International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463
Vol. 3 Issue 8, August-2014, pp: (25-33), Impact Factor: 1.252, Available online at: www.erpublications.com

Effect of Aluminum (metal) and Silicon (non-metal) on Convective Heat transfer from a Heated Circular Cylinder in an oscillating channel flow

Sohan Singh[1*], Nirmal Singh[2], Sunil Nain[3]
[1,2,3]Department of Mechanical Engineering, University Institute of engineering & Technology, Kurukshetra University, Kurukshetra, HARYANA, INDIA

Abstract: Experiment has been performed to investigate heat transfer enhancement factor E from a heated circular cylinder in a channel by oscillating flow. During the experiment, the input power and oscillating amplitude (A) are fixed. The effect of the Reynolds number (Re. = 696 and 957) on heat transfer enhancement factor E is examined and the oscillating frequency was kept in the range of 0Hz<f_p<60Hz. This experiment shows the effects of Aluminum (Metal) and Silicon (Non-Metal) material on the temperature, Enhancement factor E and Nusselt number w.r.t. pulsating frequency. It is also revealed that as the material change from Aluminum to Silicon, the heat transfer enhancement factor E and Nusselt number increase and the values of temperature also decreases. This experiment shows that value of Reynolds number is increased to increase the value of Nusselt number.

Keywords: Oscillating Flow, Forced Convection, Nusselt number, Heat Transfer Enhancement, Circular Cylinder.

1. Introduction

The need for high performance and an increased level of functional integration as well as die size optimization on microprocessor lead to preferential clustering of high power units on the processor. Conventional natural and forced convection cooling methods are used for removing the resulting heat flux to maintain an acceptable operational low temperature. A large number of studies of flow past circular cylinder, both experimental and numerical, two dimensional, are reported in the literature (see e.g. M .M. Zdrakovich et al., 1997, P. W. Bearman et all, 1978, R. W. Davis et all, 1982 and H. Suzuki et al., 1993). Results from previous investigators [5], [6] have shown that unidirectional flow through the porous channel yield a relatively high temperature difference along the flow direction on the substrate surface. For modern high-speed microprocessors, the reliability of transistors and operating speed are influenced not only by the average temperature but also by temperature uniformity on the substrate surface. Therefore, maintaining the uniformity of on-die temperature distribution below certain limits is imperative in thermal design. It is conceivable that oscillating flow through a porous channel will produce a more uniform temperature distribution due to presence of two thermal entrance regions for oscillating flow.

Guo et al. [7] investigated oscillating flow and heat transfer characteristics in a circular pipe partially filled with porous media. Enhanced longitudinal heat conduction due to oscillating flow and enhanced convective heat transfer from highly conducting porous material were examined. Several studies have been performed for both circular and square cylinder. However, most investigations have been focused on the questions of whether shedding occurs or not and what the effect of wall proximity is on the shedding [8-13] on mass and heat transfer has not been studied in detail. Vortex shedding can be controlled by flow pulsation. In this case, if the loading frequency is in the specific frequency range, the remarkable increase in the lift and drag forced is observed. This is referred to as “Lock on” mean structure of the wake changes when the Lock on phenomena occurs [14-15].The lock on phenomena is observed in many practical applications, i.e. the offshore exploration, the marine hydrodynamics, and the power generation. Now these phenomena can be used to intensify the wake flow to enhance heat transfer, mixing and combustion in the electronics devices and lab on different instruments etc.

The present study aims to examine experimentally the effects of different materials on the convective heat transfer from a heated circular cylinder in an oscillating channel flow. The effects of the Reynolds number (Re. = 696 and 957) based on mean velocity and the oscillating frequency (0Hz<f_p<60Hz) on the heat transfer enhancement factor E are examined. This experiment shows the effects of Aluminum (Metal) and Silicon (Non-Metal) material on the temperature, Enhancement factor E and Nusselt number w.r.t. pulsating frequency.

