International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 5, Issue 02, February-2019

EFFECTS ON THERMAL ENTRANCE LENGTH OF NON-NEWTONIAN NANOFLUID UNDER VIBRATIONAL FLOW

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Abstract
Numerically investigated the effects on thermal entrance length of non-Newtonian nanofluid flowing through pipe subjected to vibration. Vibration creates swirling effects in the plane perpendicular to the flow which produces chaotic motion leads to increment in radial mixing of fluid and thus, uniform temperature distribution across the pipe results. Effects of volume concentration, solid particle diameter, and for different Reynolds number, evaluated the performance of vibrational flow. This study shows that as Reynolds number increases, the TEL also increases but the rate of increment is much less than the steady flow. Effects of nano particles concentration on TEL was also demonstrated, by increasing the concentration, thermal entrance length decreases as more particle available to start the cyclic process of heat transfer.

Keywords: CFD; Laminar flow; Internal flow; Non-isoviscous flow

I. INTRODUCTION

Suspension of solid particle of nano size which are having much higher thermal conductivity then base fluid, increases the heat transfer at a higher rate than the base fluid. Convective heat transfer characteristics of suspensions of different nanoparticle in an non-Newtonian base fluid flowing through a heated pipe were investigated experimentally and numerically by many researcher [1, 2, 3, 4, 5, 6, 7] and reported higher heat transfer and Prandtl number compared to base fluid. Nusselt number of non-Newtonian nanofluid proved to be a function Reynolds and Prandtl numbers. Illbeigi & Nazar (2017) used both power-law and Newtonian model to investigate the laminar convective heat transfer and pressure drop for water based Al_2O_3 flowing through pipe and concluded that power-law model shows better agreement with respect to the experimental data [8] than that of the Newtonian model for comparatively higher concentration of nanoparticle [9].
It has been proven by many researcher that induced vibration on the flow system, increases the heat transfer rate by producing chaotic motion, which leads to mixing of fluid [10, 11, 12] Radial mixing can be achieved either by turbulent flow, which requires higher pumping power or by inserting static mixture, but these type of device having manufacturing complexity and problem of cleaning as well.
Superimposed transverse vibration on pipe wall produces swirling effects on the plane perpendicular the flow which increases the radial mixing, hence more uniform temperature distribution results. This also reduces the thermal entrance length that replaces the use of long pipe to transfer same amount of heat, has been numerically [13] proven by Easa and Barigou (2011).
In current study, A CFD model is used to investigate the effects on **T**hermal **E**ntrance **L**ength **(TEL)** with different Reynolds number of non-Newtonian nanofluid vibrational flow, receiving heat from wall, maintained at constant temperature. Al_2O_3 nanoparticles with two average diameter of 25 & 50 were diapered in aqueous solution of CMC. The nanofluid with three different Al_2O_3 nanoparticles concentrations (0.5%, 1.0%, and 1.5%) were used. Effect of nanoparticle size, volume concentration, vibration frequency, and amplitude, on TEL were also investigated.

II. METHODOLOGY

A. Mathematical modelling

Physical properties of nanofluid
Temperature dependent physical properties of base fluid (0.5% aqueous CMC solution) was calculated from the equations available in the literature [14] and then, obtained values were used to calculate the physical properties of nanofluid.
Single phase flow model has been considered here to simulate the flow of non-Newtonian nanofluid under the vibration conditions which is the dispersion of Al_2O_3 nano particles in 0.5% aqueous CMC solution. Widely excepted, classical mixture model has been used to define density and specific heat capacity of nanofluid [15]. Chou et al (2005) has derived the empirical correlation for the nanofluid effective thermal conductivity, by using Buckingham-Pi theorem with a linear

regression for the experimental results with 95% confidence; was used to define thermal conductivity [16]. Power-law type non-Newtonian model has been considered and temperature dependent rheological properties of nanofluid were taken out from the Hojjat's experimental data [1].

