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Vertical Vibrations Effect on Forced convection heat transfer from a Longitudinal Finned Tube

Saleem Khalefa Kadhim[1*], Sinan Abdulghafar Ali[1], N F D Razak[2], M S M Sani[2,3]

[1]Control and System Engineering Department, University of Technology-Iraq, Baghdad, Iraq
[2]Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang Pekan Campus, 26600 Pekan, Pahang, Malaysia
[3]Automotive Engineering Centre, Universiti Malaysia Pahang Pekan Campus, 26600 Pekan, Pahang, Malaysia

*Corresponding author: 60014@uotechnology.edu.iq

Abstract. Thermal systems more efficient by emanating from industrial applications and space program galvanized interest in ways by increasing heat transfer is the system. The main aim of this paper is to investigate experimentally the effects of the vertical vibration and force convection on the average Nusselt number in a longitudinal finned tube. The finned tube was located inclined or horizontally in different angles of 0°, 30° and 45°. The effect of the excitation frequency covers below 16 Hz with various heat fluxes ranged from 500-1500 W/m^2. It was noticed that the good agreement between the experimental measurement and the previous experimental studies with deviation of 5%. The results showed that average Nusselt number values at angle 45° from longitudinal finned tube were higher by up to 14%, 16% compared with the angles 30°, and 0°, respectively. Furthermore, it can be summarized that the vertical vibration significantly affects to the average Nusselt number from longitudinal finned tube cylinder and the influence on the heat transfer coefficient for this system should be considered.

Keywords. Vertical Vibration; Forced Convection; Longitudinal finned tube

1. Introduction

Heat exchangers are utilized in generally in the oil, chemical, refrigeration, control and electronic ventures by heating or cooling. One technique for increment that has been explored has incorporated the utilization of vibration [1]. The effect of vibration on forced convective heat transfer has been explored for cylinders, fin arrays, and flat plate. This vibration for these surfaces are either vertical or horizontal vibration affect, and different range of amplitude and frequency, also, the different of heat flux. There has been a difference in these investigations in terms of the effects either to be large or small on the average Nusselt number [2].

Experimentally, Takahashi, and Endoh [3] studied the effect of vibration on forced convection heat transfer occurring on the sphere, a cylinder and a square-section tube to water. They found that the average Nusselt number with the vibration effect is good correlated in terms of the energy dissipation calculated from the fluid drag acting on the vibrating bodies. Experimental investigation was conducted by Eid and Gomaa [4] vibration of the thin planner fins to improve of heat transfer rates. they found that the excitation vibration lead to improvement of heat transfer may however equal or slightly more than that of the vibration due to pulsating flow.

Tian et al. [5] performed experimental study on heat transfer enhancement by crossflow-induced vibration. They conclude that the increase of the average Nusselt number is registered at vibrations of low and average excitation frequencies for a heat pipe with large diameter. Also, they also found out that the vibrations of higher excitation frequencies indicate an increase of the average Nusselt number for the heat pipes with small diameters.

Jin et al. [6] conducted experimental and studied the effects of the pulsating flow agitation on the heat transfer in a triangular grooved channel, had been considered for the ranges of $270 \leq Re \leq 910$. They summarized that the Nusselt number increase at Reynolds number decreases. Also, they found that the frequency of pulsation flow increase at Reynolds number decreases.

In the work of Hommema et al. [7], they performed experimentally investigation of the heat transfer in a condensing pulsating flow. Pulsate flow experiment at the Reynolds number range between 2600 to 4300, and frequency is 34 Hz. In their result they observed that the pulsate flow was shown to enhance Nusselt number to increase up to a factor of 1.8. Sun et al. [8] investigated the forced convection heat transfer from a circular cylinder with a flexible fin in laminar flow numerically using a Fluid Structure Interaction (FSI) solver. This process considering heat transfer, with Reynold number 200 and also investigated the vibration effect on their model occurred due to flow-induced vibration. The result stated that the flow-induced vibration considered, a maximum of 11.07% enhancement in Nusselt number is obtained by the flexible fin.

Experimentally study the effect of pulsatile flow on finned-tube heat exchangers was carried out by Michaud et al. [9]. They used Reynolds number range from 50 to 900. In their results stated that the heat transfer rate was inversely proportional with the pulsatile flow. Kore et al. [10] performed experimentally the heat transfer enhancement from dimpled pin fin. They used Reynolds number in the range from 150 to 208. They conclude that the maximum of 99.75% improvement in heat transfer coefficient is obtained by the dimpled pin fin.

Izadpanah et al. [11] carried out the effect of rotating and oscillating blade on heat transfer enhancement of Newtonian and non-Newtonian fluid flow in a channel. The study is performed analysis through numerical and used Reynolds number as 50, Prandtl number of 1. From the simulation result, the maximum heat transfer enhancement to straight channel is 58.7% for a stationary blade with n= 0.4. Also, the output shows that the presence of the blade for all power law indexes has a positive effect on the heat transfer enhancement. Kim et al. [12] studied experimentally the effects of mechanical vibration on critical heat flux in vertical annulus tube. It concludes that the critical heat flux increased by mechanical vibration up to 16.4%.

