ISSN 2229-5518

Experimental Study Of Heat Transfer By Free Convection For Horizontal Cylinder Of Composite Material Under The Effect Of Vibrations

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Abstract : In the present work, experimental studies of heat transfer from cylinder which is made of composite materials have been accomplished. In addition, the effect of vibration on the heat transfer by free convection with different composite materials and samples . The samples contain eight cylinders, two of the random fiberglass, two of the woven fiberglass, two of the woven fiber carbon, and the final two of aluminum. Lee's disk samples were manufactured to measure the thermal conductivity of the samples. The cylinders were heated at a constant heat flux by electrical current through a resistance, which is passed through the internal space of the cylinder. The cylinders used in this research have internal diameter (40mm) and external diameter(50mm). A cylinder made from aluminum which has a 38 mm diameter, is used for comparison. values of the implemented heat flux rates were between (500 – 1000 W/m²). Excitation frequencies were at the range of (0-20 Hz) were applied at the cylinders. It was found that increasing both,the number of layers of composite material and the frequencies of vibration will lead to an increase in heat transfer coefficient . However, the increase in heat flux will cause a decrease in the vibration heat transfer coefficient.

Key words: Composite Materials, Vibration, Convection Heat Transfer

1. Introduction

It is generally accepted that composite materials have reasonably good mechanical and thermal properties. It has been developed for a wide range of industrial application, including piping, pressure vessels, fluid reservoirs, aerospace components. Composite materials have many favorable properties, including high strength-to-weight ratios and also, high corrosion resistances [1]. The increasing application of the advanced composite materials in the components design of principal structural makes the investigation for both, dynamic characteristics and vibrations for these structures a very interesting case [2]. Vibrations are utilized to increase the rate of heat been focused on scientific studies on this topic in previous decades. The study in this field could focus on increasing the rate of heat transfer in industrial units avoiding heat transfer above the design value of the items which exposed to vibrations. The modern requirements in the performance of the machine under extreme operating conditions such as missiles confirmed the lack of knowledge in mechanical principles of heat transfer by presence of vibrations [3]. The most important applications which belong to the current study are chimneys, transmission shafts, bottles for compressed petroleum gas, nozzles and flywheels [4].

Dougall et al. [5]obtained the basic equations for the boundary conditions controlling the problem of coupled transverse vibrations and free convection from a heated horizontal cylinder. It was shown that the presences of harmonic oscillations modify the steady-flow solution only when pressure gradients are present. Also, the modifying forces have their most pronounced effect on the fluid closest to the surface. It was shown that four dimensionless parameters are needed to fully describe the flow.

Ahmed [6] studied the vibration relief process was accomplished on rectangular carbon steel plates (st12) carbon contain (0.10% c) .The residual stresses was induced by flame heating process with the same boundary conditions(fully free) and the treatment time was 150mm/min. The level of residual stresses in the plate was measured using non- destructive method by shifting damping ratio (ζ) of heated plate. The damping ratio for The stress Free State was (0.1499) .This value was compared with the damping ratio was measured experimentally which was (0.1525) giving reasonable agreement. It was concentrated on the effect of vibration characteristics (force, amplitude, velocity) on residual

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stresses relief produced by the heating process on carbon steel plate. It was found the velocity is more effective from other characteristics. In addition, the best results in reduction of residual stresses was investigated when an increase in the force and velocity together where the reduction in residual stresses was (89.29%), which was higher than other results.

Kayhani et al. [1] presented a steady analytical solution for heat conduction in a cylindrical multilayer composite laminate in which the fiber direction may vary between layers. The analytical solution was obtained for general linear boundary conditions which were suitable for various conditions. The Sturm-Lowville's theorem was used to derive an appropriate Fourier transformation for this problem. The temperature distribution is accomplished by applying this transformation to the governing equation. The coefficients of the solution were obtained by solving a set of equations generated by applying the boundary conditions inside and outside the cylinder, and also, the continuity of temperature and heat flux at boundaries between adjacent layers.