CFD modelling

Consider the case of thermal laminar flow through pipe, temperature dependent apparent viscosity; and thermal conductivity is the function of particle diameter, volume concentration and Brownian motion considered. To define such flow, the following governing equations i.e. the continuity equation, equation of motion and the energy equation respectively; are considered [17].

$$\nabla . U = 0 \tag{1}$$

$$\rho \frac{DU}{Dt} = -\nabla p + \nabla . \eta \dot{\gamma} + \rho g \tag{2}$$

$$\rho C_p \frac{DT}{Dt} = \nabla . (\lambda \nabla T) + \frac{1}{2} \eta (\dot{\gamma} : \dot{\gamma}) \tag{3}$$

Physical properties of non-Newtonian nanofluid used to solve these equations simultaneously.

To incorporate the vibration in transverse direction in to the pipe wall, following equation of displacement and velocity of wall (first derivative of motion equation) used.

$$x = Asin(2\pi f t) \tag{4}$$

$$\dot{x} = A2\pi f cos(2\pi f t) \tag{5}$$

Where A and f are the vibrational amplitude and frequency, respectively; values of these parameter were selected such that the flow remain laminar in transverse direction, which is defined by the vibrational Reynolds number equation, given below [18].

$$Re_v = \frac{\rho A 2\pi f D}{\eta} \tag{6}$$

η , is the apparent viscosity of non-Newtonian nanofluid.

B. CFD Simulation

CFD simulation performed on commercially available software ANSYS 17 as discussed in the following points: 1) Pre-processing: ICEM-CFD used to modelling and grid generation of pipe geometry of $6\,mm$ diameter and of $500\,mm$ length. Structure grid with hexahedral cell was used for meshing and grid independence study performed to optimise its size; 2) Analysis: CFX used for CFD analysis, where CEL expression were used to insert all the equations, required to the flow simulation. Isothermal fully developed steady laminar flow used as an initial solution for transient flow simulation under in superimposed transverse vibration, to capture the required effects; 3) CFD post-processing tool was used for CFD result.

Table 1: Range of parameters used for flow simulation.

$D\ (mm)$	$L\ (mm)$	$f\ (Hz)$	$A\ (mm)$	$Re\ (-)$
6	300-1000	10-40	5-20	50-300

III. RESULTS AND DISCUSSION

Validation of CFD model

CFD codes are well verified for internal steady flow in both isothermal and non-isothermal condition. In this study, validation of isothermal vibrational flow has been done with Deshpande and Barigou (2001) experimental data [19], shown in Fig (1) and Shah Equation and Churchill-Ooze equation used to validate the steady flow subjected to heat transfer from wall [20], shown in Fig (2). Both figure shows the good level of accuracy with experimental and theoretical result respectively and thence CFD model could be able to well predict the flow which are considered here.

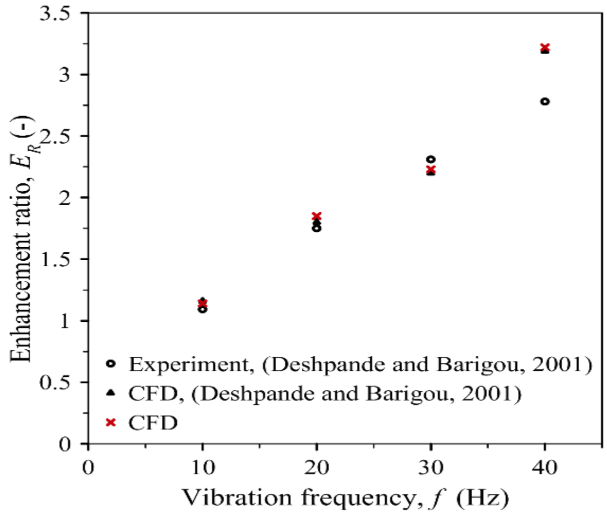

Figure 1: Validation of CFD results with experimental results for a power-law fluid subjected to longitudinal vibration:
$K = 1.47\ Pa\ s^n; n = 0.57;\ \rho = 1000\ kg\ m^{-3};$
$A = 1.60\ mm;\ \Delta p/L = 9.81\ kPa\ m^{-1}$