Testing related to investigate the effect of vertical vibrations upon heat transfer rate from a horizontal tube immersed in a tank of water was carried out by Martinelli and Boelter [13] through experimental work. The results revealed that the Nusselt number was not affected at low Reynolds numbers, but that Nusselt number increases by as much as 400% when comparison without vibrations. Li et al. [14] was carried out numerical work and simulated the novel flapping vortex generator mounted on a heatsink fin for airside heat transfer improvement. The findings stated that the flapping vortex generator can improve the average Nusselt number by 200%.

Mittal and Al-Mdallal [15] developed a two-dimensional mathematical model in order to investigate of forced convection from an isothermal cylinder performing rotational oscillations in a uniform stream. The finite difference method was applied which solved the Naiver–Stokes, momentum equations and factored in the relationship between Nusselt number and Reynolds number. The result show that the frequency and amplitude of oscillation have a noteworthy effect on the heat transfer mechanism. Sellapan and Pottebaum [16] experimental investigations the nusselt number from rotationally oscillating cylinders placed in a cross-flow at Renolds number 750. They found out that the forced oscillation frequency and amplitude are crucial parameter and play a significant role in the enhancement of heat transfer rates. Also, they found that significant enhancement in the heat transfer rates was reported in the lock-on regime.

Beskok et al. [17] numerical investigate to Nusselt number from the uniformly heated walls of a straight channel in presence of a rotationally oscillating cylinder at Reynolds number 100. They found that the probability of utilize rotationally oscillating cylindrical with air flow for electronic chip cooling applications. Pottebaum, and Gharib [18] investigated the effects of transverse oscillations on the heat transfer from a circular cylinder in cross-flow experimentally. Their results revealed that the heat transfer is significantly improved to be strongly dependent on synchronization with harmonics of the natural shedding frequency. Rahman et al. [19] experimentally study the investigated the effect of fin in the performance of closed loop pulsating heat pipe. Moreover, they compared the effects on the heat transfer performances of closed loop pulsating heat pipe with finned and un-finned condenser section with different angles from 0 (vertical), to 45). Their results indicate that the finned closed loop pulsating heat pipe at 45 degree exhibits the considerable enhancement of heat transfer compared with that of closed loop pulsating heat pipe without fin.

Past researchers performed their research based on the influence of vibration on the heat transfer coefficient of cylindrical surfaces and plate. To the best of our knowledge no research was performed to investigate vertical vibrations on the heat transfer rate in longitudinal finned tube. Consequence, this paper investigated the effect of vertical oscillation on the longitudinal finned tube, including considering different frequency (2 - 16 Hz), different heat flux and different inclination angle (0°, 30°, and 45°), and different Reynolds number (250 - 900) on the average Nusselt number.

2. Methodology

2.1. Experimental Setup

Experimental test rig is developed and setup in order to measure the temperatures at the base of the fins, amplitude and acceleration occurs at the longitudinal finned tube. This measurement is used to validate the previous experimental studies. The schematic of the test rig system and the experimental test rig components used as shown in Figure 1a. The test rig is divided into (test section, vibration circuit, and electrical circuit). The system schematic for the finned tube test rig shows the rig components, and instrumentations as illustrated in Figure 1a.

Table 1 shows the overall physical measurement of the test rig components. Eight triangular longitudinal fin (made of an aluminum) equally distributed by (45°) in model was used (Figure 1b) [20]. Varied of heat flux is applied and the heater has been placed inside the cylinder tube. In order to reduce the heating loss at its ends, the cylinder tube is fixed to connection arms using Teflon substances. The angle of the finned tube can be varied from 0° to 45°, using a lever mechanism which connects the holder and its base.

