluids (Keblinski *et al.*, 2005).

PREPARATION OF NANO FLUID

The preparation of the Nanofluid is the first important step in using Nano Phase particles to change the heat transfer rates of conventional fluids. Fabrication of the Nano particles can be classified into two broad categories: Physical process and chemical process (Kimoto *et al*., 1963; Granqvist and Buhrman, 1976; Gleiter, 1989). To synthesize nanofluids by suspending nano particles into base liquids, some extraordinary prerequisites will be fundamental such as even suspension, strong and stable suspension, low agglomeration of particles and no chemical change of fluid (Lee *et al*., 1999).

Figure 1: Two Step Method

Stable suspension of Nano particles in the conventional heat transfer fluids are produced by mostly used two-step methods.

Nanoparticles, Nano strands, nanotubes, or other nanomaterial utilized as a part of this technique are initially synthesized as dry powders by concoction or physical techniques. At that point, the Nano measured powder will be scattered into a liquid in the second transforming venture with the assistance of intensive magnetic force agitation, ultrasonic disturbance, high-shear blending, homogenizing, and ball processing. Murshed *et al.* (2005) prepared TiO_2 suspension in water using the two-step method (Murshed *et al.*, 2005).

Table 1: A summary of preparation process of nanofluids used by different researchers

Metal Particle Prepared	**Starting Material**	**Reducing Agents**	**Medium**	**Stabilizer**	**Condition**	**Mean Particle Diameter (nm)**	**Ref.**
Ti	Titanium Tetra Chloride	Ar-H_2Plasma	Gas	No	Plasma	2-10	[10]
Cu	Copper acetate	$NaBH_4$	Water	AOT reverse Micelles	Room Temperature	2-10	[11]
Ag	$AgNO_3$	$NaBH_4$	Biphase (Toluene/water)	1-Dodecane Thiol	Room Temperature	5-8	[12]
Au11	Au-aryl Phosphine complexes	$NaBH_4$	Water	ArylPhosphine	Inert	0.82	[13]
Au55	$HAuCl_4$	(Ph_3P) AuCl	Benzene	B_2H_6	-	1.4	[14]
Zn	$[Zn(C_6H_{11})_2]$	Thermal Reduction	Anisol/ water	PVP	13^0C	6-17	[15]

STABILITY OF NANO FLUIDS

Nanofluids which can lose their capability to exchange heat because of their inclination to coagulation. So the investigation on the stability is also a key issue. There are various ways to enhance the stability of nano fluids: (a) Addition of Surfactants (Yu *et al*., 2010; Chandrasekar, 2010; Hwang, 2008); (b) Surface Modification Technique (Yu, 2012; Yang, 2010; Chen, 2010); (c) pH control of the nano fluids (Wen, 2009; Foyet, 2001). The stability of nanofluids is controlled by distinct mechanisms (a) Zeta Potential Analysis (Kim, 2009; Zhu, 2009); (b) Sedimentation method (Wei, 2010; Zhu, 2007); (c)Centrifugation method (Singh, 2008); (d) Spectral Analysis Method (Hwang, 2007).

Figure 2: Stability of Al_2O_3 without any stabilizer[30]

Figure 3: The settling of Gold nano particles with time is as follows: a) 0min b)1 min c)2min d)3min e)4min f)5 min g) 6min[31]

Reduced particle clogging as compared to conventional slurries, thus promoting system miniaturization (Das, 2006).

THEORETICAL BACKGROUND AND MATHEMATICAL RELATIONS

Heat exchangers are normally dissected utilizing either the Logarithmic Mean Temperature Difference (LMTD) or the Effective–Number of Transfer Units (ε-NTU) methods. The section explains various mathematical relations (Incropera, 2007; Shah, 2003).

