AN EXPERIMENTAL STUDY OF FORCED CONVECTIVE HEAT TRANSFER CHARACTERISTIC OF GOLD WATER NANOFLUID IN LAMINAR FLOW.

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ABSTRACT:: Nanofluids (suspensions of nanosize metallic particles in fluid) are center of interest in heat transfer enhancement research but inconsistency reports in mechanism and extent of heat transfer enhancements limits their practical applications. This work is concerned with experimental analysis of convective heat transfer enhancement of gold/water nanofluid in laminar flow under constant heat flux condition. Nanofluid of different concentrations was prepared by one step laser ablation method. Results showed enhancement in heat transfer coefficient up to 8%, 15% and 23% with 0.00015, 0.00045 and 0.000667 volume fraction of nanoparticles simultaneously. Heat transfer coefficient and Nusselt number also increases by increasing concentration and Reynolds's number and well known shah correlations failed to predict that much enhancement. Possible heat enhancement mechanisms are also discussed such as particle migration, Brownian motion, high effective thermal conductivity and enhanced thermal entry length region

Keywords: nanofluid, nanoparticles, gold, Nusselt number, convective heat transfer.

INTRODUCTION:

Nanotechnology provides incipient opportunities for processing of materials with less than 50nm average crystallite sizes. The dispersion of metallic particles in fluids to enhance thermal properties was old idea which was limited to micrometer level, but Choi and Eastman [1] extended this to nanometer sized particles and gave the concept of "nanofluid" at the Annual Mechanical Engineering meeting in 1995. Nanofluids are dilute suspension of nanometer size particles in fluids and they are gaining attention worldwide as next generation fluids due to their novel properties such as dispersion stability, less erosion, high thermal conductivity, minimum clogging and high convective heat transfer coefficient. Advanced cooling systems are in need of more efficient coolants that can improve heat flux and reduce size of the system. The ongoing research on nanofluids could lead to major impact in developing more efficient coolants for engineering and medical applications because they possess 1) high surface area to volume ratio, 2) Better dispersion stability then micro size particles 3) reduced pumping power [2].

Nanofluids were originally investigated for their large effective thermal conductivities which gave elevate to the conception of exploiting nanofluids as heat transfer fluids. An immensely colossal fraction of the literature containing the term "nanofluid" has been devoted to studying how nanoparticles fundamentally change conductive and convective heat transfer. After an astronomically immense number of conflicting results (a trend which perpetuates to this day), an emerging consensus is being reached that any unwonted enhancement of k appears to be due to nanoparticles aggregation. Particle aggregation can result into percolation paths which enhance k beyond what is soothsaid by mean field theories for well-distributed nanoparticles. Incorporating aggregation dynamics into conventional mean-field theories (e.g., Maxwell's model) yields results which ostensibly describe the observed dependence of k on nanoparticle volume fraction and temperature. However, there still remain a consequential number of researchers who do not subscribe to the notion that nanoparticle aggregation is the primary cause of enhanced k.

Keblinski *et al.* [3] discussed different possible mechanism including Brownian moment, liquid layer formation at liquid/particle interface, nanoparticles clustering and ballistic phonon transport for enhanced heat transfer in nanofluid. Due to nanoparticles size Brownian motion was topic of interest. They concluded that Brownian moment is too slow to affect heat transfer. The liquid layer formation at solid/liquid interface results into a crystal like arrangement which has ability to transfer more heat .So liquid layering can be a possible phenomenon for high thermal conductivity.

Nanofluids containing metal oxide nanoparticles in water were first batch of nanofluids that were investigated for enhancement in thermal conductivity. Masuda et al [4] , Xuan and Li [5] , Hwang et al [6] , Choi et al. [7] , Eastman *et al.*[8] Lee et al. [9] and Das et al. [10] conducted experiments to measure the enhancement in thermal conductivity of conventional heat transfer fluids including water, ethylene glycol and oil by addition of different nanoparticles such as Al_2O_3 ,CuO ,Cu, TiO_2 , MWCNT(multi walled carbon nanotubes). Most of them reported enhancement ranging from 10- 40 % by addition of only small fraction of nanoparticles. Maximum enhancement was reported by Choi et al. [7] which were up to 150% by addition of MWCNT in poly- α olefin oil. Patel et al. [11] added small fractions of Au and Ag nanoparticles in water and reported that enhancement in thermal conductivity was more by addition of gold nanoparticles.