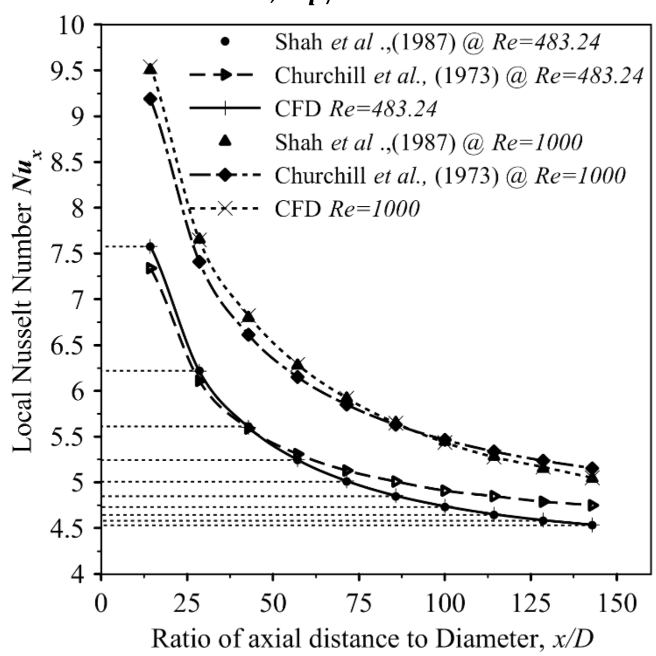

Figure 2: CFD results compared with equation of thermally developing Hagen-poisslile flow (Shah et al., 1987) for water subjected to different Reynolds number:
$D = 7\ mm;\ L = 1\ m;\ q_s = 10500\ W\ m^{-2}; T_{in} = 25$℃.

Several CFD simulation were conducted by varying; the Reynolds number, nanoparticle concentration, dimeter of nanoparticle and vibration parameters; and hydrodynamically fully developed flow were considered for both steady and vibrational flow of Non-Newtonian nanofluid through pipe subjected to constant wall temperature $(T_{w)}$ to capture the effects of vibration on TEL. Dimensionless temperature used to make the comparison among the parameters selected [21].

$\psi = (T_w - T_{(r,z)})/(T_w - T_{m(z)})$ (7) Where $T_{(r,z)}$ is the temperature function, $T_{m(z)}$ is the area average mean temperature in axial direction.

TEL increases with increasing the Reynolds number as it is the function of Reynolds number and Prandtl number, Fig (3) depicts the usual feature of variation of TEL with varying the Reynolds number for steady flow, as very long pipe required to develop the flow, whereas flow under superimposed mechanical vibration which produces chaotic and spiral motion in transverse direction that leads to radial mixing of fluid, as results fully developed flow can be achieved in much shorter pipe and hence, enhance the heat transfer in many fold. Fig (3) shows that flow has been fully developed approximately $\sim 0.3\ m$ length of pipe and rate of variation of developing region are less in vibration flow as compared with steady flow. Vibration effects are reduces further increment of Reynolds number that reduces the enhancement of heat transfer as results vibration not much effects the TEL, promote reduction of TEL can be achieved through increasing the vibration parameters.

