Experimental investigation of heat transfer characteristics of pulsating turbulent flow in a pipe

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Abstract - ***There are many engineering practical situations where heat is being transferred under conditions of pulsating and reciprocating flows such as the operation of modern power producing facilities and industrial equipment used in metallurgy, aviation, chemical and food technology. The performance of this equipment in thermal engineering applications is affected by the pulsating flow parameters.***

The objective of the present work is to evaluate experimentally the heat transfer characteristics of pulsatile turbulent flow in a pipe. The effect of pulsation frequency, location of pulsation mechanism on the heat transfer characteristics in pulsatile flow has been evaluated. At the same time pulsating flow visualization with smoke generation has been done. The effect of flow pulsation on average and local heat transfer coefficient has been experimentally evaluated.

The result shows that, the values of mean heat transfer coefficient are increases if pulsation is created in flow of air but the local heat transfer coefficient either increased or decreased with increasing the value of pulsation frequency. The values of mean Nusselt number are increases if pulsation is created in flow but local Nusselt number either increases or decreases with increasing the pulsation frequency. The effective way of increasing the average heat transfer coefficient is by locating the pulsation mechanism at the downstream. The maximum enhancement occurred in average Nusselt number is 38 % at pulsation frequency of 3.33 Hz as compared with plain tube.

Key Words: *Heat transfer enhancement, pulsation, Turbulent flow, Pipe flow*

1. Introduction

Conventionally, uniform fluid flow system is used in many fluid flow and heat transfer systems in conventional size as well as micro channel systems. Thus, many studies do exist in literature that deals with such systems which helped to understand the thermo-hydrodynamics of single phase as well as two-phase systems. Additionally, two more types of fluid flow that find application in many engineering systems (a) oscillating flow (or oscillatory flow), and (b) pulsating flow (or pulsatile flow). When there is no net mean velocity of the fluid in any direction and it is only oscillating back and forth about a fixed point with a superimposed frequency only then the flow is called oscillating flow. Where in case of pulsating flow, an oscillating velocity is superimposed with the one directional translational velocity. Therefore in pulsating flow time-average velocity is non-zero whereas in oscillating flow time-average velocity is zero over any particular period of cycle at any instant. This type of flow mainly characterized by two parameters namely (i) frequency of oscillation, f (or Womersley number, Wo), and (ii) amplitude of oscillation (A). Because of rapid motion, convective heat transfer may increase in such cases. The effect of pulsations on heat transfer is an interesting problem for researchers due to its wide occurrences in many real time situations at macro as well as mini/micro level.

The enhancement and determination of pipe wall convective heat transfer characteristics has likely been one of the most interesting engineering aspects of heat transfer research. Different methods to enhance the heat transfer coefficient were developed. Pulsating flow which is defined as flow with periodic fluctuations of the bulk mass flow rate may have the same influence on enhancing the heat transfer coefficients.

2. Literature Review

Several researchers have presented experimental, analytical and numerical studies on the effect of pulsation on heat transfer characteristics.

The characteristic of laminar pulsating flow inside tube under uniform wall heat flux have been experimentally investigated by Habbib et al.[12]. It is reported that an increase and reduction in Nusselt number are observed, depending on the values of both the frequency and Reynolds number. Zheng et al [8] used self-oscillator in their investigations and concluded that the convective heat transfer rate is greatly affected by the configuration of the resonator. An analytical study on laminar pulsating flow in a pipe by Faghri et al. [13] reported that higher heat transfer rates are produced. They related that to the interaction between the velocity and temperature oscillation which introduces an extra term in the energy equation that reflects the effect of pulsations. On the other hand,

Tie-Chang et al. [14] reported that the pulsation has no effect on the time averaged Nusselt number. An investigation to pulsating pipe flow with different amplitude was carried out by Guo et al. [15]. In case of small amplitudes, both heat transfer enhancement and reduction were detected, depending on the pulsation frequency. However, with large amplitudes, the heat transfer rates are always enhanced. Hemeada et al. [16] analyzed heat transfer in laminar incompressible pulsating flow, the overall heat transfer coefficient increases with increasing the amplitude and decreases with increasing the frequency and Prandtl number.