The convective heat transfer coefficient of nanofluid (alumina/water) was first experimentally studied by Pak and Cho [12] and then lot of researchers such as Heris *et al.*[13], M.M.Heyat et al. [14], Wen and Ding [15], Murshed et al. [16], K.S.Hwang et al. [17], A.Azari et al [18], T.H.Nassan *et al.* [19] and Xuan and Li [20, 21], Chien et al.[22] and Tsai et al.[23] investigated different nanofluids for convective heat transfer enhancement. Lack of consistency exists between research results. Many of above researchers reported enhancement higher then thermal conductivity enhancement. A further detailed study needed to understand the behavior of nanofluids in flow.

Table 1:Review of Enhancement in Thermal Conductivity

Author	Nanofluid	Particle size	Results	Year/ Reference
Masuda et al	Al_2O_3/water	13nm	30% enhancement at 4.3 vol%	1993,[4]
Xuan and li	Cu/ water	100nm	successful suspension of relatively big metallic nanoparticles	2000,[5]
Hwang et al	MWCNT/ water	-	11.3% enhancement at vol fraction 0.01	2006,[6]
Choi et al	MWCNT/PAO	-	150% enhancement in TC for 1 vol%	2001,[7]
Eastman et al	Cu/EG	36nm	40% increase in TC for 0.3 vol% Cu-based nanofluids	2001,[8]
Lee and choi	Al_2O_3/ water	24.4nm	10% enhancement in TC for 4.3vol%	2008,[9]
Das et al	Al_2O_3/ water CuO/water	38nm 26nm	2–4 fold increase over range of 21 C to 52◦C	2003,[10]
Patel et al	Au/water Ag/water	15nm 70nm9999	8.3% enhancement at 0.026vol% 4.5% enahncemnt at 1 vol%	2003,[11]

Table 2:Review of Convective Heat Transfer Enhancement with Nanofluids

Auther	Nanofluid	Vol fr.	Flow regime	Results	Year/ Reference
Pak and Cho	Al_2O_3/water TiO2/ water	0.01-0.03	Turbulent flow	Nusselt number increases with reynold number and volume concentratiom Heat transfer coefficient decreases by 12%	1998, [12]
Heris et al	Al_2O_3/water CuO/ water	0.2-3	Fully developed turbulent flow	HTC increased by 41% HTC increased by 38%	2007. [13]
H.H.Heyat et al	Al_2O_3/ water	0.02	Laminar flow	HTC increased with volume concentratiom Enhancement upto 23% occur	2012, [14]
Wen and Ding et al	γ - Al_2O_3/water	0.6, 1, 1.6	Laminar flow	HTC increases upti 41% at Re=1050 HTC increases upto 47% at Re=1600	2004, [15]
Murshed et al	TiO_2/ water	0.2,0.4,0.6,0.8	Laminar flow	HTC increases with reynold number and volumetric loading	2008 [16]
K.S.Hwang et al	Al_2O_3/ water	0.01-0.3	Fully developed laminar	HTC enhanced by 8% at Re=700 and volume fraction 0.3	2009 [17]
A.Azari et al	Al_2O_3, SiO_2, TiO_2/ water		laminar	Al2O3 showed better performance	2013, [18]
T.H.Nassan et al	Al_2O_3/water CuO/ water		laminar	CuO showed more enhancement then Al_2O_3	2010, [19]
Xuan and Li	Cu/water	0.3-2	turbulent	HTC increases with volume fraction and flow velocity	2003 [20]
Xuan and Li	Cu/ water	0.5-2	Laminar	Nu enhanced by 29% compared to water	2004, [21]
chien et al	Au/water	17nm		Significant reduction of thermal resisitance	2003,[22]
Tasai et al	Au/water	2-35nm,15-75nm		High potential to take place conventional fluid	2004,[23]

MATERIALS AND METHODS:

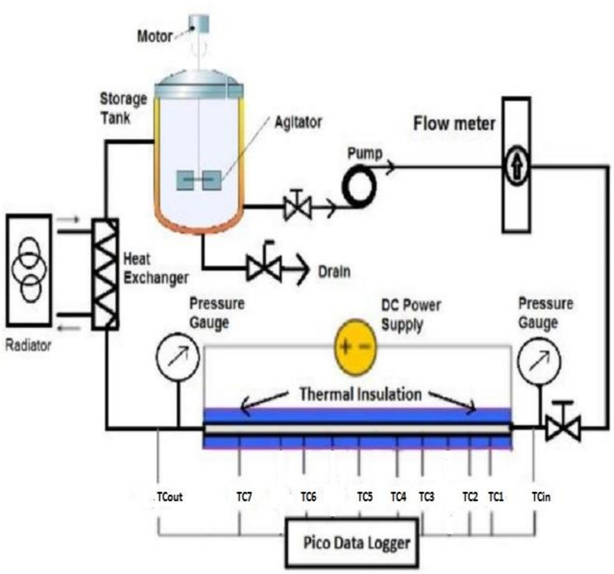
Sample preparation:

Gold/DIW nanofluid was used for investigation of convective heat transfer coefficient which were prepared by laser ablation of 4N (99.99%) pure gold target by using Nd-YAG laser. The Nd-YAG laser has 10mJ/pulse energy, 1064 nm wavelength and pulse time 12ns. The deionized water was obtained by ion exchange method. Gold target was placed in deionized water and different laser shots ranging between 40,000 and 70,000 were used to prepare different concentrations of nanofluid. The prepared nanofluids were of small quantity so they were further diluted with deionized water to get the required amount and to ensure dispersion stability they were agitated well with ultrasonic agitator. Three different nanofluids of concentration 0.015vol%, 0.045vol% and 0.066vol% were obtained.

EXPERIMENTAL SYSTEM AND PROCEDURE:

The main components of experimental system were cooling unit, two pumps, and flow meter (rotameter) test section and storage tank as shown in Fig:1. The test section consists of well insulated circular stainless steel tube (Length = L = 580mm, Diameter = D =2.27mm, Thickness=δ= 2mm).constant heat flux condition was obtained by DC power supply. 7 k-type thermocouples were fused into the wall to measure its temperature at different locations. Two more thermocouples were also installed at inlet and outlet of the test section to measure the bulk fluid temperature.

These thermocouples were attached to two data logger to record readings. Two pressure gauges were installed at inlet and outlet of the test section to measure pressures and pressure drop during nanofluid flow. Two magnetic pumps were used in this setup one for the flow of fluid through the main flow loop and second for the flow of coolant (water) in the heat exchanger.



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ig:1 Experimental System

Nanofluid samples of different concentration were run through this setup at varying flow rate and temperature readings were noted.

Data Analysis:

The physical properties of nanofluid such as viscosity, density and specific heat are calculated by the mixture rule. One of the standard empirical model for calculating suspension viscosities known as Batchelor's model [24] was used to calculate viscosity of nanofluid

$$\mu_{nf} = \mu_f(1 + 2.5\emptyset + 6.2\emptyset^2) \qquad (1)$$

$\emptyset$ is particle volume fraction and μ_f is base fluid viscosity.

Volume fraction mixture rule was used to calculate specific heat of nanoparticles and base fluid mixture

$$c_{pnf} = \emptyset c_{pp} + (1-\emptyset)c_{pf} \qquad (2)$$

c_{pp} = specific heat of nanoparticles, c_{pf}= specific heat of nanofluid

Similar formula defines Nanofluid density, ρ_f and ρ_p are density of particle and fluid

$$\rho_{nf} = \emptyset\rho_p + (1-\emptyset)\rho_f \qquad (3)$$

Hamilton and crosser model [25] was used to calculate effective thermal conductivity of nanofluid

$$k_{nf} = \left[\frac{k_p + (n-1)k_f - (n-1)\emptyset(k_f - k_p)}{k_p + (n-1)k_f + \emptyset(k_f - k_p)}\right] \qquad (4)$$

k_p is thermal conductivity of nanoparticles and k_f represents thermal conductivity of fluid. $\emptyset$ is volume fraction of nanoparticles and n is empirical shape factor and for spherical particles its value is 3.

Newton's law of cooling was applied to calculate local convective heat transfer coefficient

$$h_{nf} = \frac{q^{\circ}}{T_{i,w}(x) - T_{mb}(x)} \qquad (5)$$

h_{nf-x} = local heat transfer coefficient $\left(\frac{W}{m^2K}\right)$

q° = heat flux of the test section(W/m^2)

$T_{i,w}(x)$ = inner wall temperature of the tube (K)

$T_m(x)$ = mean bulk fluid temperature at $x(K)$

Heat flux was calculated using following equation

$$q^{\circ} = \frac{m^{\cdot} c_p(T_{out} - T_{in})}{\pi D_i L} \qquad (6)$$

Where m = mass flow rate (kg/s) = $\rho u A_c$, c_p = specific heat of the fluid ,D_i= inner diameter of the tube,L= length of the test section, Tout and T_{in} = inlet and outlet temperature of fluid.