Sarah [7] studied the effect of forced vibrations on pool boiling heat transfer coefficient made in a glass chamber cylinder shape (75 mm bore and 300 mm length). An electrical heater was use inside it (12 mm diameter and 80 mm length) to heat the distilled water at different values of heat flux (27.521 kW/m^2-53.08 kW/m^2).It was carried out at a range of frequency (2-40 Hz) and at a range of amplitude (1.8-3.5 mm). The results obtained showed that the pool boiling heat transfer coefficient was increased with the increase in the vibration frequency within a range of (2-14 Hz), compared with that heat transfer without frequency. And, the maximum enhancement ratio is about 250% at 5 Hz and q"=27.521 kW/m^2, 231% at 6 Hz and q"=36.727 kW/m^2, 181% at 6 Hz and q"=41.83 kW/m^2 and 93% at 8 Hz and q"=53.08 kW/m^2.It is found that the difference in the temperature had been maintained at the highest value of vibration frequency range of (14-40 Hz),and the value of heat transfer coefficient was significantly increased with the increase in vibration Reynolds number (Rev).The effect of vibration frequency had improved not only the boiling heat transfer coefficient, but also led to improve the amount of heat drawn by the cooling water (condensation) by increasing the amount of falling drops. The empirical relations had been obtained between the experimental heat transfer coefficient with vibration (h_v) and some of important parameters, such as excess temperature (ΔT_{exsses}) in ^oC, input heat flux (q") in (W/m^2), and vibration frequency (f) in Hz.

Saleem et al. [8] performed an experimental study for the effect of forced vertical vibrations on free convection heat transfer coefficient using a longitudinally finned cylinder made of Aluminum. The cylinder was heated under the condition of a constant heat flux which is generated by applying an alternating voltage on a fixed resistor mounted inside the interior space of the cylinder which was located horizontally or inclined in multiple angles at a range of (0°-45°). The longitudinally finned cylinder prototype has the dimensions of inner diameter (16 mm), and outer diameter at the inner base of the fin of (48 mm), the effect of the frequency at the range of (2-16 Hz) and the amplitude at the range of (0-.2.2mm) have been studied with various heat flux range from(500-1500W/m^2). It was found that the relation between the heat transfer coefficient and amplitude of vibration is incrementally for all inclination angles from (0°-45°), reaching a maximum ratio of (18.34 %).Also increment of inclination angle decreases the values of forced convection heat transfer coefficient. This is because the fins works as obstructions for the convection current to decrease the movement of convection currents in the case of inclined prototype. However, in case of horizontal cylinder, fins helped to increase the convection current and thus reducing convection vibration heat transfer coefficient.

2.Test Section

It is consists of frame, testing region of eight cylinders. The measurement devices contain a voltage regulator, clamp meter, thermocouples, temperature recorder, DC power supply, vibration exciter, power amplifier and vibration meter as shown in figure (1).Six samples has been made with a volume fraction (0.6), two models of random fiber glass (case 1 & 2), two models of fiber glass (case 3 & 4), two models of fiber carbon (case 5 & 6). Each cylinder have the dimensions (L = 25 cm, OD = 5 cm, ID = 4 cm).Another two cylinders made from aluminum, the first one (case 7) has (L = 25 cm, OD = 5 cm, ID = 4 cm) and the second one (case 8) has (L = 38 cm, OD = 3.8 cm). These are used to compare with results obtained from the composite materials cylinder with that obtained from previous works [9].To facilitate and not to repeat the names of the samples, the adoption of the number of each sample is shown in the table (1). With regards to thermal conductivity samples three different samples have been used. Each has a volume fraction (0.6) using mold manufactures from cast iron as

Fig. 1-a Photograph of the test rig.

