Experimental Studies on Heat Transfer in Pulsating Turbulent Flow in a Pipe

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Abstract:- *This study presents result about Heat transfer characteristics of pulsating turbulent air-flow in a pipe heated at uniform heat flux were experimentally investigated. The experiments were performed over a range of $1*10^4 < Re < 7*10^4$. This situation finds applications in modern power generation facilities and industrial processes. With installing the oscillator downstream of the tested tube exit, results showed that Nu is strongly affected by both pulsating turbulence and Reynolds number. Its local value either increases or decreases over the steady flow value. The variation is more pronounced in the entrance region than that in the downstream fully developed region. It is observed also that the relative mean Nu either increases or decreases, depending on the frequency range of turbulence. Although the deviations are small, it seems to be obvious at higher values of Reynolds number. The obtained heat transfer results are classified according to turbulent bursting model and looked to be qualitatively consistent with previous investigations.*

Key Words: Pulsating, Heat flow, Turbulence

1.INTRODUCTION

One of the most important areas in the mechanics is the mechanical behaviour of materials when subjected to thermal effects. The thick walled cylindrical pipe subjected to internal heat flow is used in many applications. When a thick walled cylindrical pipe is subjected to a temperature gradient, uniform deformation is induced and heat fluxes are developed.

Two types of flow mainly exist in pipes namely, laminar and turbulent flows. The characteristic that distinguishes laminar from turbulent flow is the ratio of inertial force to viscous force, which can be presented in terms of the Reynolds number. Viscosity is a fluid property that causes shear stresses in a moving fluid, which in turn results in frictional losses. This is more pronounced in laminar type of flow; however, the viscous forces become less important for turbulent flows. The reason behind this is due to that in turbulent flows random fluid motions, superposed on the average, create apparent shear stresses that are more important than those produced by the viscous shear forces.

The eddy diffusivities are much larger than the molecular ones in the region of a turbulent boundary layer removed from the surface (the core region). Associated with this condition, the enhanced mixing has the effect of making velocity, temperature and concentration profiles more uniform in the core. As a result, the velocity gradient in the surface region, and therefore, the shear stress, is much larger for the turbulent boundary layer than for the laminar boundary layer. In a similar manner, the surface temperature, and therefore, the heat transfer rate is much larger for turbulent flow than for laminar flow. Due to this enhancement of convection heat transfer rate, the existence of turbulent flow can be advantageous in the sense of providing improved heat transfer rates. However, the increase in wall shear stresses in the case of turbulent flow will have the adverse effect of increasing pump or fan power requirements. On the other hand, the conductive heat transfer becomes more important in laminar flow than the turbulent flow.

Barozzi and Pagliarini et al, A method to solve the conjugate heat transfer problems for the case of fully developed laminar flow in a pipe was introduced by Barozzi and Pagliarini. The superposition principle with finite element method was employed. They considered the wall conduction effect on heat transfer to fully developed laminar pipe flow with the exterior boundary was uniformly heated along a finite length. They showed that axial conduction in the wall lowered the Nusselt number with respect to the case in which the axial conduction was largest.

Parakash and Liu, analyzed the laminar flow and heat transfer in the entrance region of an internally finned circular duct by numerically integrating the governing partial differential equations. They considered two types of boundary conditions, the uniform heat input per unit axial length with peripherally uniform temperature at any cross section and the uniform temperature both axially and peripherally. Their results exhibited the expected high-pressure gradients and heat transfer coefficients in the entrance region, approaching asymptotically the fully developed values at large axial distance. Sucec et al did transient convective heat transfer to a fluid flow within a pipe due to sudden change in the temperature of the ambient

medium outside the pipe was considered by Sucec. He developed a solution by the Laplace transformation for the pipe wall temperature, surface heat flux, and fluid bulk mean temperature. He developed a criterion for the zero thermal capacity wall solution, which could be used with adequate accuracy. Schutte et al , analysed transient conjugate heat transfer in a thick-walled pipe with developing laminar flow was studied by Schutte et al. By simultaneously solving for conduction in the pipe wall and for convection in the fluid stream, they analyzed the transient behaviour of the flow and temperature fields. They considered two transient situations namely; the transient heat transfer in developing pipe flow, and heat transfer in simultaneous development flow in a pipe. They found that the ratio of wall thickness to inner diameter, Peclet number, ratio of wall to fluid thermal conductivities, significantly influenced the duration of the transient as well distribution of Nusselt number, interfacial temperature, bulk temperature, and interfacial heat flux during the transient processes. The ratio of wall to fluid thermal diffusivities had also an important effect.

Min et al., analyzed the thermally fully developed and thermally developing laminar flows of a Bingham plastic in a circular pipe. He has obtained the solution to the Graetz problem by using the method of separation of variables and discussed the effects of the Peclet number and Brinkman numbers on the Nusselt number. Faghri et al., studied the problem of heat transfer from a cylindrical pipe for a case where the flow inside the pipe consisted of a periodic motion imposed on a fully developed steady laminar flow. They showed that the interaction between the velocity and temperature oscillation introduced an extra term in the energy equations, which reflected the effect of pulsations in producing high heat transfer rates. The heat transfer in laminar oscillating flow in cylindrical and conical tubes was examined by Peattie and Budwig. They showed that the convective transport increased with frequency at constant amplitude. Laminar and turbulent oscillating flow in circular pipes was investigated by Ahn and Ibrahim. A high Reynolds number k-e turbulence model was used to account for the turbulence in the pipe. They indicated that the standard k-s turbulence model could not adequately predict the oscillating flow properties in a transition flow regime.

The present study investigates the heat transfer in a heated pipe when they are subjected to pulsating turbulent flow conditions. The heat transfers in a pipe due to fully developed pulsating turbulent flows are considered and the Reynolds number is taken into account in this regard.

The study parameters also include the change of heat transfer with the pipe dimensions. Pipe diameters, thickness to diameter ratios Reynolds numbers, Prandtl numbers, heat transfers are also employed in the study.

2. EXPERIMENTAL SETUP AND INSTRUMENTATION

Fig 1. Experimental equipment
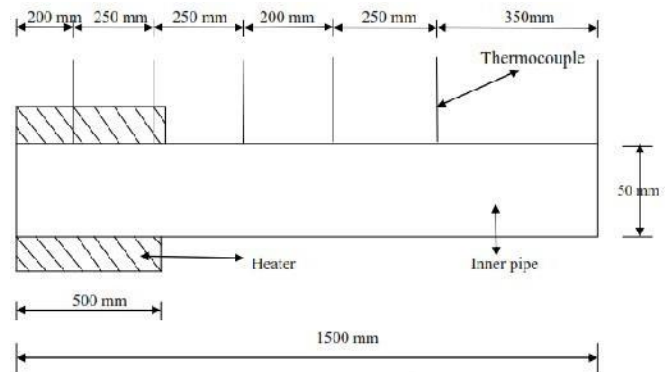

Fig 2. Turbulence Inducer

Fig 3. Test section

The experimental facility shown in Fig. 1 is constructed to investigate the effect of pulsation on the convective heat transfer from a heated pipe over a range of 1*104< Re < 7*104. 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 shown in figure 2. The air supply unit and its accessories consists of an air compressor, storage tanks, flow control valves, orifice meter, settling chamber and calming joints