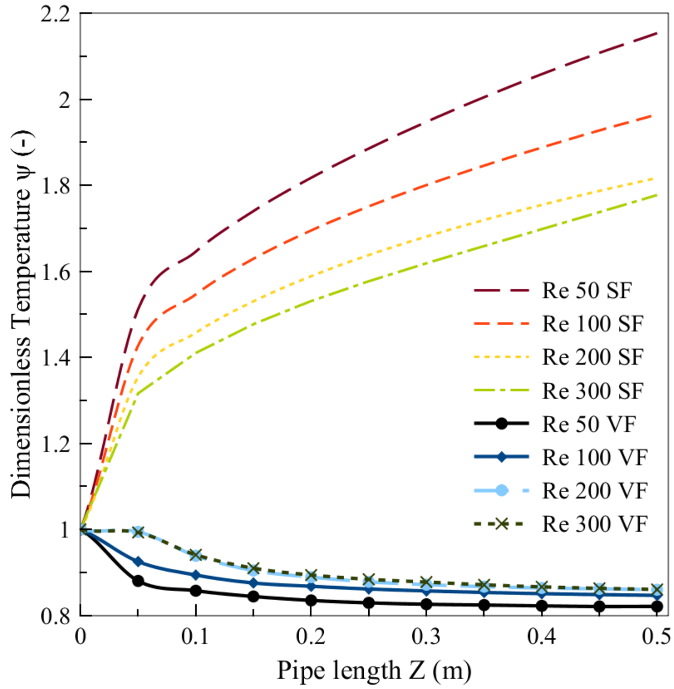

Figure 3: Variation of thermal entrance length with varying Reynolds number for Steady flow and vibrational flow:
$\boldsymbol{D = 6\ mm; L = 500\ mm;\ T_{out} = 45\ ℃; T_{in} = 5\ ℃;}$
$\boldsymbol{n = 0.495\ ; K = \text{Hojjat, et al.}, (2011);}$
$\boldsymbol{f = 20\ Hz; A = 5\ mm;\ d_s = 25\ nm;\ \emptyset = 1\ \%}$

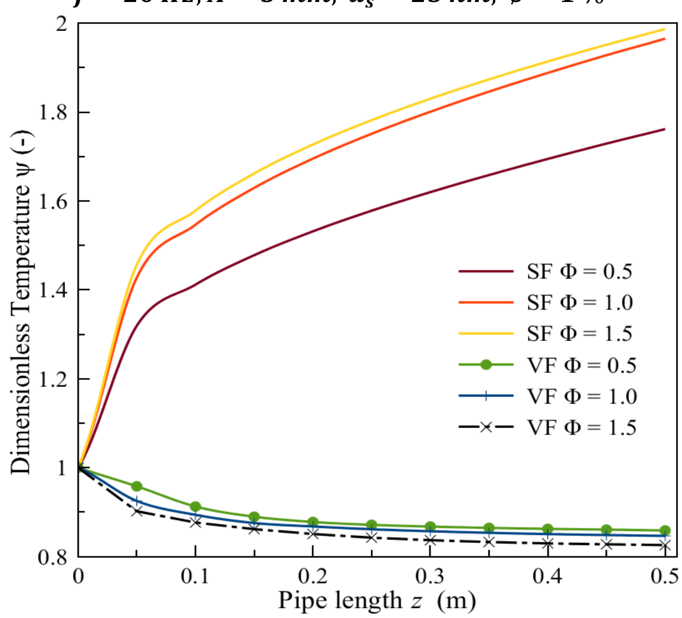

Figure 4: Effect of nanoparticles concentration on thermal entrance length for Steady flow and vibrational flow:
$\boldsymbol{D = 6\ mm; L = 500\ mm;\ T_{out} = 45\ ℃; T_{in} = 5\ ℃;}$
$\boldsymbol{n = 0.495\ ; K = \text{Hojjat, et al.}, (2011);}$
$\boldsymbol{f = 20\ Hz; A = 5\ mm;\ d_s = 25\ nm}$