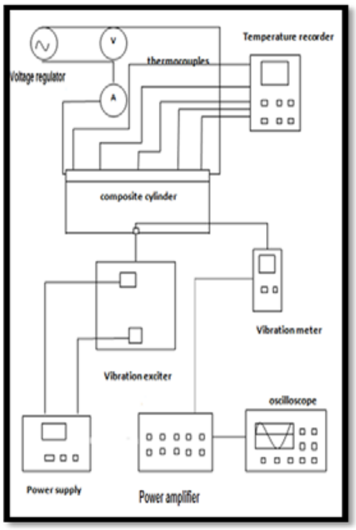


Fig.1-b schematic Diagram of The test rig.

Table 1 The samples used in this search.

Number of case	Type of sample	Number of layers
1	Random fiber glass	2
2	Random fiber glass	3
3	Woven fiber glass	2
4	Woven fiber glass	3
5	Carbon fiber	2
6	Carbon fiber	3
7	Aluminum 5 cm O.D. 4 cm I.D.	________
8	Aluminum 3.8 cm O.D.	________

Fig. 2 Photograph of cast iron mold.

Fig. 3 Photograph of samples of composite materials used in Lee's disk.

shown in fig.(2).The mold was cleaned first from dirt and then painted with an insulation material(wax)in order to prevent contact between the sample and mold. The polyester and the hardener has been mixed together and then
red inside the mold obtaining samples as shown in figure(3).With regards to measurement devices, the circuit consists of a heater with thermal resistance of (V / I) and capacity (1000 W) placed inside the glass tube of Albaerks which is isolate the ends of pottery. Voltage regulator type TDGc2J-0.5 is used to give the heater the
required power by measuring the current and voltage by clamp meter type MT87. The frame was manufactured from aluminum. This is to ensure vibration rocking cylinder with the same frequency and amplitude. Frame has dimensions (L = 50 cm, W = 50 cm and h = 50 cm) set on the tip vibrator. The second part was installed two columns of aluminum (h =30 cm and a = 25 cm distance between them) to hold the composite cylinder. The frame legs are installed to concrete blocks, including rubber isolators reducing the transmission of vibration to the ground.

3.Calculations

Heat transfer coefficient by free convection is calculated using Newton's law of cooling [10] as follows:

$$h = \frac{Q_{conv.}}{A * \Delta T} \qquad (1)$$

The heat transition by free convection is calculated from the following equation:

$$Q_{conv.} = Q_{gen.} - Q_{rad.} \qquad (2)$$

The total amount of heat generated is calculated as follows:

$$Q_{gen.} = V * I * \cos\theta \qquad (3)$$

The amount of heat transmitted by radiation is calculated as follows:

$$Q_{rad.} = \sigma * \epsilon * F_{sur.} * A * (T_{sav.}^4 - T_{\infty}^4) \qquad (4)$$

For composite materials $\epsilon = 0.05$ and for aluminum $\epsilon = 0.04$

In equation (1), (ΔT) represents the difference between the temperature of the surface of the cylinder and the temperature of the laboratory as follows:

$$\Delta T = T_{sav.} - T_{\infty} \qquad (5)$$

Where the rate of the surface temperature of the cylinder was calculated as follows:

$$T_{sav.} = {(T_1 + T_2 + \dots\dots + T_n)}/{n} \qquad (6)$$

The average temperature of boundary layer rate has been calculated as follows:

$$T_f = \frac{T_{sav.} + T_{\infty}}{2} \qquad (7)$$

This temperature has been approved in the calculation of the physical properties of the transporter medium (air) and has benefited from the tables [11] enabling to obtain at any temperature, the properties $(\vartheta, k_f, \alpha, \beta)$.

The heat flux is calculated from the following equation:

$$Q = \frac{Q_{gen.}}{A_i} \qquad (8)$$

Where $Q_{gen.}$ was calculated from the equation (3).