If q is the total rate of heat transfer between the hot and cold fluids, negligible heat transfer between exchanger and its surrounding, negligible Kinetic energy and Potential energy changes (Saidur, 2010) then on applying SFEE

$$q = m_h(h_{hi} - h_{ho}) \quad ...(1)$$

$$q = m_c(h_{co} - h_{ci}) \quad ...(2)$$

Figure 4: Counter flow Heat Exchanger

If the fluid is not going under any phase change and specific heat is assumed to be constant then

$$q = m_h C_{p,h}(T_{hi} - T_{ho}) \quad ...(3)$$

$$q = m_c C_{p,c}(T_{co} - T_{ci}) \quad ...(4)$$

Overall heat transfer which is extension of Newton's law of cooling is

$$q = U\,A\,\Delta T_{lm} \quad ...(5)$$

where ΔT_{lm} is log mean temperature difference and is given by

$$\Delta T_{lm} = \{\Delta T_2 - \Delta T_1\} / \ln(\Delta T_2/\Delta T_1) \quad ...(6)$$

$$\Delta T_1 = T_{hi} - T_{ci}$$

$$\Delta T_2 = T_{ho} - T_{co} \quad ...(7)$$

for parallel flow

$$\Delta T_1 = T_{hi} - T_{co}$$

$$\Delta T_2 = T_{ho} - T_{co} \quad ...(8)$$

for counter flow

The LMTD method is convenient for determining the overall heat transfer coefficient based on the measured inlet and outlet fluid temperatures. The ε-NTU method is more convenient for prediction of the outlet fluid temperatures if the heat transfer coefficient and the inlet temperatures are known (Incropera, 2007; Shah, 2003). The heat exchanger effectiveness (Incropera, 2007; Shah, 2003; Saidur, 2007; Naphon, 2007) is defined as:

$$\varepsilon = \frac{q}{q_{\max}} \quad ...(9)$$

The maximum possible rate of heat transfer for the given inlet temperature of fluids is given by

$$q_{\max} = C_{\min}(T_{h,i} - T_{c,i}) \quad ...(10)$$

where C_{min} is the smaller of the two specific heat, i.e., C_h and C_{nf}. The efficiency ε depends on the heat exchanger geometry, flow pattern (parallel flow, counter-flow, cross-flow, etc.) and the Number of Transfer Units (NTU).

$$NTU = \frac{UA}{C_{\min}} \quad ...(11)$$

For a single pass heat exchanger in the parallel flow regime

$$\varepsilon = \frac{1 - \exp\left[-NTU\left(1 + C_r\right)\right]}{1 + C_r} \quad ...(12)$$

For a single pass heat exchanger in the counter-flow regime

$$\varepsilon = \frac{1 - \exp\left[-NTU\left(1 - C_r\right)\right]}{1 - C_r \exp\left[-NTU\left(1 - C_r\right)\right]} \quad \text{if } C_r < 1$$

$$\text{if } C_r = 1 \quad ...(13)$$

Density (ρ_{nf}) and Specific heat capacity ($C_{p,nf}$)

Nanofluid have been calculated based on empirical correlations proposed by Pak (1998) and Xuan as follow

$$\rho_{nf} = \left(1 - \phi\right)\rho_{bf} + \phi\rho_p$$

$$\mu_{nf} = \frac{\mu_{bf}}{1 - 34.87\left(d_p / d_{bf}\right)^{-0.3}\phi^{1.03}} \quad ...(14)$$

The dynamic viscosity of the nano fluids is calculated using the relation (Corcoine, 2011)

$$R_{overall} = R_h + R'_{wall} + R_c$$

$$\frac{1}{UA_h} = \frac{1}{h_h A_h} + \frac{\ln\left(r_c / r_h\right)}{2\pi k L} + \frac{1}{h_c A_c} \quad ...(15)$$

The heat transfer coefficient relies on the various physical variables such as: fluid properties, velocity field, geometry temperature etc. As the function is dependent on several parameters, the heat transfer coefficient is usually expressed in terms of correlations involving pertinent non-dimensional numbers.

