Experimental investigation of heat transfer characteristics of pulsating 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.

Index Terms—Pulsating Flow, Nusselt number, Reynolds Number, Frequency

I. INTRODUCTIONE

Several techniques for heat transfer enhancement have been introduced to improve the overall thermal performance of heat exchangers resulting in the reduction of the heat exchanger size and the cost of operation. In general, the heat transfer enhancement techniques can be classified into two methods including active method (requires external power source) and passive method (not requires external power source). The mechanism for improvement of heat transfer performance in the passive method is promoting the turbulence near the tube wall surface to reduce the thermal boundary layer thickness. This turbulence introduces a chaotic fluid mixing which acted by several enhancing modified tubes such as a finned tube, tube with rib, tube with spirally roughened wall, corrugated tube, fluted tube, helical tube, elliptical axis tube and micro-fin tube, etc.

The heat spreading process is best visualized by looking at a small volume of fluid in a single tube as shown in the sketch at right. The fluid has no net motion but simply oscillates back and forth. The slug of fluid comes to equilibrium at temperature T. If it oscillates up, it will be next to a wall which is at T+ δT so the slug will absorb heat from the wall and raise its temperature (a portion of the fluid undergoes phase change). When it moves down, it will be at a higher

temperature than the adjacent wall and give up heat to the wall. While its oscillation amplitude is small, each slug provides a net transport of heat from top to bottom. Other slugs above and below it will repeat this process, resulting in macroscopic heat transport from the load to the sink. This oscillation transfers (or spreads) heat with extremely high efficiency, particularly at high oscillating frequencies.

The performance of this equipment in thermal engineering applications is affected by the pulsating flow parameters [1]. During the past few decades, numerous studies have been devoted to this pulsating flow and its associated heat transfer problems. Pulsating flow is assumed to be consisted of a steady Poiseuille flow and purely oscillatory [2]. The amplitude of the oscillatory velocity is less than the time mean velocity and flow direction never reverse. Pulsating flow is one of the unsteady flows that are characterized by periodic fluctuations of the mass flow rate and pressure. Most of investigators [1-12] considered in their studies a small number of operating variables and confined it to relatively narrow range. As a result, some investigators reported little increase, no increase, and even decrease in the rate of heat transfer. These conflicting in results showed that the heat transfer characteristics in pulsating flow are still not clearly understood. Due to the complicated nature of unsteady turbulent flow, too much theoretical investigations are needed to find a solution for the problems of hydrodynamics and heat transfer of such a flow. Therefore the experimental investigation is still the most reliable way to deal with the pulsating flow.

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].

Many parameters have an influence on heat transfer characteristics of pulsating turbulent flow. Among those, pulsation frequency, its amplitude, axial location, Reynolds number, Prandtl number and pulsator type and its location. In order to understand the phenomena of the effect of pulsation on the heat transfer coefficient and to resolve these problems of contradictory results, different models of turbulence for pulsating flows were considered. These models are well known and mostly applied; the quasi-steady flow model [22-26] and the bursting model

II. EXPERIMENTAL SET UP

A. Set Up

In order to achieve the stated objectives, the experimental set up is designed as shown in Fig.3.1 which investigate the effect of pulsation on the convective heat transfer characteristics in pulsating turbulent flow in pipe. It is an open loop in which air as a working fluid is pumped and passed the test section to the atmosphere after being heated. The rig basically consists of three part; the air supply unit with necessary adoption and measuring devices, the test section and the pulsating mechanism. The air supply unit and its accessories consist of a blower, flow control valves, orifice meter. The proposed pulsating mechanism consists of slotted disc connected to the motor which is further connected to the main supply through dimmer so that we can change the pulsation frequency. The whole mechanism is kept in front of the pipe outlet which repetitively opens and closes s the flow through slotted disc and thus imparts pulsation to the air.

Fig.1 Photograph of experimental set up

B. Pulsation Mechanism

The aim this work is to study the heat transfer characteristics in pulsating turbulent flow through pipe. Ultimately the main important mechanism is the pulsation mechanism which serves the purpose of giving the pulsation to the fluid flow. The pulsation mechanism consists of slotted disc connected to the motor which is further connected to the main supply through dimmer so that we can change the pulsation frequency. The whole mechanism is kept in front of the pipe outlet which repetitively opens and closes the flow through slotted disc and thus imparts pulsation to the air.

Fig. 2Pulsation mechanism

C. Test Methodology

In this investigation, an experimental program is conducted to study the heat transfer characteristics of pulsating turbulent air flow through pipe. Several parameters affect the performance of heat transfer of such a flow. Among all the frequency of pulsation, Reynolds number and the location of pulsation mechanism relative to the test-section may have the great effect. Experiments in pulsating flow were executed while the pipe wall is heated with different heat input and the pulsation mechanism was located downstream of the test section. The mass flow rate of air was adjusted and held unvaried while varying the pulsation frequency from 0.0 up to 3.33 Hz. The investigation covered different values of Reynolds numbers in the range of $6700 < Re < 13400$.