And A_i is the surface area of the inner tube of the cylinder where is calculated as follows:

$$A_i = \pi * D_i * L \qquad (9)$$

The frequency of vibration is calculated from the following equation:

$$F = \frac{Acc.}{(2*\pi)^2 * \sqrt{2} * V} \qquad (10)$$

The amplitude of vibration is calculated from the following equation:-

$$X = \frac{V}{F} \qquad (11)$$

With regards to dimensionless Parameters, These will be discussed briefly as follows:

a) Nusselt Number: It is the ratio between the conduction thermal resistance to thermal resistance of convection:-

$$Nu = \frac{h * D_o}{K_f} \qquad (12)$$

b) Rayleigh Number: It is the ratio between the forces of buoyancy to viscous forces:

$$Ra = \frac{\beta * g * (T_{sav.} - T_{\infty}) * D_o^3}{\vartheta * \alpha} \qquad (13)$$

c)Vibrational Reynolds Number: It is the ratio between the forces of inertia and viscous forces in the boundary layer of the speed and caused from the vibration effect:

$$Re_v = \frac{2 * \pi * F * X * D_o}{\vartheta} \qquad (14)$$

4.Results and Discussion

The analysis of experimental results obtained from (168) tests for eight models. This was accomplished by different materials for different number of composite layers. The heat flux used was in the range of (500-1000 W/m^2), while the frequency ranges was (0-20 Hz), in which most of the results were achieved experimentally. These will be explained in the following paragraphs.

The experimental relationship between the vibrational Reynolds number (Re_v) with heat transfer coefficient (h_v/h_w) are shown in figures (4, 5, and 6). Reynolds number leads to that increase in vibrational be shown. It can general increase in heat transfer coefficient for all samples .However, this due to low effect of this flux with increasing of heat increase diminishes vibration on thermal boundary layer contiguous to surface as result of high surface temperature. Also, the increase in the number of layers of composite material except samples (5 & 6) leads to more increase in heat transfer coefficient.

The relationship between the amplitude of vibration (X) and heat transfer coefficient (h_v/h_w) of the experimental results are shown in figures (7, 8, and 9). It can be seen that an increase in vibration amplitude leads to a decrease in heat transfer coefficient for all samples. However, the increase in both, the number of layers of composite materials and the surface area of samples have little effect. This is because the vibration amplitude is the same for all samples which have the same density compared to the surface area.

Figure (10) shows the relationship between the amplitude of vibration (X) and vibrational Reynolds number (Re_v) for reference [9]. It can be shown that the increase in amplitude of vibration leads to increase in vibration Reynolds number for all samples and that is different on the work in the present research. This is because in reference [9] take the frequency constant and the amplitude is variable while in this work, the frequency and the amplitude are variables which are the difference between the two researches.

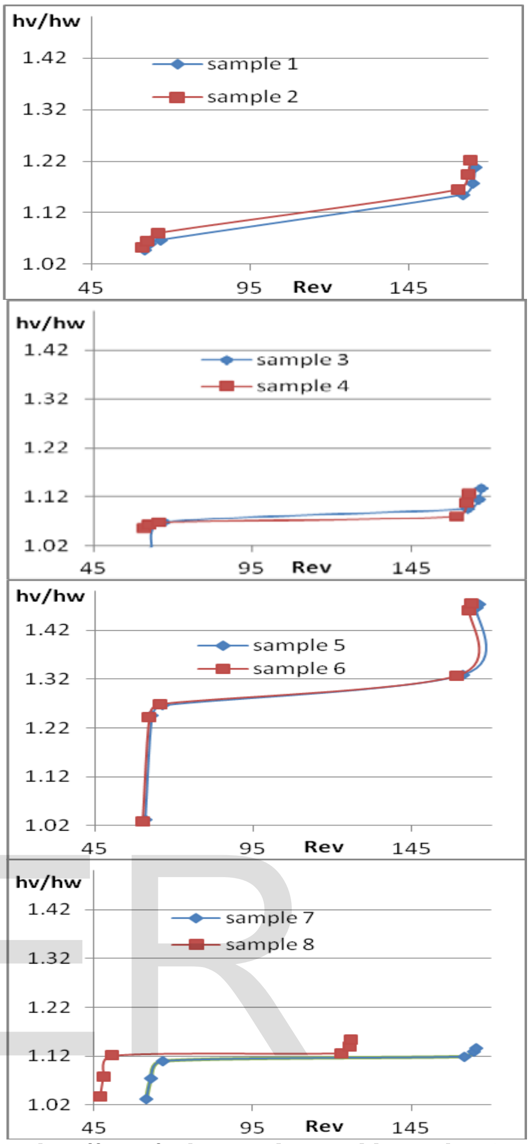
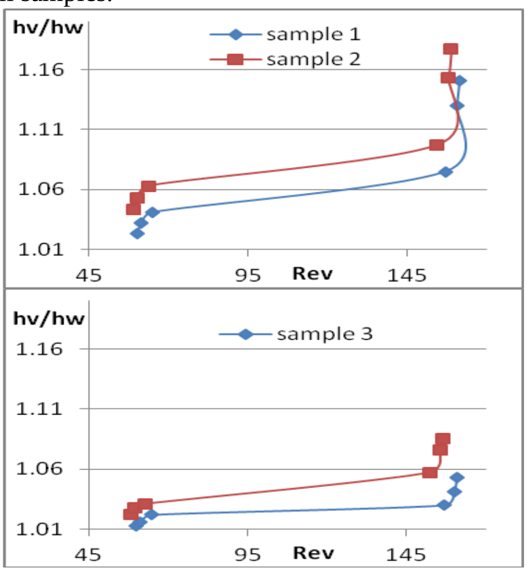