Table 2: Non Dimensionless Numbers

Number	Formula	Refrence
Reynolds Number	$\mathrm{Re} = \frac{2\rho_{bf} k_b T}{\pi\mu_{bf}^2 d_p}$	[40]
Prandtl Number	$\mathrm{Pr}_{nf} = \frac{c_{p,nf}\,\mu_{nf}}{k_{nf}}$	[41]
Peclet Number	$\mathrm{P}e_d = \frac{\mu_{nf} d_p}{\alpha_{nf}}$	[41]
Nusselt Number	$Nu = 0.023\mathrm{Re}^{0.8}\ \mathrm{Pr}_{0.4}$	[42][43]

Hot fluid is flowing inside tube and cold outside then heat is exchanged and overall resistance is given by

$$R_{overall} = R_h + R_{wall} + R_c$$

$$\frac{1}{UA_h} + \frac{1}{h_h A_h} + \frac{\ln(r_c / r_h)}{2\pi kL} + \frac{1}{h_c A_c} \quad ...(16)$$

Figure 5: Mini Heat Exchanger[44]

EXPERIMENTAL SETUP

A schematic of the trial setup used to examine heat exchange qualities of nanofluid. It comprises of two flow loops, heating unit to heat the nanofluid, and temperature estimation framework (Mapa, 2005).

Table 3: Various parameters of nano fluids and water at 343 K[45]

Fluids	K(W/mk)	ρ (Kg/m^3)	µ X 10^4 (Kg/ms)	C$_p$ (KJ/Kg K)
Water	0.663	977.5	4.040	4.190
Cu-Water	0.749	1136.7	4.271	4.111
Al-Water	0.749	1012.3	4.271	4.121
Al_2O_3-Water	0.744	1037.4	4.271	4.119
Ti_2O Water	0.730	1034.9	4.271	4.117

PROPERTIES OF NANO FLUIDS

The various parameters for the distinct nano fluids is tabulated below:

Figure 6: Thermal conductivity of Fe and Al_2O_3 nanofluids with volume fraction of nanoparticles[49]

Figure 7: Thermal conductivity of Al_2O_3 / water and Al_2O_3 / pH nanofluids, depending on volume fraction and pH values[49]

Figure 8: Thermal conductivity accretion of nanofluids with different nanoparticles volume fraction[37]

Figure 9: Thermal conductivity variations of nanofluids with different temperature[37] .

RESULTS AND DISCUSSION

Thermal Conductivity of Nanofluids

Nano fluids enhance the rate of heat transfer. The suspended ultra-fine particles increase the thermal conductivity of the nanofluid (Xuan, 2000). Cu in ethylene glycol enhance the thermal conductivity by 60% for only 0.3% volume fraction (Eastman, 2001) while Al_2O_3 and CuO with water enhance the thermal conductivity by about 12% at 3% volume fraction (Wang, 1999).

Figure 10: Convective heat transfer coefficient of various nano fluids[37]

Thermal Conductivity depends on various parameters: Size Of Particle, Volume Fraction, Particle Material, Particle Shape, Temperature, pH of the fluid (Heat Transfer, 2012).

Convective Heat Transfer Coefficient of Nano Fluids

Convective heat transfer is the crucial parameter to increase the heat transfer rate of fluids. The graph depicts convective heat transfer coefficient for various nano fluids.

The graph depicts convective heat transfer coefficient of Cu-water, Al-water, Al_2O_3 water and TiO_2-water nanofluids are 81%, 63%, 66% and 64% higher compared to pure water respectively.

In contrast to these studies, Pak and Cho (2011) found that the convective heat transfer coefficient of water-based nanofluids with 3 vol.%Al_2O_3 and TiO_2 nanoparticles was 12% smaller than that of pure water when tested under the state of consistent average speed. Zeinali *et al.* (2007) experimentally investigated convective heat transfer of Al_2O_3 water nanofluids in a circular tube and found increment of the heat transfer coefficients with increasing nanoparticles.

Overall Heat Transfer Coefficient

Nano fluids enhance the overall rate of heat transfer which can be predicted by the Figure 11 and 12. Overall heat transfer coefficient of a heat exchanger has been calculated by using the different type of fluids of 2% nano particle concentration. It is found that overall heat transfer coefficient of Cu-water, Al-water, Al_2O_3-water and TiO_2-water nanofluids are 23%, 20%, 21 % and 20% higher compared to pure water respectively (IEEE, 2011).