2. Experimental Set Up

The experimental arrangement consists of flow around a circular cylinder, as demonstrated in fig.1. The air is undergoing a transient vertical oscillation motion that changes harmonically with time. The circular cylinder with side length (D) is placed in the rectangular channel of height (H) and length (L). The work piece is placed in the rectangular channel at a distance (x_u) from the channel inlet and at a distance (x_d) from the outlet. A woofer is placed on the rectangular channel for producing pulsation in the air flow. The cylinder has a vertical displacement with oscillation motion and the following harmonic expression describes the motion. The experimental arrangement consists of the following apparatuses:-

2.1 Work piece

The experiment can be performed on a two different materials. There are many alternative both in the materials and dimensions of the work piece. But there are many factors considered the work piece such as the material of work piece, dimensions and properties of the materials. There are some common factors are considered for the dimensions of the work piece which are given below:-

(a) Blockage ratio is 1/10 mean side length of work piece size per unit channel height. Channel height is 10^{th} times more than work piece height.

(b) The dimension of the work piece is taken according to the rectangular channel cross-section. The ratio of the channel length to the height of the work piece is not greater than 65. If this ratio is greater than 65 then it affect the heat transfer enhancement in the channel flow.

(c) Selection of work piece materials is very challenging because it is depends on the properties of the material such as thermal conductivity, density, boiling temperature, melting temperature and specific heat capacity etc. In this experiment compared the performance of two different materials and there is alternative for work piece materials which is suitable for experimental study. Properties of the two different work piece material:-

Aluminum and silicon work piece is the two different materials used in the present experimental study after the study of different materials properties. The thermodynamic properties of the aluminum and Silicon work piece are given in the table 1 and table 2 respectively.

Table 1: Thermo physical properties of Aluminum work piece

S. No.	Properties	Aluminum
1	Density	2.7g/cm^3
2	Melting point	660.32°C
3	Boiling Point	2519°C
4	Thermal conductivity	237W/mk

Table 2: Thermo physical properties of Silicon work piece

S. No.	Properties	Silicon
1	Density	2.329g/cm^3
2	Melting point	1414°C
3	Boiling Point	3265°C
4	Thermal conductivity	149W/mk