Fig. 4 The effect of vibrational Reynolds number (Re_v) on heat transfer coefficient (h_v/h_w) using 500 W/m^2 heat flux for all samples.



ISSN 2229-5518

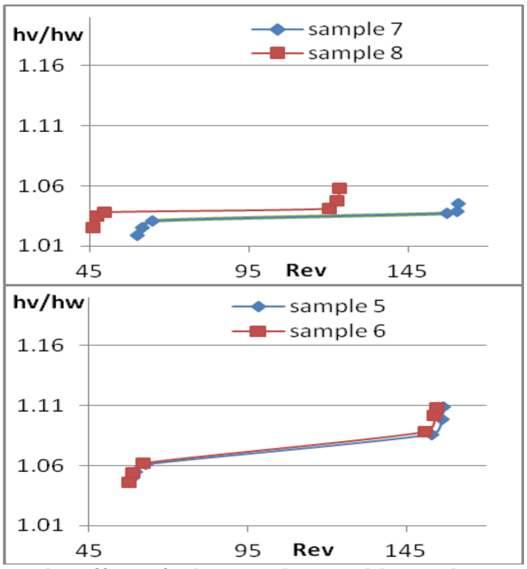


Fig. 5 The effect of vibrational Reynolds number (Re_v) on heat transfer coefficient (h_v/h_w) using 750 W/m^2 heat flux for all samples.

