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Empirical Research of Heat Transfer in Oscillating Pipes

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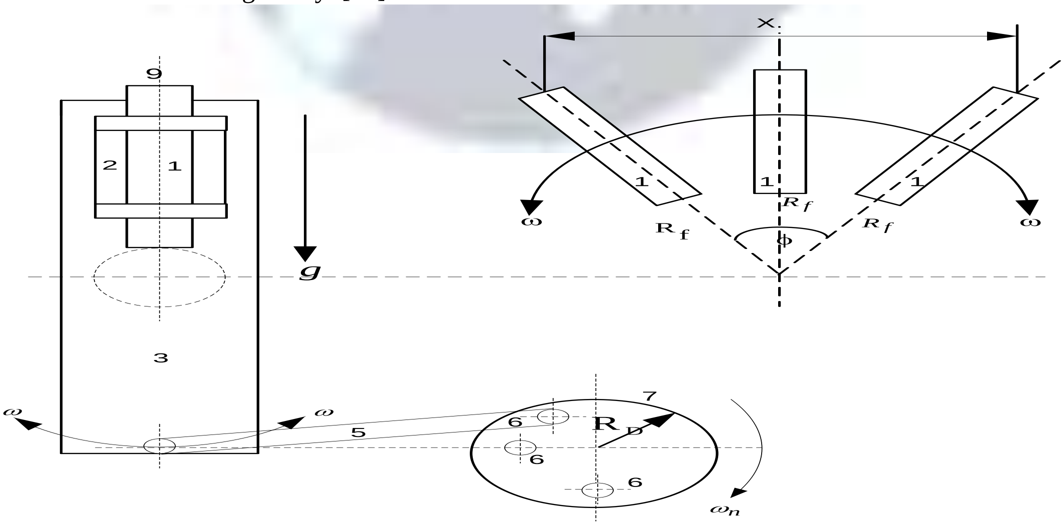
Abstract: In this research, characteristics of heat transfer and pressure loss of oscillating pipes at certain amplitudes and frequencies were investigated. For this aim, an oscillating mechanism was designed. Experiments were conducted for the oscillating frequency f, in the range of 0.008- 1.988 Hz and dimensionless amplitude X=3, 6, 9. , Reynolds number was changed from 5000 to 25000. It was determined that oscillating amplitude and frequency was reasonably effective on heat transfer and friction factor.

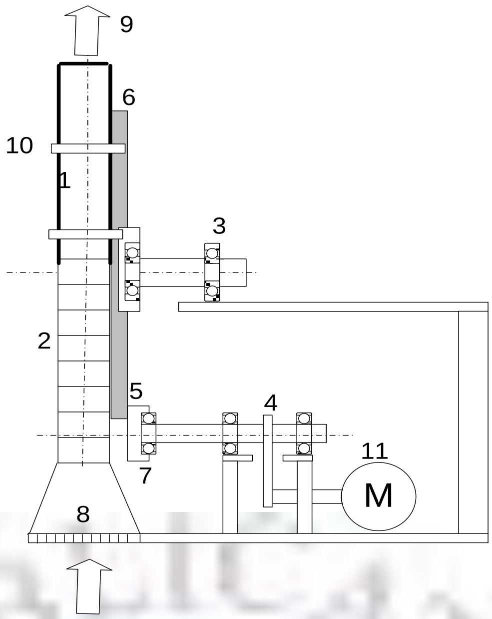
Keywords: Pulsating flow, oscillation, heat transfer, turbulent flow.