In order to Experimental Evaluation of Heat Transfer through pipe at pulsating flow, it has been decided to vary the manometer water column difference from 10mm to 40mm in the step of 10mm. The heat input is a range from 25W-100W.Testing is carried out at without pulsation and with pulsation. Pulsation is created with the help of rotating motor, kept at outlet of flow. Motor speed is kept varying as 30RPM, 50RPM ,75RPM, 100RPM.

Pulsation motor speed is kept varying as 30RPM, 50RPM,75RPM, 100RPM.

For selected mass flow rate of air and different heat inputs, inlet, outlet and surface temperatures of the thermocouples are noted at steady state. The same experimentation is repeated for different pulsation frequency and the corresponding voltmeter and ammeter readings are noted and power supplied to electrical heater is calculated.

Air flow is measured with the help of orifice meter.Experimentation was carried on the circular pipe at various frequencies of pulsation.

Parameter	**Description**
Heat input (W)	25 W to 100 W
Manometric difference	10mm to 40mm
Speed of Pulsation Motor or frequency	30RPM(1Hz), 50RPM (1.67Hz), 75RPM(2.5Hz), 100RPM(3.33Hz).
Location of mechanism	At upstream and downstream

III. RESULTS AND DISCUSSIONS

Fig. 3 to Fig. 16 showed the average heat transfer coefficient increases with increasing the pulsation frequency and Reynold number. The Nusselt number increases by creating pulsation in flow of air. The Nusselt number increases with increasing the pulsation frequency and Reynold number. With increase in heat input the enhancement in average heat transfer coefficient and Nusselt number were observed for pulsation mechanism at upstream and downstream position of pulsation mechanism. Enhancement in heat transfer coefficient and Nusselt number is obtained by locating the pulsation mechanism at downstream of flow. The flow visualization clearly depicts the mixing of the fluid under pulsatile flow which enhances the heat transfer.

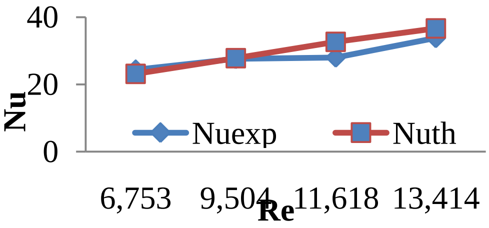

Fig. 3 experimentally and theoretically Comparison of Nusselt Number calculated experimentally and theoretically without Pulsation

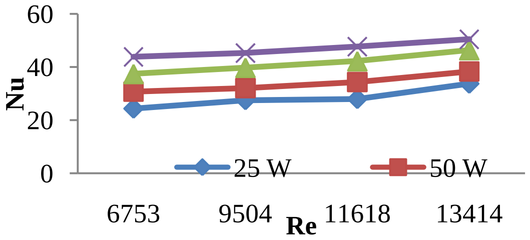

Fig. 4 Variations in Nusselt Number Coefficient with Reynolds Number at different heat input

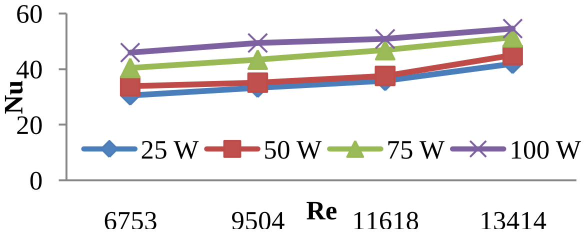

Fig. 5 Variations in Nusselt Number Coefficient with Reynolds Number at different heat input with pulsation frequency 1 Hz

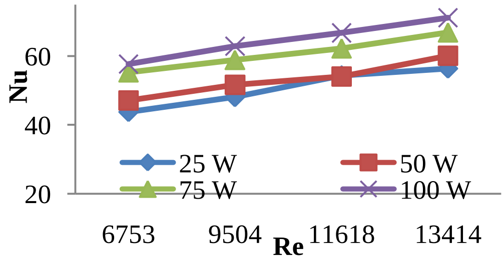

Fig. 6 Variations in Nusselt Number Coefficient with Reynolds Number at different heat input with pulsation frequency 3.33 Hz at downstream.

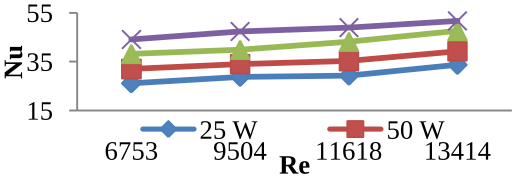

Fig. 7 Variations in Nusselt Number Coefficient with Reynolds Number at different heat input

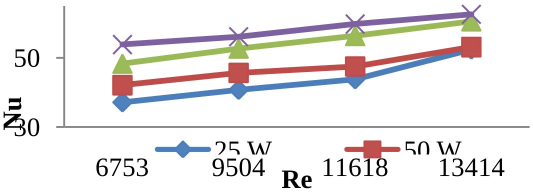

Fig. 8 Variations in Nusselt Number Coefficient with Reynolds Number at different heat input with pulsation frequency 3.33 Hz