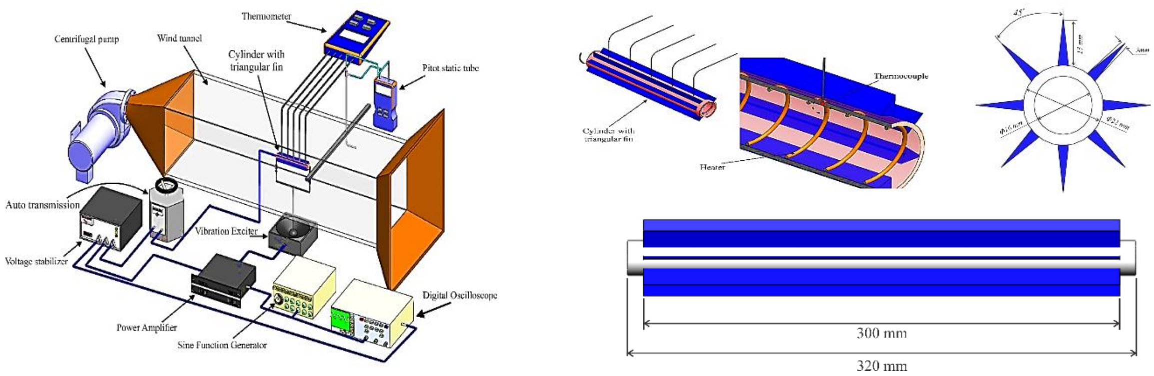
Table 1. Test Rig Measurements Rate

Components	Size (mm)
Length: Cylinder tube	320
Length: Finned tube	300
Outer Diameter: Finned tube	48
Height: Finned tube	13

A heating coils power of 1000W are applied in electric circuit. There are 12 thermocouples type k were installed at the fin surface and distributed uniformly. A thermocouple was used to measure ambient temperature which is located 15 cm away from the finned tube. The thermocouples were connected to a selector switch, then connected to digital thermometer. Test rig suspended horizontally inside air duct by oscillating arm which receives its oscillatory motion from exciter which had been fixed at inside the air duct working as guides to keep the movement of test model assembly horizontally, as shown in Figure (1a). However, the measured vibration amplitude for both the holder and the heated cylinder are not much different.

The air duct has been designed (1× 0.5 m) cross-section with 2 m length. The duct walls are built from wood of 2 cm thickness in order to improve the radiation heat transfer from the square cylinder to the walls. The air duct has been provided with centrifugal fan fixed horizontally to deliver proper parallel air flow, air duct at finned tube as shown in Figure 1a. A Pitot static tube is installed which is fixed at upstream of the finned tube. This is for measure the air flow velocity in the air duct. The air duct outlet is connected to the variable speed electric Centrifugal Blower inlet. The centrifugal blower [Brook Compton, Parkiuon Motor and Doncaster-England] is driven by A.C. motor of 550 W at 2800 r.p.m. The flow of air is controlled by using an adjustable throttling valve mounted just at the air outlet to control the velocity of air between (1-5 m/s).

The experimental work was performed by heating the finned tube and to make sure constant conditions was occurred after 1.5 to 2 hours [20]. Then, temperature measurement was recorded without vibration effect. After that, vibration effect was applied ranged between 2 to 16 Hz and temperature readings were obtained as well. Same procedure was implemented in order to achieve stable period, record the vibration amplitude and temperature. The vibration system consists of three main parts: The Random Function Generator, which generates and sends the signal to the digital Oscilloscope, and the Power Amplifier, which amplifies the signal and sends it to the Vibration Exciter, which vibrates according to the desired frequency. The test model and stand are mounted vertically by the vibration system inside the duct.



(a) Schematic diagram of the test rig. (b) Schematic diagram of the fined tube.

Figure 1. Schematic diagram of the test section, vibration circuit, and electrical circuit used in the test rig.

2.2. Processing and boundary conditions

The amount of heat generated due to electric heater through to test section (longitudinal finned tube) by conduction and then dissipate to the surroundings by force convection in addition to radiation.
When energy balance is implemented on the test section, the convection heat transfers from the longitudinal finned tube [20], which gives

$$Q_{gen} = Q_{con} + Q_{rad} \tag{1}$$

where Q_{gen} is represented heat generation in electrical heater (W), Q_{con} is the conduction heat transfer (W), Q_{rad} is represented radiation heat transfer (W). The heat generation (Qgen) due to electric heater related to the current (I) and voltage (V) in the electrical heater, as follows:

$$Q_{gen} = I \times V \tag{2}$$

where I is represented current (Amp), V is the voltage (Volt). The radiation heat transfers through a longitudinal finned tube is commonly expressed as:

$$Q_{gen} = \sigma \cdot A_f \cdot \epsilon \cdot (T_s^4 - T_a^4) \quad (3)$$

Where σ is the Steven poltzman constant, ε is represented emissivity, T_s is the surface temperature (°K), Ta is the air temperature (°K), A_f is represented fins area (m^2). However, the heat transfers coefficient through the finned tube may be determine using the following formula [20]:

$$h = \frac{Q_{con}}{A_f(T_s - T_a)} \quad (4)$$

where h is represented heat transfer coefficient ($W/m^2.°C$). The air properties have been calculated based on the on the average value of finned tube surface temperature and ambient temperature:

$$T_f = \frac{T_s + T_a}{2} \quad (5)$$

where T_f is the film temperature (℃). The vibration intensity (U_v) and amplitude of vibration is commonly expressed as:

$$U_V = a * f \quad (6)$$

$$a = \frac{a_{cc}}{\sqrt{2}*(2*\pi*f)^2} \quad (7)$$

where *a* is the amplitude of vertical vibration (*m*), *f* represents the vibration frequency (*Hz*), a_{cc} the acceleration of vibration, (m/s^2).