1. INTRODUCTION

The periodicfluctuation of fluid causes heat transfer and makes differ on the characteristics of flow. The flow surge or vibration is usually fall into two categories: wavy and oscillating flow. Pulsating flows are found in several engineering applications. These include: flows at the inlet exhaust ducts of reciprocating engines, or in pipelines fed by reciprocating pumps and compressors. Flow in systems whose operation is based on the wave action such as the pulse-jet and compressors is another example of pulsating flows. The screech phenomenon in rocket engines, which is accompanied by high wall temperature, involves flow superimposed oscillations. Other applications include the circulation of blood and the heat interchange between the blood and tissues, unsteady phenomena in equipment used in power production or process engineering, metallurgy, aviation, chemical and food technology. Fluctuating laminar flow had been studied by many researchers; but the heat transfer of fluctuating turbulence flow is so interesting and important because of its practical application and the researches about this subject are still not completed. [1-6].In this research; frequency does not affect directly the Nusselt number [7], there is not any improvement in heat transfer [8], the heat transferaffected negatively under a certain frequency valuesof Nusselt number [9], reached to the result that heat transfer improvement are happens at a certain frequency and at high amplitude values of are worth a certain frequency and large were found for the other results.[10] .In this research; the effect of amplitude and frequency on heat transfer experimentally studied by making an oscillating mechanism and the effect of these two important parameters experimentally had been examined. Gbadebo and his friends at constant heat flux with regard to turbulence and vibrated flow, experimentally had studied. The researchers here found that, with a known range the Reynold number values firstly increases; but after increasing the frequency it fall down, meaning that at high and so low frequency values effects the heat transfer negatively. [11]



(a)
1-Test pipe, 2-Insulation 3- Supporting arm 5- oscillating arm 6-Amplitude adjuster pins 7. Amplitude adjustment rotating disc 9. Air output



(b)

1-Test pipe, 2-flexible pipe, 3-Bearings, 4-belt-pulley, 5-oscillating arm, 6-support 7-Amplitude adjustment rotating disc, 8-air intake, 9-Air output -10. Holders, 11.Electric motor.

Fig. 1: Oscillating mechanism

2. OSCILLATING SET-UP

As shown in Figure 1-a the electric motor (11) as a result of the return with the angular velocity$\omega_n$depending on the arm pins(6) gives oscillating movement to part (3) which test pipe no. (1) connectedby means of oscillating arm part (5) that moves with Amplitude adjusterpinspart (6) on rotating disc (7).The pins no. (6) are mounted on disc no. (7) in such a way that gives different radius (R_D) by connecting arm (5) to part (7) with part (6). The amplitude value that achieved by (R_D) are token 15 mm, 30 mm, 45 mm. In this study the x value as shown in fig. 1a are chosen as 30, 60, 90 mm. Dimensionless amplitude value is known as X = x/D, hence the dimensionless amplitude values will be 3, 6, 9. The rotating speed of motor varies between 250 rpm to 1000 rpm and the angular velocity varying accordingly.

The arm no. (5) that moves with constant rotating speed of motor (ω_n) moves the experiment element part no. (3) with angular velocity value (ϕ), and this value varies between (0-π/4), Test pipe (1) angular velocity can be written as follows:

$$\omega = \frac{R_D}{R_f}\omega_n Sin\phi \qquad (1)$$

as shown in Equation (1) the angular velocity changes according to the ϕangle

3. EXPERIMENTAL METHOD AND MEASUREMENT SYSTEM

As seen in Figure 1 schematic experiment assembly picture consists of oscillating arm, testpipe, heating and measuring element. As an experiment element, length 200 mm, internal diameter of 9 mm and outside diameter 10 mm stainless steel were used. Test pipewere carried out with electrical resistance heating wire. Test pipes wrapped with resistance wire in equal distances so provided a uniform heat flux over it. There are heat-resistant insulating contact between wires and test pipe.constant heat fluxgiven to the test pipe. To measure temperature values on the wall of test pipe we using 10 pieces thermocouples with equal distances and elongation of test pipehelically that fixed by opening so thick canals on the wall and to avoid heat loss of the pipe and there are insulation material on the wall.Also the test pipe insulated from inside to measure heat values with different frequencies and different amplitude values and heat loss experiment had been done. Experimental operating conditions determined by the frequency and amplitude of the wall temperature of the schedule change and thermal equilibrium has been established, the wall temperature and the ambient temperature has been recorded. The measured temperature of the wall along the test pipe is given in Figure 2.