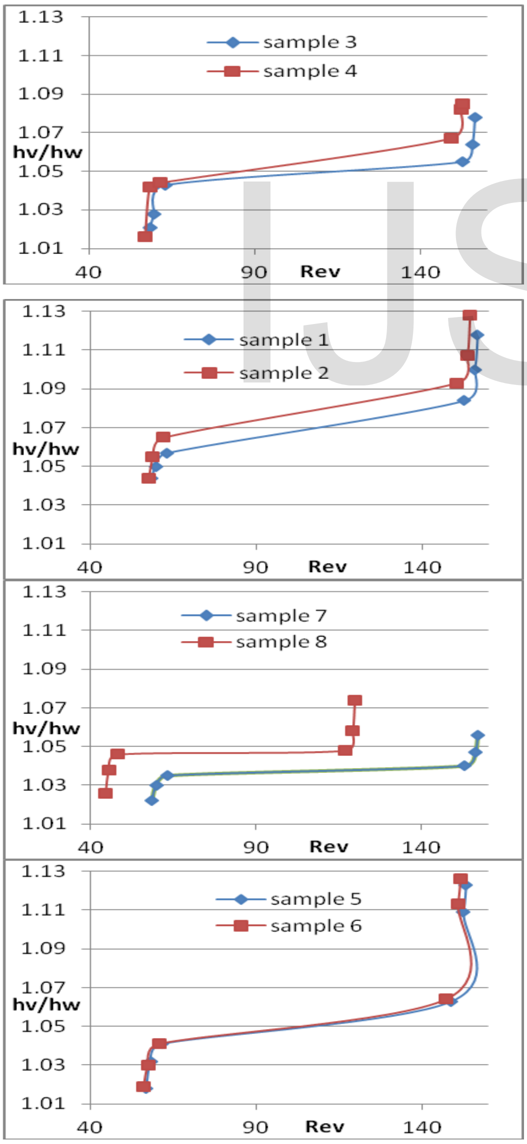


Fig. 6 The effect of vibrational Reynolds number (Re_v) on heat transfer coefficient (h_v/h_w) using 1000 W/m^2 heat flux for all samples.

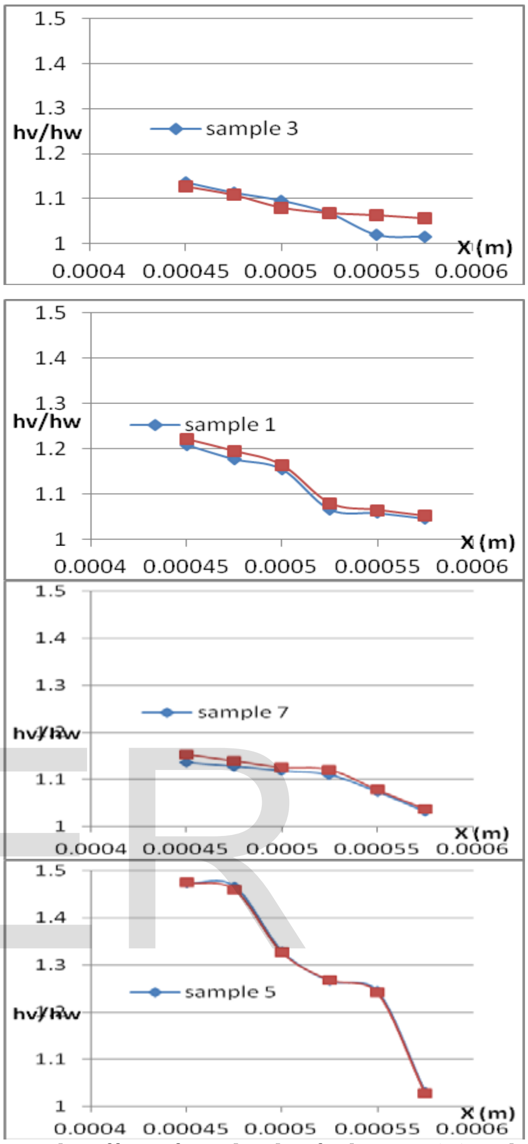


Fig. 7 The effect of amplitude of vibration (X) on heat transfer coefficient (h_v/h_w) using 500 W/m^2 heat flux for all samples.