Outer wall temperature was measureable but inner wall temperature need to be calculated. For that purpose cylindrical coordinated equation for heat conduction was used

$$T_{i,w}(x) = T_{o,w}(x) - \frac{q[2D_o^2 \ln(D_o/D_i) - (D_o^2 - D_i^2)]}{4\pi(D_o^2 - D_i^2)k_s x} \qquad (7)$$

$T_{o,w}$ (x)= outer wall temperature (measured by thermocouple)

,q = heat supplied to the test section (W),
k_s = thermal conductivity of the stainless steel tube ,D_o = outer diameter of the tube , x = longitudinal location of section of interest from entrance. Energy balance on test section cross section gave relationship for mean bulk fluid temperature

$$T_m\ (x) = T_{in} + \frac{(T_{out} - T_{in})}{L} x \qquad (8)$$

Finally above calculated parameters were put into following equation to calculate convective heat transfer coefficient

$$Nu = \frac{h_{nf}\, D_i}{k_{nf}} \qquad (9)$$

INITIAL TEST OF EXPERIMENTAL SYSTEM AGAINST WATER:

To check the equipment al system reliability accuracy before conducting any experiment with nanofluid initial test was taken with DIW and values were compared with the well known shah correlations [26] given below for laminar flow constant heat flux condition

$$Nu = 1.953(RePr\frac{D}{x})^{1/3}\ for\ \left(RePr\frac{D}{x}\right) \geq 33.3 \qquad (10)$$

Reynolds number is ratio of inertial and viscous forces and prandtl number is ratio of momentum and thermal diffusivities. For flow of incompressible nanofluid through uniform cross-sectional area they are defined as

$$Re = \frac{4\mathring{m}}{\pi D_i \mu_{nf}} \qquad (11)$$

$$Pr = \frac{c_{pnf}\mu_{nf}}{k_{nf}} \qquad (12)$$

Fig 2 shows comparison of experimental data of water with shah correlations. A reasonable conformity can be observed between both. Shah correlations slightly over predicts the enhancement in Nusselt number and this can be explained as these correlations are developed for large flow channels while in my experimental system the flow channel is of very small diameter. Similar disagreements were also reported by Wen and Ding and S.M.S Mursheed et al.[15,16].

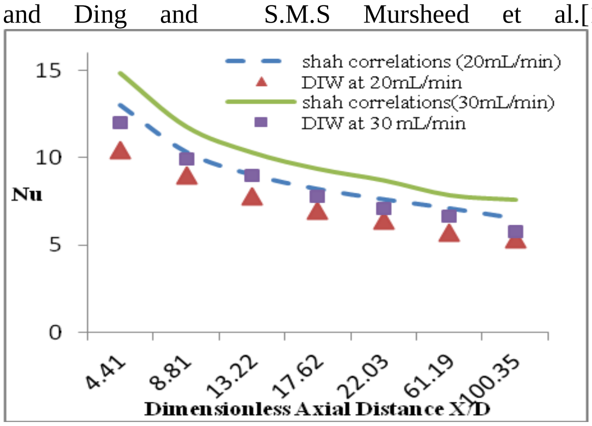

Fig:2 Comparison with Shah Equation along Axial Distance at Reynolds number 200 and 400.

RESULTS AND DISCUSSIONS:

The heat transfer characteristics of Gold/DIW nanofluid were investigated by taking into consideration of different factors such as effect of axial distance, volume fraction, and fluid velocity and Reynolds number. The range of Reynolds number is 200 to 700.