The effect of many parameters on time average Nusselt number was numerically studied by [17, 19, 20 and 21]. It is reported that the increase of Nusselt number depends on the value of the pulsation frequency and its amplitude. With amplitude less than unity, pulsation has no effect on time averaged Nusselt number [20]. In the thermally fully developed flow region, a reduction of the local Nusselt number was observed with pulsation of small amplitude. However, with large amplitude, an increase in the value of Nusselt number was noticed.

In summary, the time-average Nusselt number of a laminar pulsating internal flow may be higher or lower than that of the steady flow one, depending on the frequency. The discrepancies of heat transfer rate from that of the steady flow is increased as the velocity ratio (Δ) is increased. For hydro dynamically and fully developed laminar pulsating internal flow, the local heat transfer rate in the axial locations for $X/D < \pi Re/20\ \lambda 2$ can be obtained based on a quasi-steady flow [2].

Numerical investigations on turbulent pulsating flow have been carried out by several researchers [22, 23 and 24]. It is reported that there is an optimum Womersly number at which the rate of heat transfer is enhanced [22 and 23]. In pulsating turbulent flow through an abrupt pipe expansion, Said et al. [24] reported that the %age enhancement in the rate of heat transfer of about 10 was observed for fluids having a Prandtl number less than unity. Experimental investigations on pulsating turbulent pipe flow have been conducted by many authors The results showed an increase and reduction in the mean Nusselt number with respect to that of the steady flow.

3. Experimental Investigation

Calculation of Heat Transfer Coefficient Experimental) at upstream flow:

Results obtained by experimental set up For upstream air flow at heat input of 98.98 watts (1350 $w/m2$), manometer water column difference of 40 mm, pulsation motor speed is 100 RPM.

$$\Delta Ts = (T2+T3+T4+T5)/4$$
$$\Delta Ta = (T1+T6)/2$$
$$Q = \mathrm{h\ A}\ (Ts- Ta),$$
$$\text{Where } Q = VI$$
$$A = \pi DL$$
$$\mathrm{h} = Q/\ [A*(Ts-Ta)]$$

Calculation of Heat Transfer Coefficient (Theoretical) by Correlation Method By correlation method at $Tmean$ temp

Discharge through orifice $q = CdAo\sqrt{2gha}$

Where $Cd = 0.65$,

A_o is the area of orifice

$\rho_a = (density\ of\ water \times head\ of\ water)\ /\ (density\ of\ air)$

$Velocity = qA = 2.19\times10^{-3}\times2.54\times10^{-4} = 4.46\ m/s$

$Re = VD\gamma = 4.46\times0.025\times19.80\times10^{-6} = 11470.54$

γ is kinematic viscosity obtained from data hand book properties of air which is 19.80×10^{-6} $Re=11470.54$ based on Re no correlation has been chosen that is Dittus-Boelter equation

$$Nu = 0.023\ Re^{0.8} Pr^{0.4}$$

We know $Nu = hD/k$,

Where h is heat transfer coefficient,

D is pipe inner diameter and

k is thermal Conductivity of air at mean temperature obtained from properties.

$Nu = hDK$

$h = (Nu * k)/D$

Calculation of Pulsation Frequency

Pulsation Frequency (f) = 2N/60

4. Results and Discussions:

The effect of pulsation on the heat transfer characteristics are presented in terms of both relative local and relative mean Nusselt number and heat transfer coefficient for pulsated flow to the corresponding ones for steady flow at the same Reynolds numbers. The local heat transfer coefficient and Nusselt number is calculated by varying length of tube by considering location of thermocouples.

Calculation of Mean Thermal Characteristics for upstream flow

Comparison between Experimental and Theoretical Heat transfer coefficient with and without Pulsation

Graphs showed that the value of heat transfer coefficient calculated by experimental and theoretical method is similar. From this graphs it is proved that experimental setup is validated.