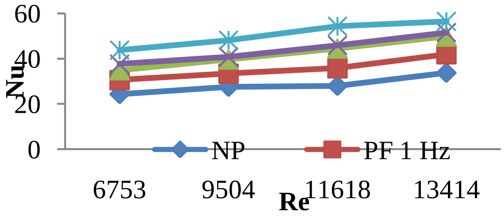

Fig. 9 Variations in Nusselt number with Reynolds Number with various pulsation Frequencies at 25 W

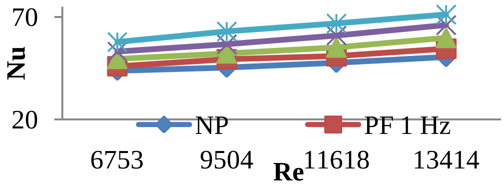

Fig. 10 Variations in Nusselt number with Reynolds Number with various pulsation Frequencies at 100 W

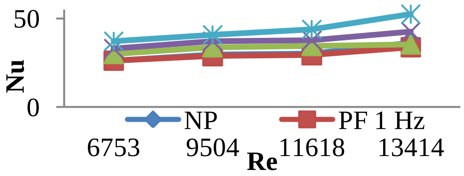

Fig. 11 Variations in Nusselt number with Reynolds Number with various pulsation Frequencies at 25 W

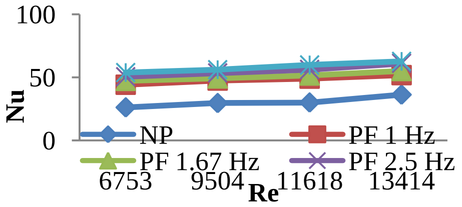

Fig. 12 Variations in Nusselt number with Reynolds Number with various pulsation Frequencies at 100 W

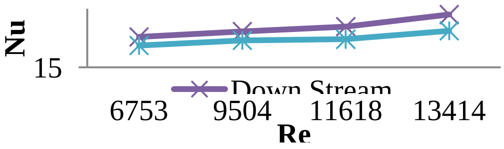

Fig. 13 Comparison of Nusselt Number calculated for pulsating mechanism at both side and Pulsation frequency 1 Hz and heat input 25 W

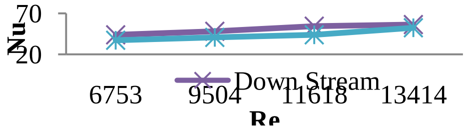

Fig. 14 Comparison of Nusselt Number calculated for pulsating mechanism at both side and Pulsation frequency 3.33 Hz and heat input 25 W

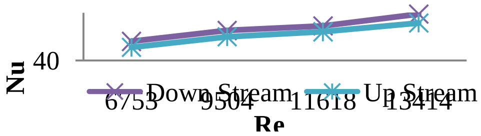

Fig. 15 Comparison of Nusselt Number calculated for pulsating mechanism at both side and Pulsation frequency 1 Hz and heat input 100 W

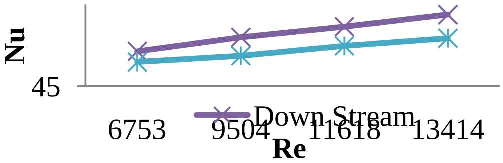

Fig. 16 Comparison of Nusselt Number calculated for pulsating mechanism at both side and Pulsation frequency 3.33 Hz and heat input 100 W

IV. FLOW VISUALIZATION

Flow visualization can be achieved through introducing smoke into the airflow. The smoke follows the air currents, allowing the observer to visualize the flow. There are several ways to introduce the smoke into the system. The flow visualization was carried out using smoke injection technique. The system consisted of an acrylic tube fitted with test section, smoke generator and a digital camera as shown in Fig. 18 and Fig. 18.

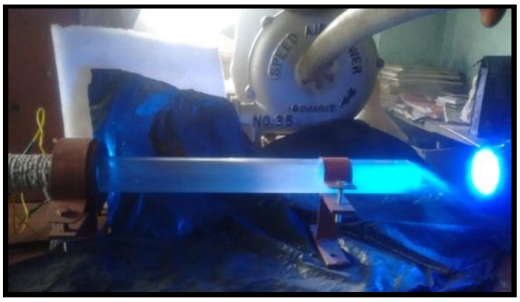

Fig. 17 Flow visualization with smoke injection and blue colored lamp

Fig. 18 Flow pattern for pulsation frequency f = 1.67 & Re = 6753

V. CONCLUSION

The experimental investigation was carried out to found out heat transfer characteristics for turbulent flow through pipe. The effect of pulsation frequency, Reynold number and heat input on heat transfer coefficient and Nusselt number in case of upstream and downstream location of pulsation mechanism is experimentally investigated. The heat input to band air heater is varied from 25W to 100W and air stream flow rate varied in such way that orifice manometer shows difference of water column 10 mm to 40 mm. The pulsation mechanism is designed by using variation in pulsation motor speed.

The maximum enhancement obtained in heat transfer coefficient is 32% at pulsation frequency 3.3 Hz.The Nusselt number increases by creating pulsation in flow of air. The Nusselt number increases with increasing the pulsation frequency and Reynold number. The maximum enhancement obtained in Nusselt number is 36% at pulsation frequency 3.3 Hz.

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