From the graph show that the increase in overall heat transfer coefficient for 2% γ-Al_2O_3 nanoparticles in water at $Re_{nf}=8000$ compared with $Re_{nf}=6000$ is about 2.4%.

Figure 11: Variations of overall heat transfer coefficient for nanofluid at different volume fractions for Al_2O_3-water[53]

Figure 12: Effect of coolant Reynolds number on overall heat transfer coefficient for different volume fraction[53]

Bai *et al*. (2008) scrutinize cylinder body and found when the Cu nanoparticles concentration is 5%, the average heat dissipating capacity of the single cylinder is enhanced by 43.9% compared with pure water. This show that nanofluids have much stronger heat-transfer capability than pure water.

Pumping Power and Pressure Loss

With increasing nanoparticles stacking in the base fluid, viscosity and density of the nanofluids increase and therefore must be increased the friction factor and the pressure drop. Subsequently, nanofluids require the more noteworthy pumping force than their base fluid.

Figure 13: Effect of copper nanoparticle in the base fluid on pressure drop

Figure 14: Effect of the copper nanoparticle in the base fluid on pumping power

Leong *et al*. (2010) investigated and analyzed of the pressure drop and pumping power for a radiator that is shown in Figures 13 and 14.

Lower Specific Heat

As per various studies Specific heat of nanofluids is lower than base fluid. Namburu *et al*. (2009) reported that CuO/ethylene glycol nanofluids, SiO_2/ethylene glycol nanofluids and Al_2O_3/ethylene glycol nanofluids exhibit lower specific heat compared to base fluids. More the specific heat , more it will extract heat.

APPLICATIONS OF NANO FLUIDS

The key features of nanofluids present a great opportunity for thermal scientists to explore new frontiers in wet nanotechnology and allow a variety of nanofluids, such as nanotechnology-based coolants, lubricants, hydraulic fluids, and metal-cutting fluids, to be used for a wide range of industrial applications. Lee and Choi (1996) develop an advanced cooling technology to cool crystal silicon mirrors used in high-intensity x-rays. Nanofluids could be used to produce

higher temperatures around tumors, to kill cancerous cells without affecting nearby healthy cells (Jordan *et al.*, 1999). The diverse applications of nanofluids in various fields are as follows (Das, 2006).

a) Heat-transfer nanofluids.

b) Surfactant and coating nanofluids.

c) Chemical nanofluids.

d) Tribological nanofluids.

e) Bio- and pharmaceutical-nanofluids

f) Medical nanofluids (drug delivery and functional tissue–cell interaction)

g) Defense Applications

h) Space and Nuclear Systems Cooling (Vassallo, 2004)

CONCLUSION

- For a particular Volume fraction the increment in Reynolds number enhances the overall heat transfer rate..
- Using nano fluid effectiveness of the heat exchanger is increased.

This study assuredly will help to light up the way for analysts and cooling commercial enterprises to choose practicality of substituting nanofluids for customary coolants in hotness trade applications.

Further research is necessary to explain non-idealities observed in the experiment. So we obliged some more endeavors in the examination of nano-fluids.

REFERENCES

APPENDIX

Nomenclature

A= Area (m^2)

C_p = Specific heat capacity (kJ/kg .K)

m = mass flow rate(kg/s)

h= Enthalpy (kJ/s)

q= Rate of heat transfer (kJ/s)

T= Temperature(K)

U= Overall heat transfer Coefficient

Re = Reynolds number

Pr=Prandtl Number

Pe=Peclet Number

Nu= Nusselt Number

ΔT = Temperature difference (K)

R = Resistance

ρ =Density (kg/m^3)

x=volume fraction

μ=dynamic viscosity

K_b=Boltzmann constant

K=thermal Conductivity

α = thermal diffusivity

subscripts

bf=base fluid

nf nano fluid

hi,o =hot fluid input,output

ci,o=cold fluid input,output

h = Hot side

c= Cold side

International Journal of Engineering Research and Science & Technology
Hyderabad, INDIA. Ph: +91-09441351700, 09059645577
E-mail: editorijlerst@gmail.com or editor@ijerst.com
Website: www.ijerst.com

ISSN 2319-5991
04
9 772319 599001