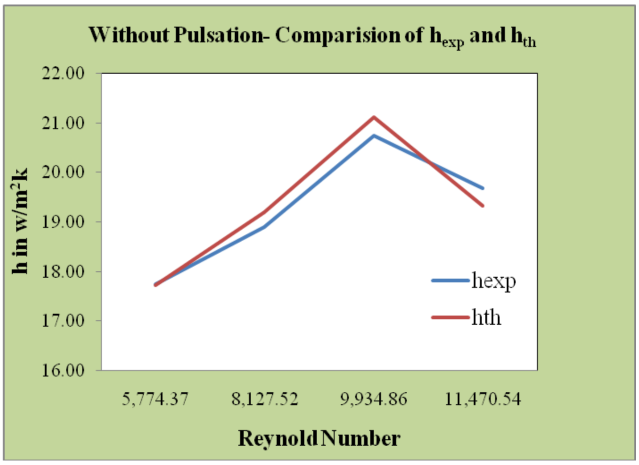

Figure 2 Comparison of heat transfer coefficient calculated experimentally and theoretically

Fig. 2 shows that the value of mean heat transfer coefficient either increased or decreased with increasing the value of Reynolds number.

Comparison between Experimental and Theoretical Nusselt Number with and without Pulsation

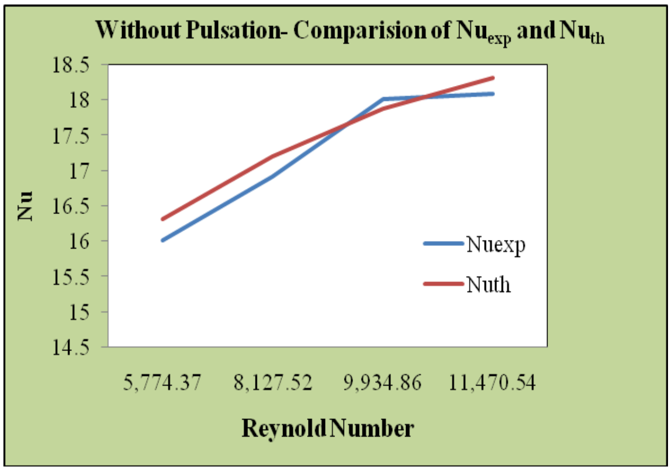

Figure 3 Comparison of Nusselt Number calculated experimentally and theoretically without Pulsation

Fig. 3 shows that the values of mean Nusselt number are similar to each other without pulsation with increasing the value of Reynolds number.

Comparison between Experimental and Theoretical Heat Transfer coefficient at Pulsation frequency is 3.33

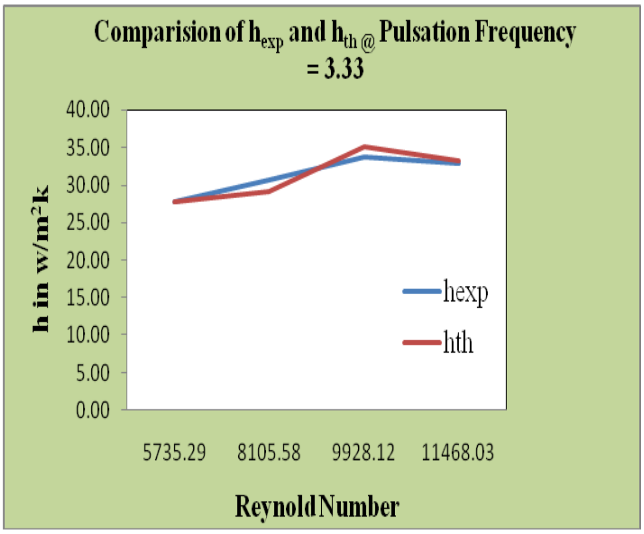

Figure 4 Comparison of Heat Transfer Coefficient experimental and theoretical when (f= 3.33 Hz)

Fig. 4 shows that the value of mean heat transfer coefficient calculated by experimentally and theoretically either increased or decreased with increasing the value of Reynolds number.