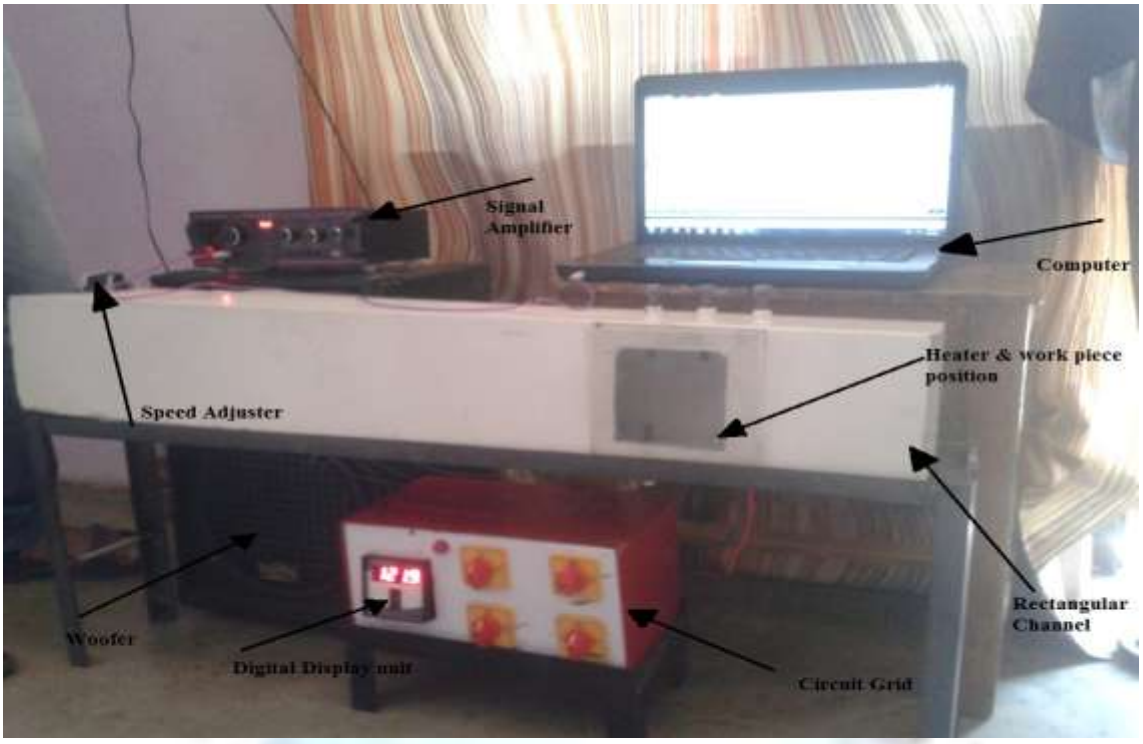


Fig.1: Photograph of experimental setup

2.2 Rectangular channel

This is most important part of the experiment setup because the experiment is conducted in a rectangular channel which is fabricated with 10mm thick Plexiglas and 150mm channel height as shown in figure 2. The work piece is hanged in the rectangular channel through which the heat is transfer. The rate of heat transfer from the work piece is depending on both design and dimensions of the rectangular channel. But some factor affects the design and dimensions of the channel such as blockage ratio and size of the experimental setup. The following are the considerations which are taken into account while designing a channel:-

(a) Cross section of the channel should be taken equal to 150×150 mm^3 as blockage ratio is not exceed to 1/10

(b) Length should be taken equal to 900 mm as L/d is not to exceed 65 to reduce the effect of the channel outside boundary layer.

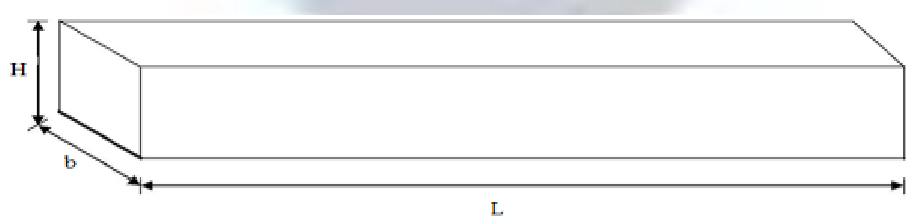


Fig. 2 Rectangular channel for flow

2.3 Heater

The heater is selected according to the work piece material and dimension. To create uniform heat flux for the work piece, a cylindrical cartridge heater is embedded into the work piece through a center hole using thermal compound. According to the dimension of the work piece, very small heater is required to provide the uniform heat. The heater is control by an AC power supply and kept at 24W. The three thermocouples (temperature measuring device or sensor) to measure the surface temperature are groove-install on the surfaces of the work piece. The output of these thermocouples is shows on the digital display unit which is located on the circuit grid.

2.4 Circuit grid

The fig.1 shows the circuit grid which supply the power to the apparatuses used in the experimental setup. It contains four switches for different apparatus such as main on/off, fan, heater and woofer. It is also contain a digital display which shows the temperature of the work piece at different faces. The 12V transformers are used in the grid for the uniform and continuous power supply.

2.5 A.C. Fan

The experiment is performed both with free and force convection. In case of force convection, an A.C. fan is used for supply air or heat transfer from the aluminum work piece. Fan is installed at the one end of the rectangular channel as shown in fig.1. The air flow rate is control by provide a speed adjuster for the fan. Because of the small heat accumulation is needed in the work piece.