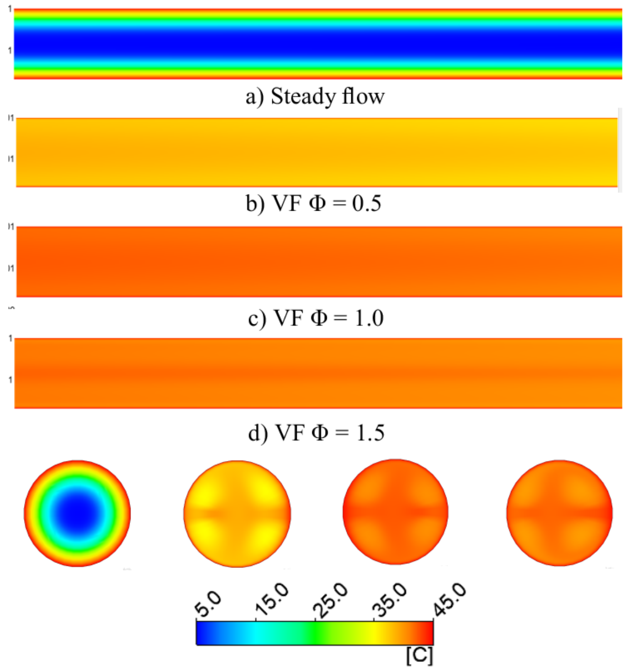

Figure 5: Axial and Radial temperature profile of nanofluid at different concentration of nanoparticle (Flow Direction from right to left)

The nanoparticles, which have the same temperature as the main flow, move to position near the wall under the imposed vibration and exposed to high temperature zone near the wall, then thus heat source performs a high efficiency heat transfer with the pipe wall. Because of cyclic process, chaotic motion forms as shown in Fig (5) leads to increase the heat transfer. Heat transfer rate increases with increasing the particle size and volume concertation. For comparatively small diameter and concentration, nanoparticle better exposed the wall surface, but with increasing the diameter and concentration after certain value, rate of increment of heat transfer decreases because effective interaction of nanoparticle to pipe wall gets maximum of its limit, Fig (4) also agree with the above statements, shows the variation of TEL with concentration. CFD result also agree with this argument, as percentage increase of heat transfer rate for low concentration nanofluid to high concentration is about 78% to 107% whereas, decreases to 89% further increment of volume concentration.

IV.CONCLUSION

A well validated CFD model used to show the effects on thermal entrance length of non-Newtonian nanofluid flow through pipe for steady and vibrational flow. Vibration creates swirling effects in the plane perpendicular to the flow which produces chaotic motion leads to increment in radial mixing of fluid. Presence of nano particle nearer to the wall, which are having higher thermal conductivity then the base fluid, received heat from source at higher rate and then move to another location as because of vibration fresh particle takes the left position, because of this cycle, heat transfer increases in several fold and thence flow becomes developed comparatively in much shorter pipe. This study shows that as Reynolds number increases, the TEL also increases but the rate of increment is much less than the steady flow. Effects of nanoparticle concentration on TEL was also demonstrated, with increasing the concentration thermal entrance length decrease because more particle available to start the cyclic process of heat transfer because of vibration. Further this study can be extended for two-phase approach to better capture the effects.

REFERENCES

[1] M. Hojjat, S. G. Etemad and R. Bagheri, “Laminor heat transfer of non-Newtinian nanofluid in circular tube,” *korean Journal of Chemical Engineering,* vol. 27, no. 5, pp. 1391-1396, 2010.

[2] M. Hojjat, S. G. Etemad, R. Bagheri and J. Thibault, “Convective heat transfer of non-Newtonian nanofluids through a uniformly heated circular tube,” *International Journal of Thermal Sciences,* vol. 50, pp. 525-531, 2011.

[3] M. Moraveji, M. Darabi, S. Hossein Haddad and R. Davarnejad, “Modelling of convective heat transfer of a nanofluid in the developing region of tube with computational fluid dynamices,” *Int. Commun Heat Mass Transfer,* vol. 38, pp. 1291-1295, 2011.

[4] M. K. Moraveji and A. Beheshti, “CFD study of the turbulent forced convective heat transfer of non-Newtonian

nanofluid," *Iranian Journal of Chemical Engineering,* vol. 11, no. 2, pp. 92-102, 2014.