Comparison between Experimental and Theoretical Nusselt Number at Pulsation frequency is 3.33

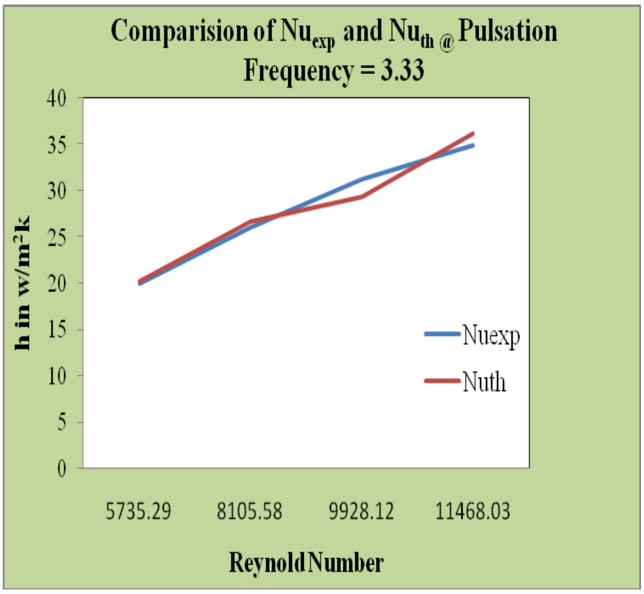

Figure 5 Comparison of Nusselt Number when frequency is 3.33 calculated experimentally and theoretically

Fig. 5 shows that the values of mean Nusselt number are similar to each other when pulsation frequency is 3.33 Hz with increasing the value of Reynolds number.

Variations in Heat Transfer Coefficient with Reynolds Number at diff pulsation Frequencies

For increment in pulsation frequency, it can be seen from Fig. 6 that enhancement is found in mean heat transfer coefficient in comparison of with and without pulsation. Fig. 6 shows that the values of mean heat transfer coefficient are either increases or decreases with increasing both the value of Reynolds number and pulsation frequencies.

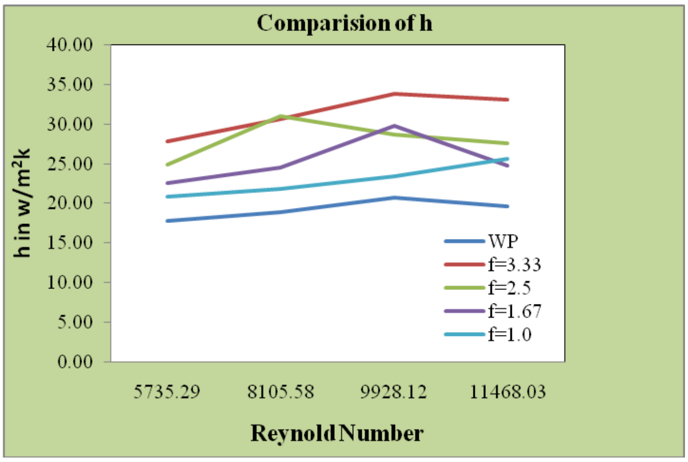

Figure 6 Variations in Heat Transfer Coefficient with Reynolds Number at various pulsation Frequencies

Variations in Nusselt Number with Reynolds Number at diff pulsation Frequencies

For increment in pulsation frequency, it can be seen from Fig. 7 that enhancement is found in mean Nusselt Number in comparison of with and without pulsation. Fig. 7 shows that the values of mean Nusselt number are either increases or decreases with increasing both the value of Reynolds number and pulsation frequencies.

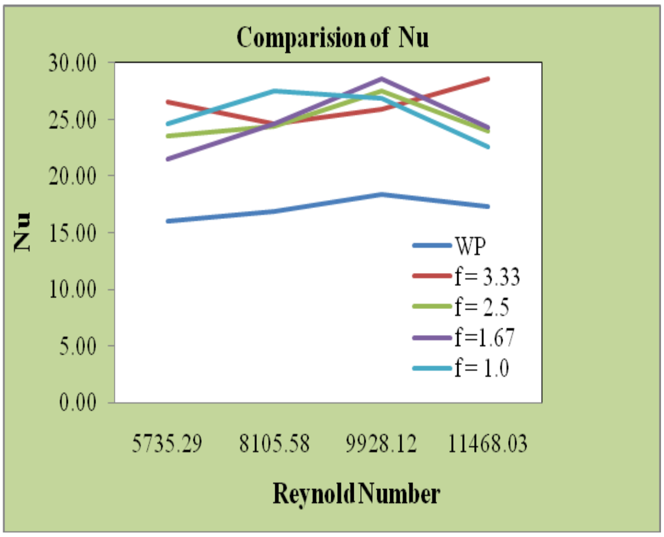

Figure 7 Variations in Nusselt Number with Reynolds Number at various pulsation Frequencies