An experimental work has been performed using air as a working fluid in order to create the effect of forced vertical vibration and force convection on the average Nusselt number of the longitudinally finned tube. Variation inclination angle was set and heat generation and vibration frequency were applied for each test. Furthermore, the heat transfer coefficient, vibration intensity, Reynolds number, and vibration Reynolds number, in addition to the amplitude of a vibrating system and their acceleration of vibration for different values of air flow velocity were determined for the analysis. The results of this longitudinally finned tube are obtained for forced convection and force vibration. As stated, the heat flux was set up with range between 500 to 1500 W/m^2.

3. Result and Discussion

3.1. Validation of the current present work and literature

As mentioned in section II, the experimental had validate against the result from experiment which is determined from the previous study. For presented work, the validation is performed by comparing the average Nusselt number from literature with measured average Nusselt number in the experiment.

The average Nusselt number is used to analyze the effect of vibrations on the heat transfer rate in longitudinal finned tube. The values of Reynolds number utilized in this study is from 250 to 900. In order to investigate the effect of vertical vibration on the heat transfer rate in longitudinal finned tube, firstly, the values of amplitude, used in this study is from 0.2 mm to 0.5 mm, and the range of heat generation from 500 to 1500 w/m2.

The current experimental was validated against previous experimental studies. Figure 2 shows the comparison of the current experimental result with the experimental result obtained by previous researcher [4-7]. Comparison was performed using average Nusselt number longitudinal finned tube. The average Nusselt number altitude for the finned tube from 74 to 93 (at Re = 250, Re = 900), respectively, obtained from the experiment. Tian et al. [5] found that the average Nusselt number altitude obtained from their experimental value was 53 to 75 at Re from 100 to 750. Also, Eid and Gomaa [4] found that the average Nusselt number altitude obtained from their experimental value was 67 to 70 at Re from 230 to 900. Figure 2 shows that the average Nusselt number obtained from the current experimental results was altitude 5% at Re from 250 to 900. Therefore, the current work possible give an improvement of about 84% in average Nusselt number over that from the steady state flow case (Eid and Gomaa [4]). Consequently, the present work could be used with confidence in this study to perform heat transfer analysis.

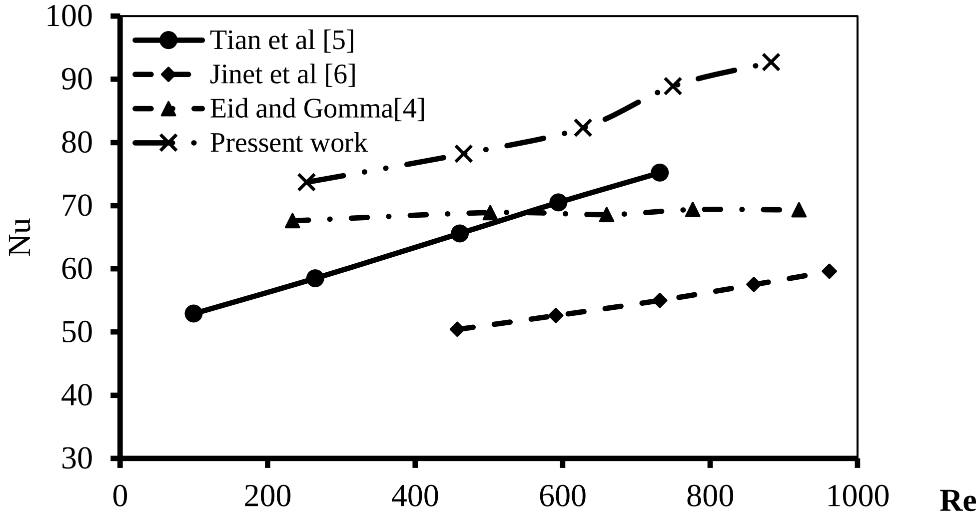


Figure 2. Comparison between current work and previous studies.

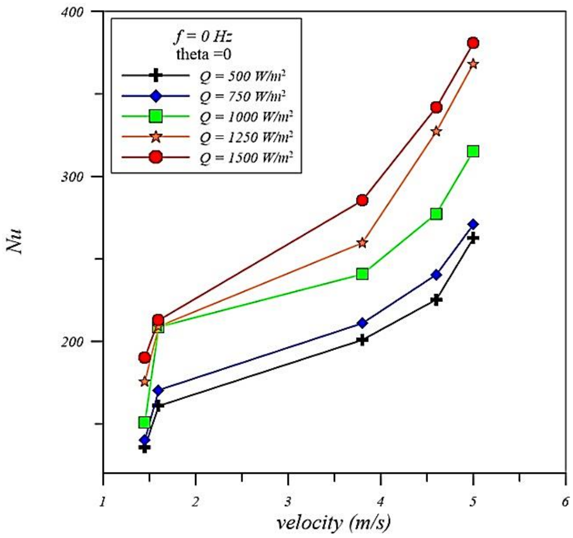
3.2. Effect of vibration on the nusselt number

Primary parameters that determine the performance of finned tubes are the amount of heat transfer from the surfaces, include heat transfer coefficient due to the external vibration of the finned tubes. A series of frequency at different angles and different heat flux are shown in Figures 3, 4, 5, 6 and 7 to present the performance of finned tubes under investigation. Figures 8 to 12 show the effect vibration intensity on the average Nusselt number at different angles.