[5] H. Eshgarf and M. Afrand, "An experimental study on rheological behaviour of non-newtonian hybrid nono-coolant for application in cooling and heating systems," *Experimental Thermal and Fulid Science,* vol. 76, pp. 221-227, 2016.

[6] S. A. Sajadifar, A. Karimipour and D. Toghraie, "Fluid flow and heat transfer of non-Newtonian nanofluid in a microtube considering slip velocity and temperature jump boundary conditions," *European Journal of Mechanics B/Fluids,* vol. 61, pp. 25-32, 2017.

[7] O. A. Akbari, D. Toghraie, A. Karimipour, A. Marzban and G. R. Ahmadi, "Teh effect of velocity and dimension of solid nanoparticles on heat transfer in non-Newtonian nanofluid," *Physica E,* vol. 86, pp. 68-75, 2017.

[8] M. Heyhat, F. Kowsary, A. Rashidi, M. Momenpour and A. Amrollahi, "Experimental ivestigation of laminar convective heat transfer and pressure drop of water based Al2O3 nanofluids in fully developed flow regime," *Experimental thermal and fluid science* , vol. 44, pp. 483-490, 2013.

[9] M. Illbeigi and A. S. Nazar, "Numerical simulation of lamianr convective heat transfer and pressure drop of water based Al2O3 nanofluid as a nanofluid by CFD," *Trans Phenom Nano Micro Scales,* vol. 5, no. 2, pp. 130-138, 2017.

[10] A. Klaczak, "Report from experiments on heat transfer by forced vibrations of exchangers," *Heat and Mass Transfer*, vol. 32, pp. 477-480, 1997.

[11] Y. H. Lee and S. Chang, "The effect of vibration on critical heat flux in a vertical round tube," *journal of Nuclear Science anf Technology,* vol. 40, no. 10, pp. 734-743, 2003.

[12] R. Chen , Y. Lin and C. Lai, "The Influence of Horizontal Longitudinal vibrations and the condensation section temperature on heat transfer performance of heat pipe," *Heat Transfer Engineering,* vol. 34, no. 1, pp. 45-53, 2013.

[13] M. Easa and M. Barigou, "CFD simulation of transverse vibration effects on radial temperature profile and thermal entrance length in laminar flow," *AIChE Journal*, vol. 57, no. 1, pp. 51-56, 2011.

[14] A. Carezzato, M. R. Alcantara, J. Romero, J. Gut and C. Tadini, "Non-Newtonian Heat Transfer on a plate heat exchanger with generalized configurations," *Chemical Engineering Technology,* vol. 30, no. 1, pp. 21-26, 2007.

[15] T. P. Teng and Y. H. Hung, "Estimation and experimental study of the density and specific heat for alumina nanofluid," *Journal of Experimental Nanoscience,* vol. 9, no. 7, pp. 707-718, 2014.

[16] C. Chou, K. Kihm, S. Lee and S. Choi, "Empirical correlation finding the role of temperature and particle size for nanofluid (Al2O3) thermal conductivity enhancement," *Appl. Phys. Lett.,* vol. 87, no. 15, 2005.

[17] D. V. Bird, R. C. Armstrong, O. Hassager and C. Curtiss, Dynamics of polymeric liquid, Fluid Mechanics, 2nd ed., vol. 1, New York: Wiley, 1987.

[18] R. P. Chhabra and J. F. Richardson, Non-Newtonian flow in the process industries: Fundamentals and engineering applications, Butterworth Heinemann, 1999.

[19] N. S. Deshpande and M. Barigou, "Vibrational flow of non-newtonian fluids," *chemical Engineering Science,* vol. 56, pp. 3845-3853, 2001.

[20] R. K. Shah and M. S. Bhatti, "Laminar Convective heat transfer in Ducts," in *Handbook of single phase convective heat transfer,* New York, Wiley, 1987.

[21] Y. A. Cengel, Heat Transfer: A Practical Approach, McGraw Hill Professional, 2003.