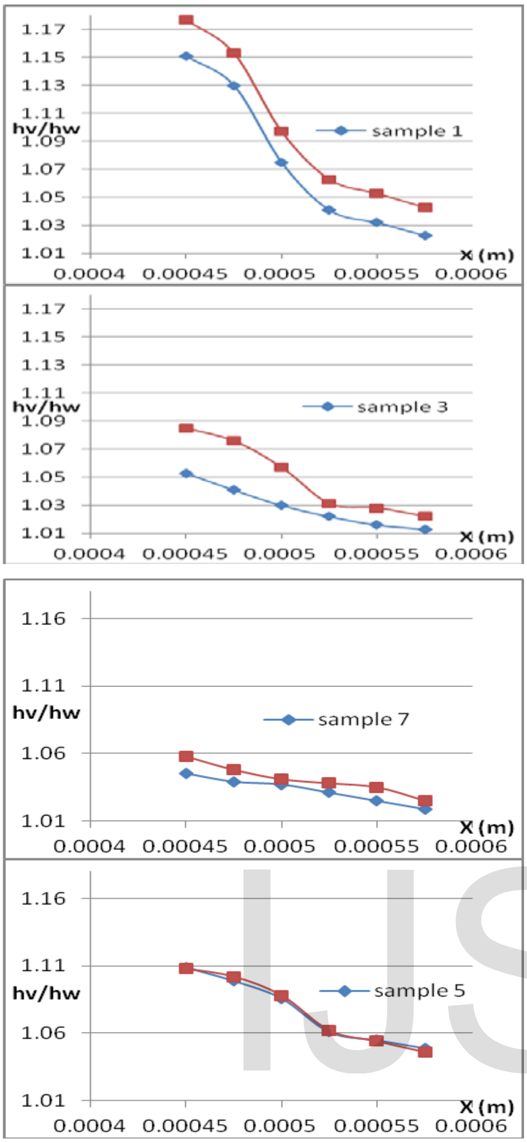
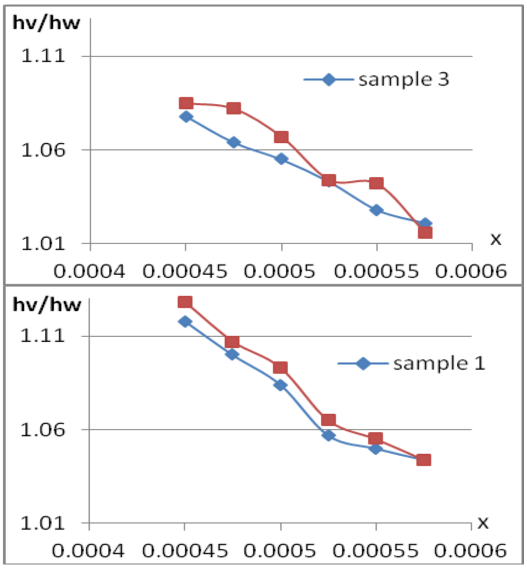


Fig. 8 The effect of amplitude of vibration (X) on heat transfer coefficient (h_v/h_w) using 750 W/m^2 heat flux for all samples.



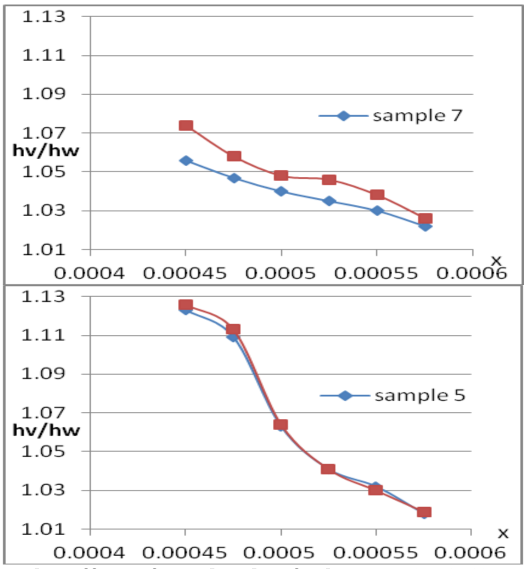


Fig. 9 The effect of amplitude of vibration (X (m)) on heat transfer coefficient (h_v/h_w) using 1000 W/m^2 heat flux for all sample.

Nomenclature

Letter	Description	Units
A_{CC}	The acceleration of vibration	m/s^2
A_i	The inner surface area of cylinder	m^2
D_i	The inner diameter of the cylinder	m
D_O	The outer diameter of the cylinder	m
F_{sur}	Shape factor	_____
F	Vibration frequency	Hz
h	The heat transfer coefficient by free convection	W/m^2. °C
h_v	The experimental heat transfer coefficient with vibration	W/m^2. °C
h_w	The experimental heat transfer coefficient without vibration	W/m^2. °C
I	The current	Amp
K_f	Thermal conductivity of fiber	W/m. °C
L	Length	m
l	The heat length	m
Nu	Nusselt number	_____
$Q_{conv.}$	The heat transition by free convection	W
$Q_{gen.}$	The total amount of heat generated	W
$Q_{rad.}$	The amount of heat transmitted by radiation	W
Ra	Rayleigh number	_____
Re	Reynolds number	_____
Re_v	Vibrational Reynolds number	_____
T	Time	S
Td	Temperature	°C
T_f	Film temperature	°C
$T_{sav.}$	The average of the surface temperature	°C
T_∞	The temperature of the ambient	°C
V	The voltage	Volt
V	Vibration velocity	m/s
X	The amplitude of vibration	M
σ	Stevan-Boltzmann constant	W/m^2. K^4
ε	Emissivity of cylinder surface	_____
ϑ	Kinematic viscosity	m^2/s
α	Thermal diffusivity	m^2/s
β	Volume coefficient of expansion	K^{-1}