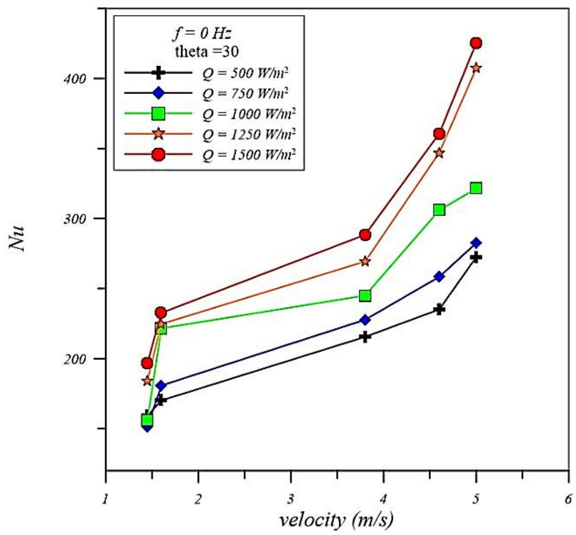
The range of vibration frequency using as all model at a different angles (θ = 0°, 30°, 45°) from 2 Hz to 16 Hz, and the ranged of heat flux from 500-1500 W/m2. The values of Reynolds number, utilized in this study is from 250 to 900, as shown in figures 3 to 7. Figure 3 shows that the increase in the average Nusselt number continues to increase, Reynolds values increased from 250 to 900 at increase in the finned tube angles. At f =0 Hz, Re = 900, and Q= 1500 W/m2, it found that the average Nusselt number increase from 381, 425, and 481 occurring at θ = 0°, 30° and 45°, respectively.

Figure 4 show the average Nusselt number increase from 440, 461, and 482, at f = 4 Hz at different angles (0°, 30°, 45°). Also, figure 5, found that the average Nusselt number at angle 45° higher than from angle 0°, and 30°, where the values of average Nusselt numbers were 533, 471, and 451, respectively, at f = 8 Hz, and Re = 900. Figure 6 show the average Nusselt number increase from 480, 495, and 561, at f = 12 Hz at different angles (0°, 30°, 45°). At Re= 900, f =16 Hz, and different angles (θ = 0°, 30°, 45°) at heat flux 1500 W/m2, it found that, the maximum average Nusselt number values were 504, 520, and 606, respectively, as shown in Figure 7. Although, average Nusselt number occurred at angle 45°, Re = 900, and Q = 1500 W/m2. This is attributed to the large-amplitude motion forced air around the bottom and top of the finned tube causing the boundary layer to thin on the leading side of the cylinder which resulted in an increase in the heat transfer in this region [21]. Wherefore, increase in average Nusselt number occurred at θ = 45°.

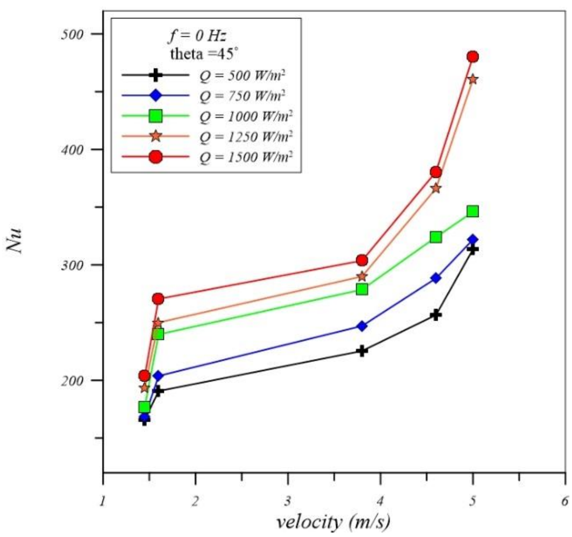
Figures 3 to 7 illustrates the average Nusselt number that occurred at different frequency and air Reynold numbers, which corresponds to different angles. The average Nusselt number at the finned tubes at various Reynold numbers from 250 to 900 are presented in Figures 3 to 7. According to the figures, slight increment occurred in the Nusselt number values with increasing Reynolds number, when compared to the with and without vibration. Figures 3 to 7 shows average Nusselt number values increased when the Reynolds number increased from 250 to 900 and vibration frequency increased from 2 to 16 Hz, respectively. It can be concluded that the average Nusselts number valued are proportional to Reynolds number.