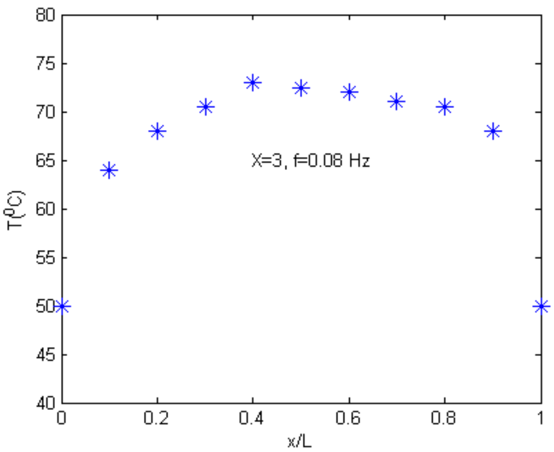


Fig. 2: A typical wall temperature distribution along test pipe

Experiment of pipe average surface temperature;

$$F = \frac{h}{2}[T_1 + 2T_2 + 2T_3 + \ldots + 2T_9 + T_{10}] \quad (2)$$

$$\overline{T}_w = \frac{F}{L} \quad (3)$$

Where h is the distance between two points that made the measurement, and T_1, T_2, T_n are temperatures of wall along test pipe, T_w is an average wall measured temperature of test pipe,Lis the length of test element. To determine Heat loss coefficient in the different heat and power, equation(4) are used.

$$\dot{Q}_{loss} = \overline{n}(\overline{T}_w - T_o) \quad (4)$$

Here $\overline{n}$ is the coefficient of frequency depending on oscillation and amplitude of the mechanism that varies between, $0.0480 \leq \overline{n} \leq 0.078$. The average heat transfer coefficient; and the average wall temperature and the average fluid temperature can be known as;

$$\overline{h} = \frac{Q_{given} - Q_{loss}}{A(\overline{T}_w - \overline{T}_b)} \quad (5)$$

and average Nusselt number is;

$$\overline{Nu} = \frac{\overline{h}D_h}{k} \quad (6)$$

Here k is thermal conductivity of fluid, $D_h$hydraulic diameter and $\overline{h}$ is average heat convection coefficient. Nusselt number of cylindrical pipes for enhanced turbulent flows, is defined by Petukhov and Popov in the following manner [14,15].

$$Nu_{corl} = \frac{(f/2)\,Re\,Pr}{(1+13.6f)+(11.7+1.8Pr^{-1/3})(f/2)^{1/2}(Pr^{2/3}-1)} \quad (7)$$

Here fis defined in equation (8).

$$f = (3.64\log Re - 3.28)^{-2} \quad (8)$$

In the heat transfer experiments the fluid that inters the oscillating test pipeare heated from outside the wall with constant heat flux.Amplitude, frequency,wall temperature, fluid input and output temperatures and flow rate of the fluid are measured. Reynolds numbers for oscillating cylindrical pipes are;

$$Re_{osc} = \frac{2\pi f x_o D}{\upsilon},\ x = x_0 \sin[2\pi f t];\ \dot{x} = x_0 2\pi f \cos[2\pi f t];\ \dot{x}_{peax} = 2\pi f x_0 = V_{scale} \quad (9)$$

$$f = \frac{\Delta P}{\left(\frac{L}{D}\right)\rho \frac{v^2}{2}} \qquad ; \; v = \frac{\dot{m}}{\rho \frac{\pi D^2}{4}} \tag{10}$$

4. RESULT AND DISCUSSION

To reduce the error rate in the experiments forf = 0 and X = 0, conditions (oscillatingpipe) validation experiments were made, and the results were [(Nu = 0.023 Re $^{0.8}$ Pr$^{0.4}$)], compared with the given correlation of Petukhov [7] and Gnielinski [16] in (Figure 3). The results of the amplitude and frequency in the experiments to determine the effect of heat transfer is givenin between (Figures 4-7). Centrifugal fluid movement in the direction of the local Nusselt number during throughout the pipeexchange is given in (Figures 4-5). Withincreasingthe Re number, the local Nusselt number increases; but this increase in the points close to the input and output pipehas been seen higher. In Figure 5 increasingthe frequency is observed made a positive impact on heat transfer. According to the experimental results, the heat transferincreases depending on the frequency of oscillation compared to the static situation. At holding amplitude value constant, an increase in frequency with the increase in the local Nusselt number is observed. However, can be seen thatthis increase was higher in the endpoints of the pipe and the Nuchanges takes a concave shape along the pipe. Figure 6 shows the change in the Nu-Re, dimensionless amplitude values X = 3, 6, 9 for f = 1320 Hz are taken constant. With increasing amplitude, thereduction in heat transfer had seen.