2.6 Woofer

A woofer speaker is used to generate oscillations in the flow. Woofer speaker is attached with the rectangular channel at a distance from the fan. It generates the oscillation in the air flow coming from the fan. The figure 1 shows the attachment of woofer speaker with the channel. Thus the woofer is the external element which makes it active technique. Pulsations are produced in range of 0 to 60Hz. Woofer speaker takes the input signal from the amplifier. According to the experimental setup, a woofer of 10 inch diameter is used for producing oscillation in flow. This is because the woofer of large diameter blockage the air flow coming from the fan.

2.7 Digital Anemometer

Anemometer is a measuring device which is used for measure the velocity of the air flow having range from 0.8 and 1.1 m/s. Velocity measured by the anemometer is used to determine the Reynolds number and hence the type of flow. An AM-4201 digital anemometer is used to measure the velocity of air flow with an accuracy of 0.1 m/s. An AM 4201 digital anemometer is a portable anemometer which provides fast, accurate readings with digital readability and the convenience of a remote sensor separately.

2.8 Function Generator

A function generator is used for providing a sinusoidal signal with a setting frequency. In this experimental setup, a computer software is used which provide the sinusoidal signal with the change in frequency. NCH Tone Generator had a range from 0 to 10 KHz as shown in fig.1. The function generator provides the signal to the amplifier.

2.9 Amplifier

A function generator provides a sinusoidal signal by setting a frequency and then the signal was amplified by a signal amplifier. Signal amplifier is necessary for the operation because the sound frequency is quite low and unable to perform required effect.

2.10 Honeycomb

A honeycomb is used to produce a uniform inlet flow with low turbulence intensity. It was installed in the rectangular channel between fan and the work piece.

3. System operations

The working principle of the experiment setup is shown in fig.3. The experiment is conducted in a rectangular channel fabricated with 10 mm thick Plexiglas of given dimension explained in the last section. A steady main air flow is supplied by an AC fan.