Calculation of Local Thermal Characteristics for upstream flow

When Tube length is 50mm

Variations in Heat Transfer Coefficient with Reynold Number at diff pulsation Frequencies when L=50mm

For increment in pulsation frequency, it can be seen from Fig. 8 that enhancement is found in mean heat transfer coefficient in comparison of with and without pulsation when tube length is considered is 50mm.

Fig. 8 shows that the values of mean heat transfer coefficient are either increases or decreases with increasing both the value of Reynolds number and pulsation frequencies.

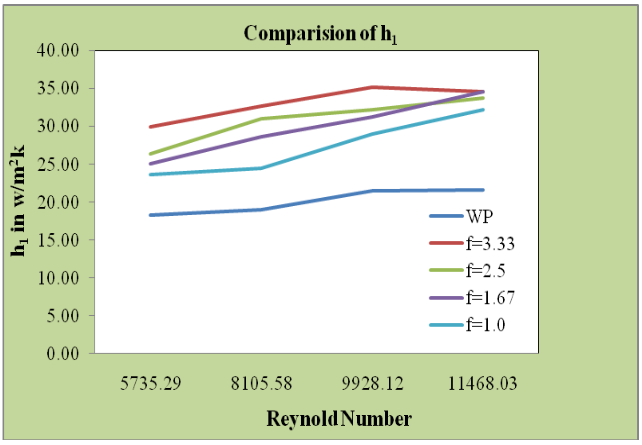

Figure 8 Variations in Heat Transfer Coefficient with Reynolds Number at various pulsation Frequencies when tube length is 50mm

Variations in Nusselt Number with Reynolds Number at diff pulsation Frequencies when L=50mm

For increment in pulsation frequency, it can be seen from Fig. 9 that enhancement is found in mean Nusselt Number in comparison of with and without pulsation.

Fig. 9 shows that the values of mean Nusselt number are either increases or decreases with increasing both the value of Reynolds number and pulsation frequencies.

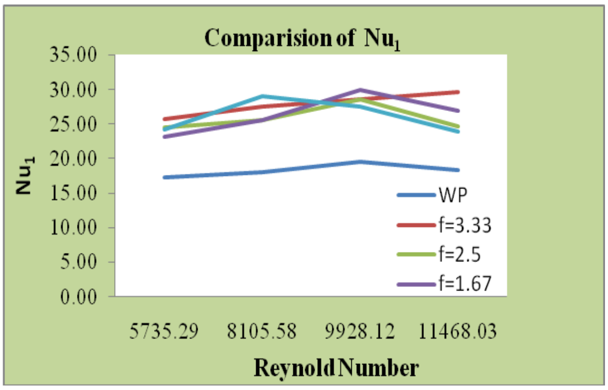

Figure 9 Variations in Nusselt number with Reynoldss Number at various pulsation Frequencies when Tube length is 50mm

5 Conclusions

The pulsation mechanism is designed by using variation in pulsation motor speed. Conclusions from studied experiment are as follows,

a) Higher values of the local heat transfer coefficient occurred in the entrance of the tested tube. The variation is more pronounced in the entrance region than that in the downstream fully developed region.

b) Value of heat transfer coefficient calculated by experimental and theoretical method is similar. From this experimental setup is validated.

c) The values of mean heat transfer coefficient are increases if pulsation is created in flow of air.

d) The value of local Heat transfer coefficient either increased or decreased with increasing the value of Reynolds number and pulsation frequency.

e) The values of mean Nusselt number are increases if pulsation is created in flow of air.

f) The value of local Nusselt number either increased or decreased with increasing the value of Reynolds number and pulsation frequency.

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