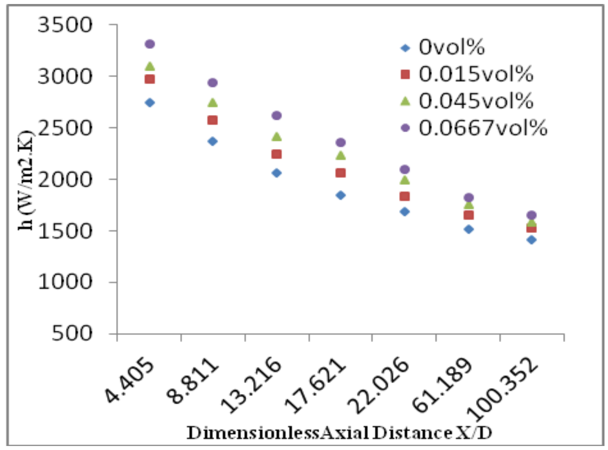

Fig:3 Axial Profile of Local Heat Transfer Coefficient at Reynold's number 200±50

Convective heat transfer coefficient:

Fig 3 and 4 shows plot of local convective heat transfer coefficient along dimensionless axial distance from the tube entrance region. Two Reynold number values are considered 200 and 400 although the Reynold number changes for each test fluid due to change in viscosity but these changes are not much significant and in the range of ±100. The results show significant improvement in heat transfer coefficient which is more significant at entrance region. For example at X/D=8.81 the enhancement in heat transfer coefficient for 0.0015 vol % nanofluid is 8.64% while at X/D=100 this value is 7%. As nanoparticles volume fraction increases the enhancement also increases which can be seen from graph. At nanoparticles volume concentration 0.0045% and 0.00667% the enhancement is 15.7% and 23% respectively at X/D=8.81.The enhancement is also higher at higher Reynolds number as shown in fig 2.

Significant decrease in heat transfer enhancement can be observed as a distance from entrance region increases. The enhancement in heat transfer coefficient is more as compared to the thermal conductivity enhancement.

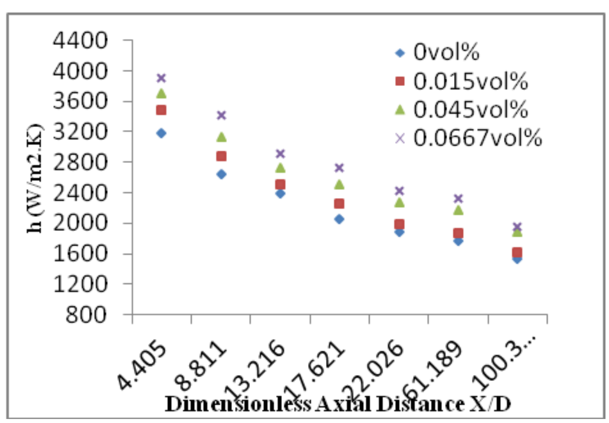

Fig:4 Axial Profile of Local Heat Transfer Coefficient at Reynold's number 400±50

As Patel *et al*.[11] reported enhancement in thermal conductivity of gold/water nanofluid up to 8% at 0.00026 volume fraction. While the results above show enhancement up to 20% in convective heat transfer coefficient. A lot of mechanisms for enhancement were proposed such as interfacial layering, ballistic transport of energy carriers and clustering. The enhancements are higher in entrance region possible reason being extended thermal boundary layer due to addition of nanoparticles and particle migration due to Brownian motion, shear stress and viscosity gradient. Wen and Ding [27] study the effect of particle migration and reported that due to high velocity gradient at entrance region particle migration is higher there and concentration does not remain uniform in the tube cross section. So non uniform thermal conductivity enhancement occur which leads to higher Nusselt number and convective heat transfer coefficient in entrance region. Particle migration effect is higher for relatively large particles.

Nusselt Number:

Fig:5 Demonstrate the effect of nanoparticles volume fraction on Nusselt number. The Nusselt number increases significantly and almost linearly with increasing volume fraction. Increasing nanoparticles volume fraction can lead to formation of clusters and in that case enhancement in heat transfer will be more. To study the exact effect of addition of nanoparticles in base fluid proper agitation is required. The relationship between Nusselt number and average fluid velocity is shown in Fig:6. As average velocity increases so does the Reynolds number and Nusselt number also increases which further lead to the enhancement of connective heat transfer coefficient.

Effect of Reynold's Number on Nusselt Number:

It is clearly seen that Nu number increases with increasing Reynold's number in Fig:7. The increment is more significant at higher Reynold's number. The reasons for this enhancement can be different such as suppression of boundary layer or addition of nanoparticles.