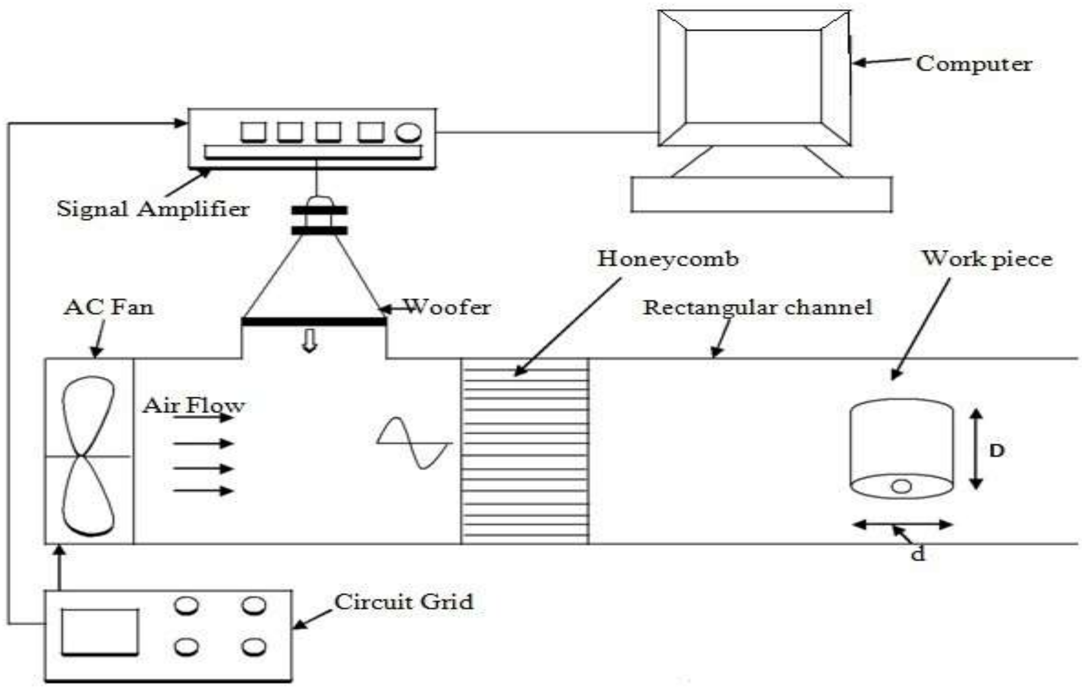


Fig.3: Schematic diagram of experimental set up

Anemometer is used in the rectangular channel to confirm the uniformity of inlet air flow and the speed of the fan is controlled by an A.C. fan adjuster. The two inlet air velocities U_i 0.8 and 1.1 m/s are taken to study the behavior of work piece. To generate uniform heat flux from the Aluminum and Silicon work piece, a cylindrical cartridge heater is inserting into the work piece using thermal compound. The cartridge heater is controlled by a DC power supply. For all the experimental runs, the power input was kept at 24 W. The temperature at the surface of the work piece is measured with the help of the thermocouples. Air temperatures at inlet as well as on the wall surface are also measured. In this Experimental setup this frequency setting is done with the help of the computer software (NCH Tone Generator). The experiment is started by heating up the heater and it is continuously heated until the steady state has not reached. After that air is supplied by the fan, through the channel without oscillating flow. The thermal steady state is declared when the variation of measure temperatures was less than $\pm 0.1^0$C for 10 minutes. After reaching the steady state, the temperature at the work piece surface is measured from the digital display on the circuit grid. After collecting the steady state data, the oscillating flow is generated by woofer. The pulsation frequency is varying in the range of 0-60 Hz in the experiment and velocity amplitude of pulsation is fixed at 0.05.

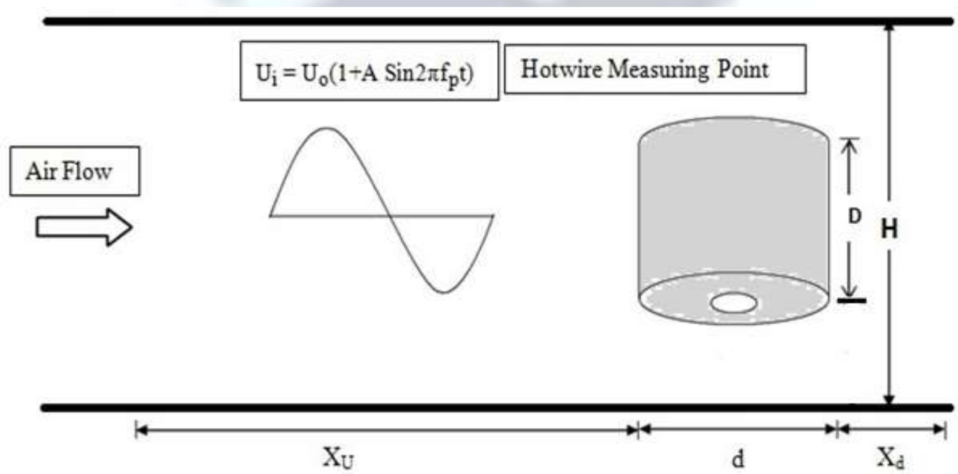


Fig.4: Heated circular cylinder in a channel

Again at the steady state condition, the temperature at the work pieces surface is measure at different oscillating frequency with the steady state. In fig.4 by changing the Aluminum and Silicon work pieces to the variation in temperature, Enhancement factor E and Nusselt number are observed.