a) θ=0°

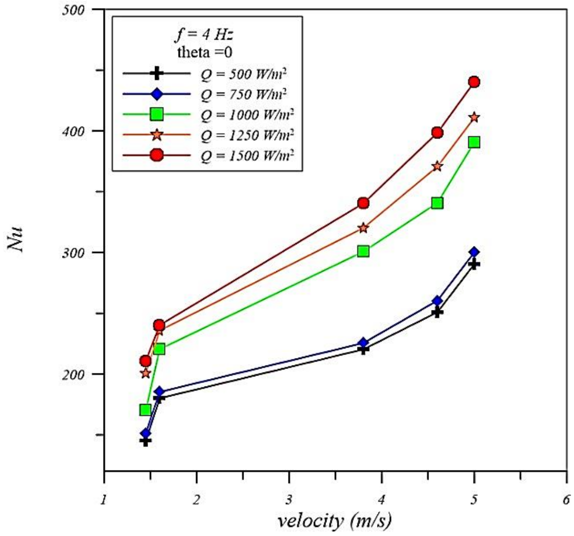


b) θ=30°

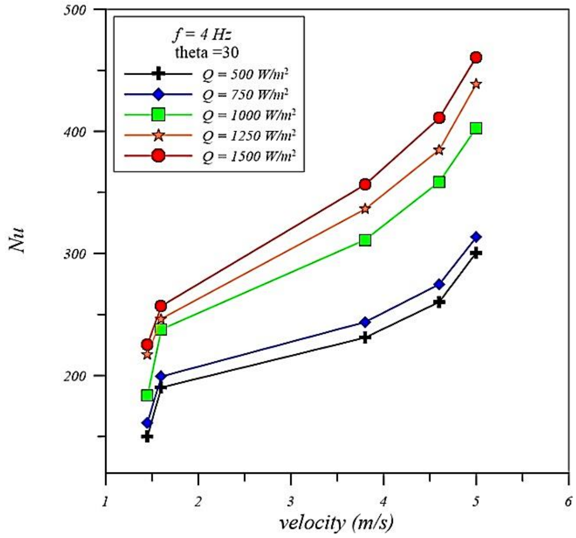


c) θ=45°

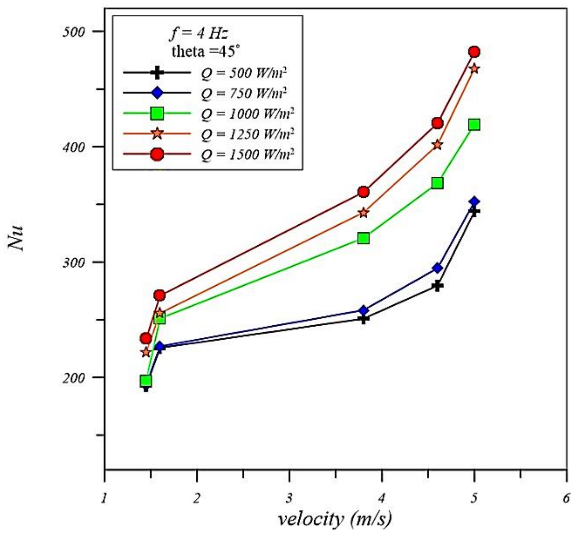
Figure 3. The effect of velocity on the Nu for the fin tube with *f* = 0 Hz at different heat rate and angle.