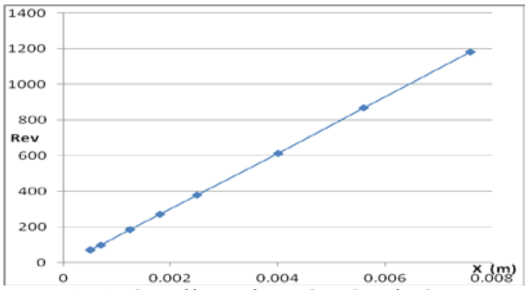


Figure (10) The effect of amplitude of vibration on vibrational Reynolds number for 500 W/m^2 heat flux for case [9].(D = 0.038m, Q = 500 W/m^2)

5. Conclusions

1. Vibration leads to an increase in heat transfer coefficient by free convection.
2. The increase in the Nusselt number leads to a decrease in the Rayleigh number for free convection.
3. The increase in vibrational Reynolds number leads to an increase heat transfer coefficient by free convection. However this increase will be diminished with the increase in heat flux.
4. Increasing the Rayleigh number results an increase in heat flux which leading to reduction in heat transfer coefficient.
5. The number of composite material layer of the specimen has a significant effect on the heat transfer coefficient for all vibration frequencies and heat flux.
6. Vibrational Reynolds number increases with the decrease in vibration amplitude.

References

[1] Kayhani, M. H., M. Norouzi, A. A. Delouei, A general analytical solution for heat conduction in cylindrical multilayer composite laminates, International Journal of Thermal Sciences, (2011), 52, pp. 73-82.

[2] Hammoudi R. Y., Effect of the composite material of the car's bumper on its fundamental natural frequency and response as a result of car vibration, Engineering and Technology Journal, 23 (2010), 28, pp. 6768-6784.

[3] Hadi A. S., Experimental study of the effect of vertical vibration on heat transfer coefficient by free convection from finned cylinder, M.Sc. thesis, University of Technology, Baghdad, Iraq, 2007.

[4] Daniel G. et.al, Composite materials design and applications, Fourth edition, 2002.

[5] Dougall R. S., T. Chiang, R. M. Fand, A study of the differential equations of coupled vibrations and free convection from a heated horizontal cylinder, J. Heat transfer, 1961.

[6] Aedam A. S., Study the effect of vibration stress relieve produced by heating process, M.Sc. thesis, Baghdad university, Baghdad, Iraq, 2008.

[7] Abed S. A., An experimental study for the effect of vertical forced vibration on pool boiling heat transfer coefficient, M.Sc. thesis, University of technology, Baghdad, Iraq, 2011.

[8] Kadhim S. K. Saad M. J., Abdul hamid R. S., The effect vertical vibration on the natural coefficient of heat transfer from the longitudinally finned cylinder, Scientific Conference of the University of Wassit, (2011), 5, pp. 381-364.

[9] Ali M. H., A study of influence of vertical vibrations on heat transfer coefficient by free convection from cylinders educational computer program, M.Sc. thesis, University of technology, Baghdad, Iraq, 2001.

[10] Incropera F. P. David P. Dewitt, Theodore L. Bergman, Adrienne S. Lavine, Fundamentals of heat and mass transfer, Seventh edition, 2011.

[11] Holman J. P., Heat transfer, Tenth edition, 2010.