4. Analysis of experimental data

To verify the reliability of the present experiment setup and data reduction procedure, some preliminary experiments are carried out for different work piece materials with a circular cylinder located in the pulsating channel flow. The mean flow Reynolds number Re are defined as

$$\text{Reynolds number Re}=\frac{\rho UD}{\mu} \qquad (1)$$

Where U and D are the time average inlet flow velocity and side length of circular cylinder respectively. The Enhancement factor E is calculated from

$$\text{Enhancement factor } E=\frac{Nu_p}{Nu_s}=\frac{(hL/K)p}{(hL/k)s}=\frac{h_p}{h_s}$$

$$\text{Enhancement factor } E=\frac{q/(T_P-T_i)}{q/(T_s-T_i)}=\frac{(T_s-T_i)}{(T_p-T_i)} \qquad (2)$$

The Nusselt number Nu is calculated from

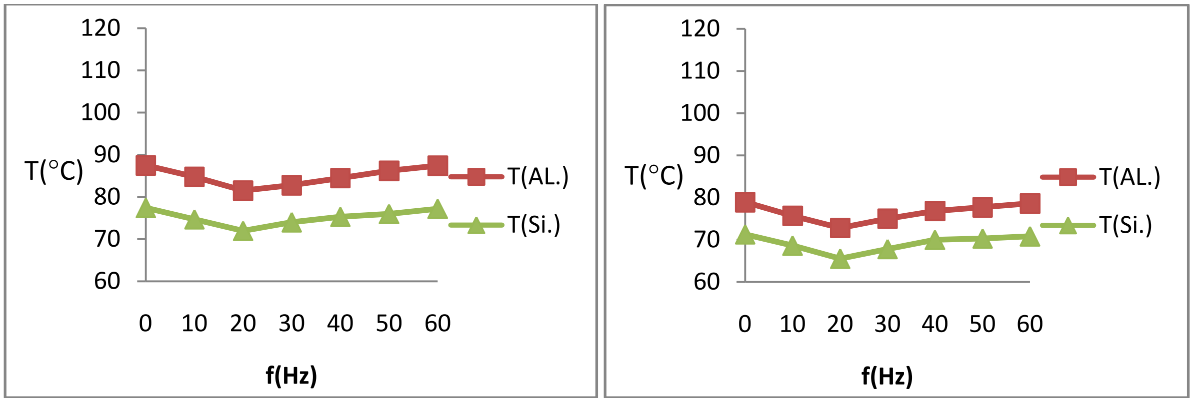
$$\text{Nusselt number Nu}=\frac{\text{hD}}{\text{k}}=\frac{\text{qD}/\text{k}}{(\text{T}-\text{Ti})} \qquad (3)$$

Here q, D and T-Ti are the heat inputs from the cartridge heater, the side length of work piece and the temperature difference between the inlet air and the surface of a circular cylinder respectively.

5. Results and Discussion

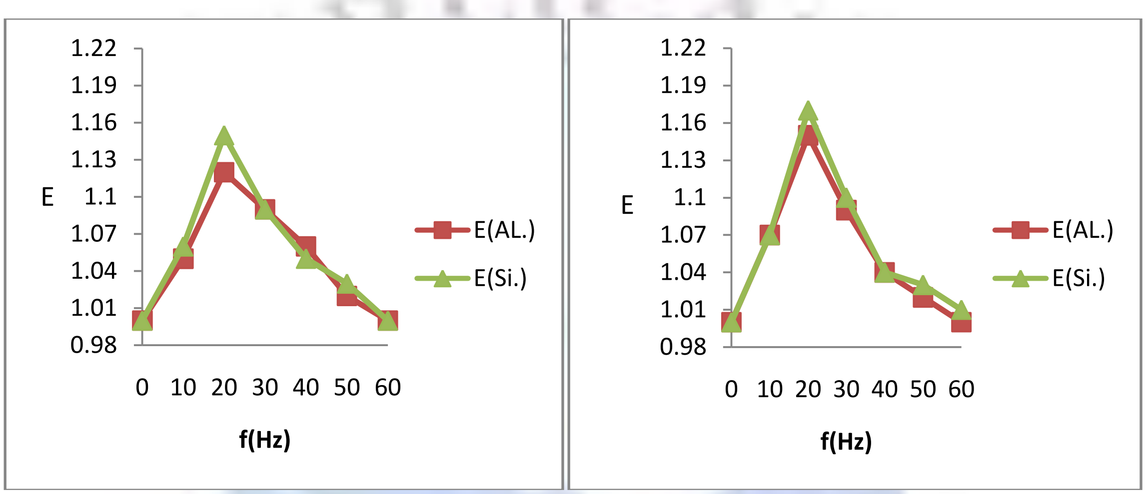
The preliminary experiment is carried out for the non-pulsating steady flow (A=0.0) when a circular cylinder is located in a uniform flow to verify the reliability of the present experimental set up and procedure. Fig.5 indicates the relationship between temperature and pulsating frequency (0 to 60 Hz) at different Aluminum and Silicon work piece materials for two different Reynolds number. Figure 5 shows that the value of temperature decreases with increase in the value of pulsating frequency up to a limit for two different Reynolds number. The minimum values of temperature was recorded at 20Hz with two different workpiece materials and after this as pulsating frequency increases, the values of temperature also increased. This is because the oscillating flow blocks the air of flow from the fan. Fig.5 indicates the values of Reynolds number is increased with decrease in the surface temperatures of work piece.