a) θ=0°

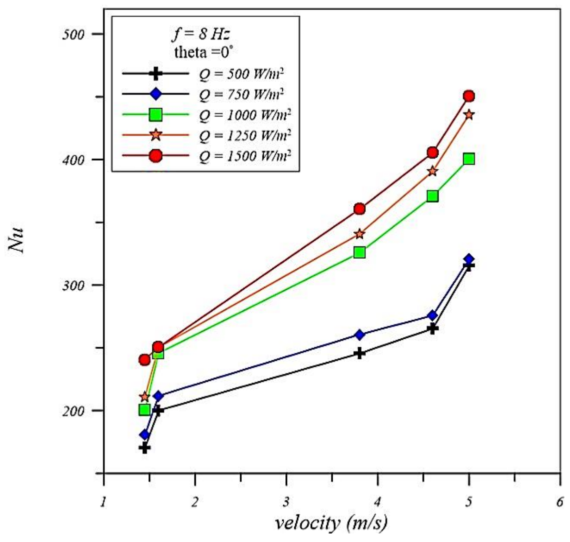


b) θ=30°

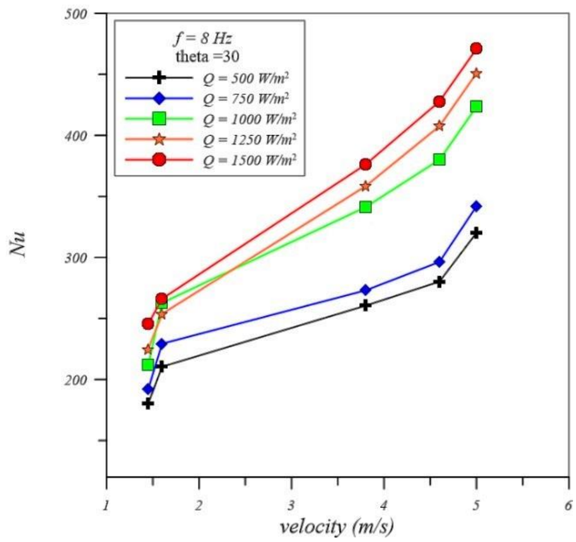


c) θ=45°

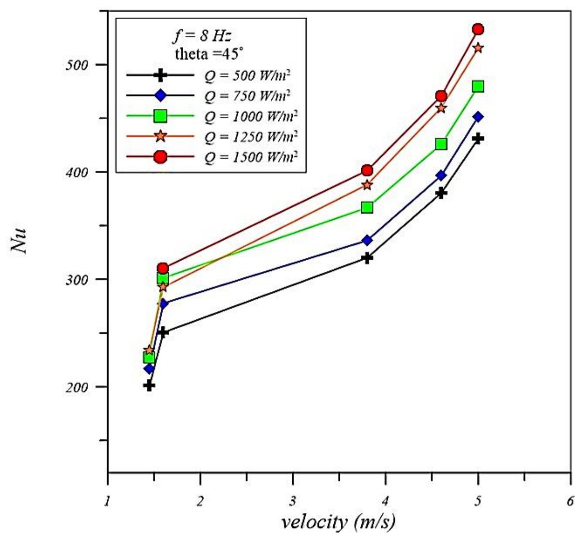
Figure 4. The effect Velocity on the Nu for the fin tube with *f* = 4 Hz at different heat rate and angle.



a) θ=0°



b) θ=30



c) θ=45°

Figure 5 The effect Velocity on the Nu for the fin tube with *f* = 8 Hz at different heat rate and angle.

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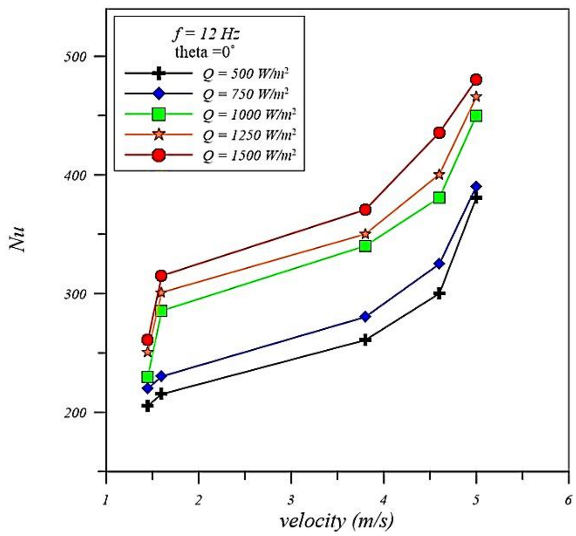
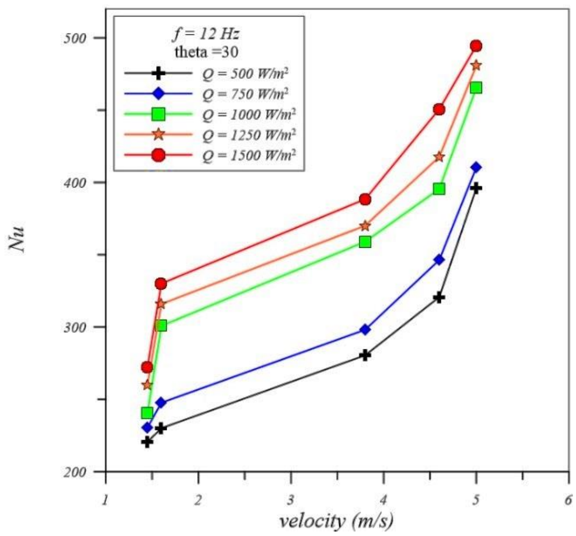
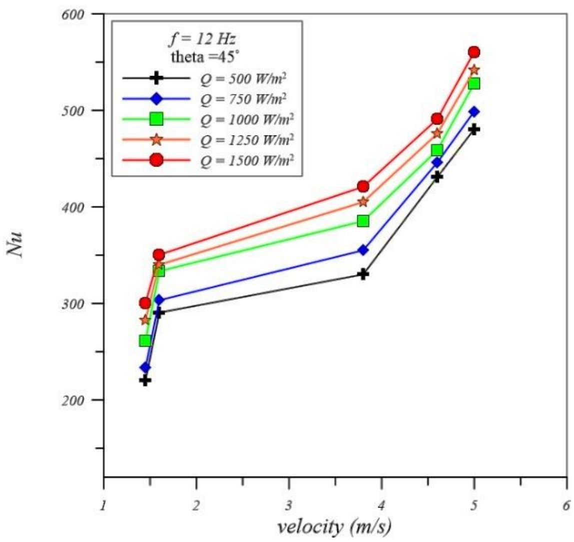