In Figure 7 by fixing the amplitude value,the effect of changing frequency valueto the heat transfer been examined. At the same amplitude values with increasing frequency,had been seen an increase in the Nusselt number comparing to the empty pipe, and in high-frequency values comparing tothe emptypipe, have been found to be an improvement in heat transfer approximately 20%.
Figure 8 shows The effects of Amplitude and frequency variations on friction coefficient.When we will compare this figure to the Petukhovstudy,we will see a brief match between them and beside that there are a good rate in increasing in coefficient of friction for about 120% - 300% depending on the frequency value.

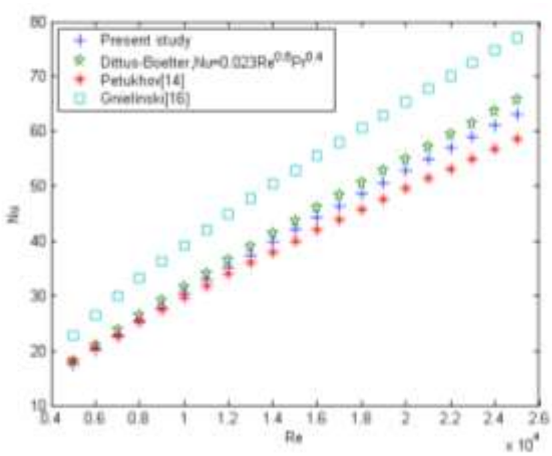


Fig. 3: Empty pipe correction experiments

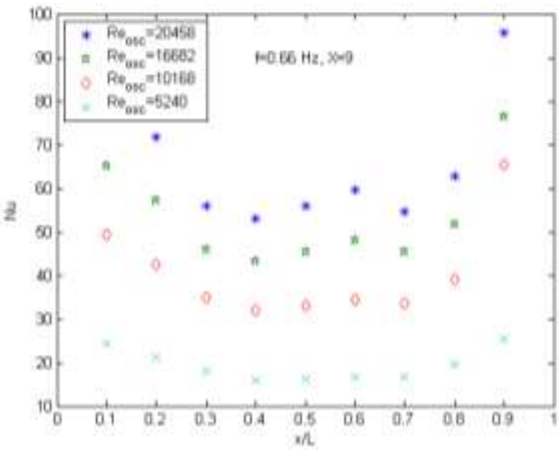


Fig. 4: Local Nusselt Number versus x/L

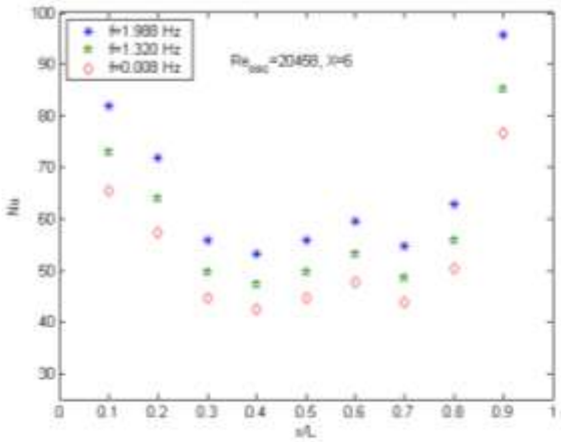


Fig. 5: Local Nusselt number versus x/L

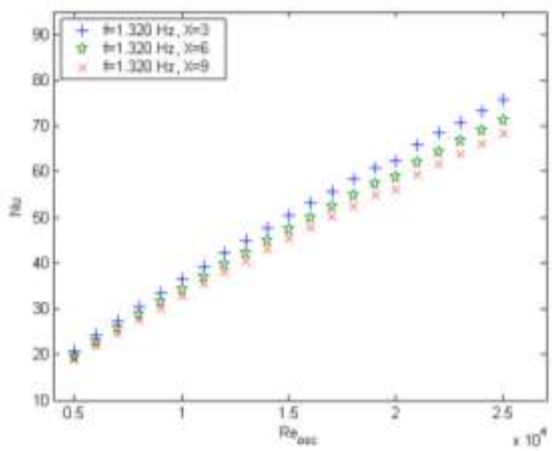


Fig: 6. Effect of dimensionless amplitudeon Nusselt Number.