Fig.6 display the variation of heat transfer Enhancement factor (E) and pulsating frequency (fp) at metal and non-metal work pieces with two different Reynolds number. When the pulsating component is superimposed over the main incoming flow, heat transfer is generally enhanced by interaction between the pulsation components. The heat Enhancement factor shows a different peak value for different materials. At low value of Reynolds number(696) in fig.6(a) on Enhancement factor E is of small peak value for different workpiece and increase the value of Reynolds number(957) in fig.6(b) on Enhancement factor E of maximum peak values for different materials.



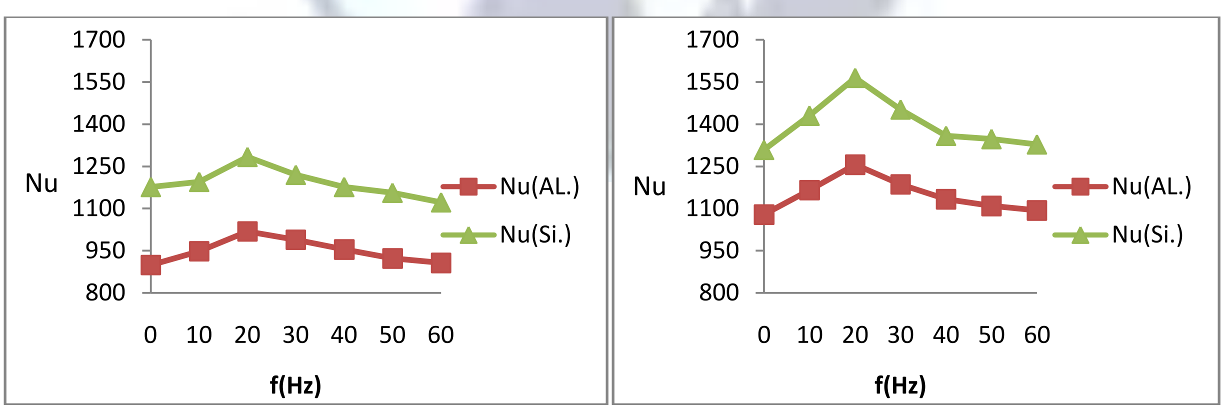
(a) Re =696 (b) Re =957

Fig.5: The relationship between Temperature (T°C) and pulsating frequency (f_p) at Aluminum(Metal) and Silicon (Non-Metal) materials for two different Reynolds number (a) Re=696 (b) Re=957



(a) Re =696 (b) Re = 957

Fig.6: The relationship between Enhancement factor(E) and pulsating frequency(f_p) at Aluminum(Metal) and Silicon (Non-Metal) materials for two different Reynolds number (a) Re=696 (b) Re=957



(a) Re =696 (b) Re=957

Fig.7: The relationship between Nusselt number(Nu) and pulsating frequency(f_p) at Aluminum(Metal) and Silicon (Non-Metal) materials for two different Reynolds number (a) Re=696 (b) Re=957