a) θ=0°

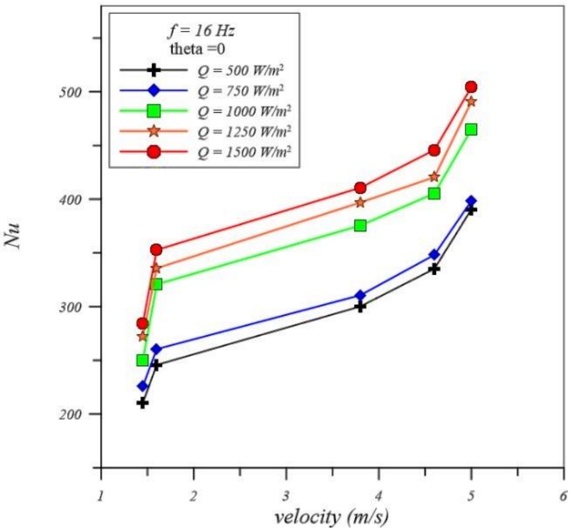


b) θ=30

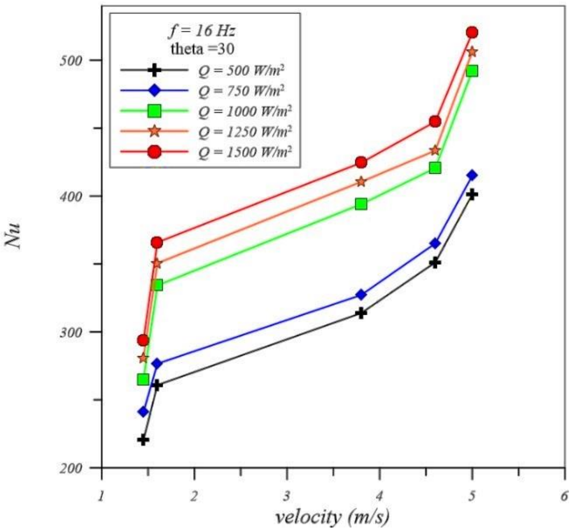


c) θ=45°

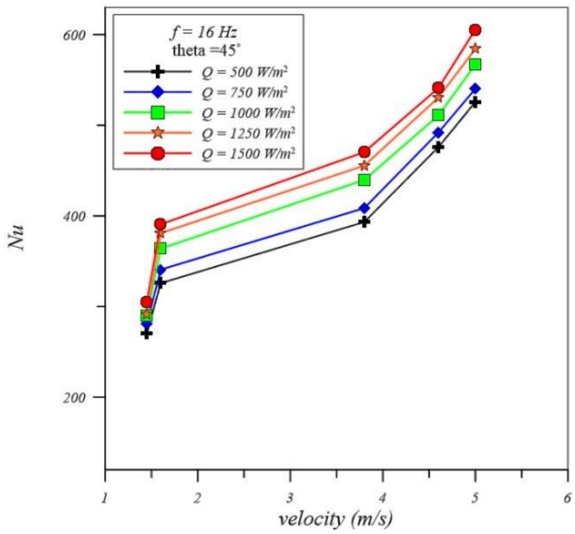
Figure 6. The effect Velocity on the Nu for the fin tube with f = 12 Hz at different heat rate and angle.



a) θ=0°



b) θ=30



c) θ=45°

Figure 7. The effect Velocity on the Nu for the fin tube with f = 16 Hz at different heat rate and angle.

4. Conclusion

A longitudinal finned tube cylinder was developed to experimental investigated average Nusselt number at different angles and different excitation frequency. The experimental measurements are validated against the previous experimental studies. From the experimental measurements found that the quantitative comparison between the previous experimental studies of the vertical vibration effect on the average Nusselt number, showed reasonable agreement with deviation of 5%. The vibration intensity affected on the average Nusselt number of angle (45°) at the model were 14% greater than those for the (30°) and exceeds that of the (0°) from the zero angle by 16%, respectively. From all the current results in this work, the vibration can significantly affect the average Nusselt number from longitudinal finned tube cylinder and its effects on the heat transfer coefficient should be considered.

IOP Conf. Series: Materials Science and Engineering 1062 (2021) 012007 doi:10.1088/1757-899X/1062/1/012007

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