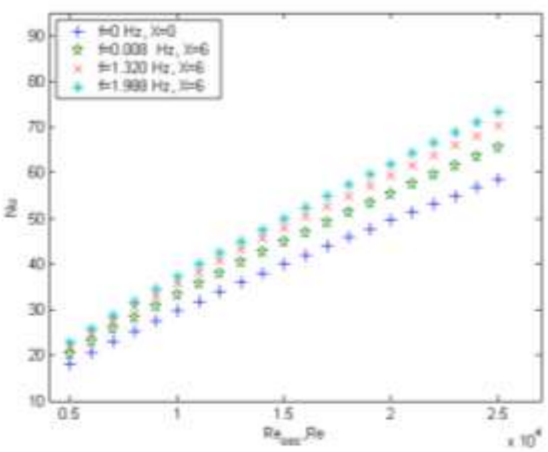


Fig: 7. Effect of frequency on Nusselt number

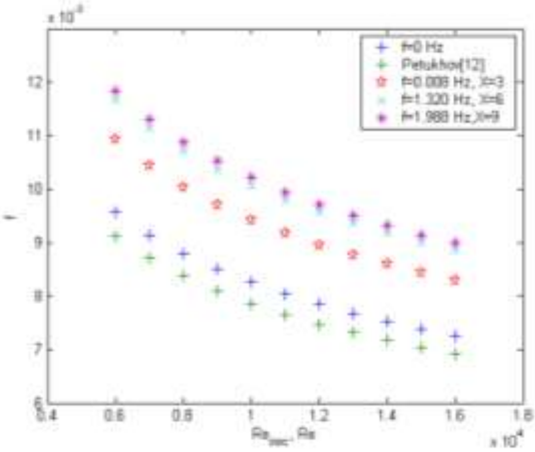


Fig: 8. The effects of Amplitude and frequency variations on friction coefficient

5. RESULTS

Fluid pipe oscillating state occurring external forces, affect the flow in the pipe. Fluid temperature flows along the axis of the pipeis lower than the temperature of thewall pipe. Centrifugal force effect the fluid always in radial direction. The fluid density particles that is greater than the fluid density particles near the wall, flows faster motion due to the centrifugal force. At the same time, periodic oscillation movement gives fluid flow an additional turbulence and hence depending on the amplitude and frequency values, it had seen that there is improvement in the heat transfer.

NOMENCLATURE

A : Heat transfer area, (m^2)
C_p : Specific heat capacity of fluid, (kJ/kgK)
D : Test pipe inner diameter, (m)
h : Heat transfer coefficient, (W/m^2K)
k : Thermal conductivity of fluid, (W/mK)
L : Test pipe length, (m)
m : Mass flow rate, (kg/s)
Nu_f : Oscillating Nusselt number
Nu : Nusselt number for static pipe
Pr : Prandtl number, ($\mu C_p/k$)
Q : Total heat, (W)
Re : Reynolds number, ($u_{av}D/\nu$)
Re_{osc} : Oscillating Reynolds number, ($Re_{osc}=2\pi X_0 D/\nu$)
T : Temperature, (K)
ΔT : Temperature difference between fluid and pipe wall T_w-T_b, (K)
V_{scale} : Average effective fluid velocity, (m/s)
f : Frequency, (s^{-1})
X_0 : Amplitude, (m)

Greek symbols

ρ : Density, (kg/m^3)
μ : Dynamic viscosity, (Ns/m^2)
ν : Kinematic viscosity, (m^2/s)
φ : Angle, (rad)

Subscripts

i : Input
s : Static pipe
w : Wall

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