Fig.6 shown in Enhancement factor E of variation for different work piece materials is of Silicon work piece on maximum peak value of heat Enhancement factor E and is of change the Aluminum work piece to decrease the peak value of heat

Enhancement factor E. However, as the Reynolds number increases, the 3D effect in the downstream becomes more significant. Because of the flow mixing is highly active [5, 8].Consequently, this results in increase in the heat enhancement factor E with the work piece change Aluminum to silicon. Fig.6 shows similar trend as in figure 7. It can be noticed in Fig.6 that relationship between the Nusselt numbers (Nu) with pulsating frequency (fp) at Aluminum and Silicon work piece for two different Reynolds number. Fig.7 shows that the value of Nusselt number increase with increase in the value of pulsating frequency up to a limit after that decreased the value of Nusselt number. The Nusselt number shows a peak value at Aluminum and silicon work piece for two different values of Reynolds number indicates in fig.7. Consequently, this result the Nusselt Number increase as the work piece change from Aluminum to Silicon work piece. Fig.7 (a) and fig.7 (b) in value of Reynolds number increase to increase the value of Nusselt number in linear nature.

6. Conclusions

An experimental study has been performed to investigate convective heat transfer enhancement factor from a circular cylinder in a pulsating channel flow. The complete experiment is performed for two different Reynolds number (a) Re=696 (b) Re=957 based on the mean velocity. The effect of the pulsating frequency ($0Hz \leq f_p \leq 60Hz$) and Aluminum (Metal) and Silicon (Non-Metal) on the heat transfer Enhancement factor E and Nusselt number are examined. The main results of present study are follows as:-

(1) The temperature decrease with change Aluminum to Silicon work piece materials. The maximum value of temperature occurs at Reynolds number (696) with Aluminum work piece materials and minimum values of temperature occurs at Reynolds number (957) with Silicon work piece materials.

(2) The heat transfer Enhancement factor E increases from 1.12 to 1.15 as the material change from aluminum to Silicon from for Reynolds number(696) and maximum values of Enhancement factor E is 1.17 for Reynolds number (957) at Silicon material.

(3) The Nusselt number increases from 1018 to 1284 as the material change from aluminum to Silicon for Reynolds number (696) and the maximum value of Nusselt number is 1565 for Reynolds number (957) with Silicon material. The occurrence of relationship between Nusselt number and Reynolds number is linear in nature.

Abbreviation

A - Pulsating amplitude
b -Channel width, mm
D-Side length of a circular cylinder, mm
d- Diameter of circular cylinder
E -Heat transfer enhancement factor, Nu_P/Nus
E (AL.) - Heat transfer enhancement factor at Aluminum work piece
E (Si.) - Heat transfer enhancement factor at Silicon work piece
f -Dimensional frequency, Hz
fp -Pulsating frequency, Hz
h –Convective Heat transfer coefficient, W/m^2k
H -Height of flow channel, mm
k -Thermal conductivity of air, W/mK
L -Length of flow channel, mm
Nu -Nusselt number
Nu (AL.) -Nusselt number at Aluminum work piece
Nu(Si.) -Nusselt number at Silicon work piece
q -Input heat flux, W/m2
Re -Reynolds number
S-Cylinder to wall gap height, mm
T -Local surface temperature, K
Ti -Inlet air temperature, K
T (AL.) - Local surface temperature at Aluminum work piece
T (Si.) - Local surface temperature at Silicon work piece
U -Inlet air velocity, m/s
X –Stream wise coordinate

X_d -Distance from the outlet to downstream face of the cylinder, mm
Xu -Distance from the outlet to upstream face of the cylinder, mm
Y -Transverse coordinate

Greek symbols

β -Blockage ratio
ν -Kinematic viscosity, m^2/s

Subscripts

p -Pulsating component
s -Steady-state component

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