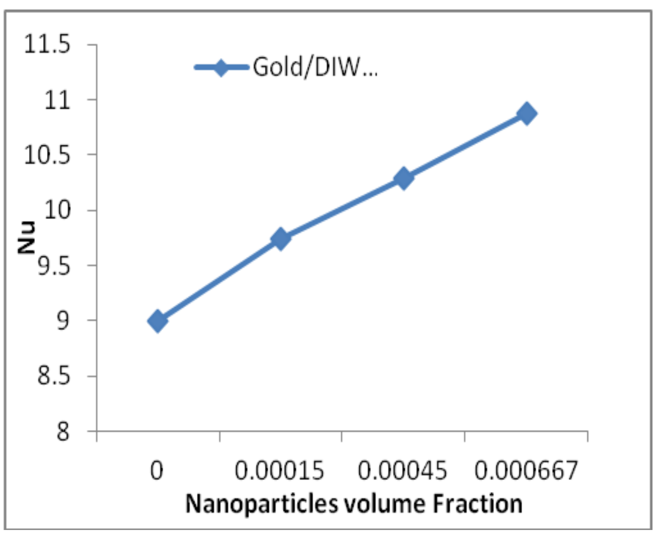

Fig:5 Particle Volume Fraction vs. Nusselt Number at Reynold Number 200 and X/D=8.81

CONCLUSION:

This paper presents a detailed experimental study on convective heat transfer enhancements of fluids by addition of nanosized gold particles. The conditions followed were laminar flow and constant heat flux. Experiments were performed with three different concentrations at three Reynolds number. The experimental results shows that

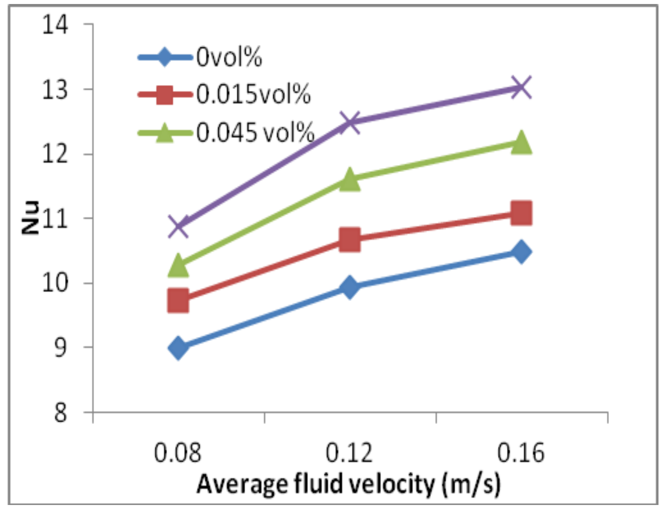

Fig:6 Average fluid velocity vs. Nusselt number at X/D= 8.81

- Under conditions of my work a reasonable enhancement in heat transfer coefficient and Nusselt number occur which increases with increasing particle concentration and Reynolds's number. The enhancement in heat transfer coefficient is upto 23% at 0.0067 vol fraction. The enhancement is higher in entrance region and thermal boundary layer of nanofluid is greater than that of base liquid. The possible mechanisms of heat transfer enhancement are enhanced thermal conductivity, viscosity, Brownian motion and partciel migration.
- For heat transfer applications in heat pipes or micro processes gold/nanofluids are good candidates but the only problem is production method and cost of the resulting fluid. Further studies need to be conducted on behavior of gold/ water nanofluids in laminar and turbulent regions at higher heat flux.

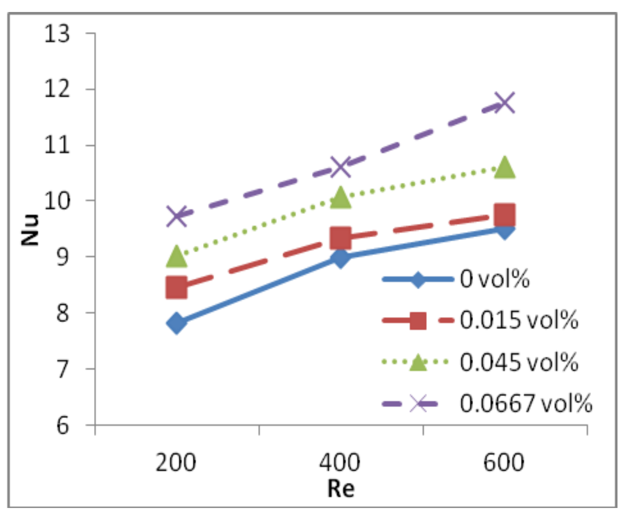

Fig:7 Reynold's number vs Nusselt number at location X/D=13

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