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# Effect of Vibration on Heat Transfer Enhancement in a Rectangular Channel Heat Exchanger

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**Abstract**: *Heat transfer characteristics in a horizontal rectangular heat exchanger with five triangular baffles inclined at fixed angle of 20$^o$ along the channel are investigated experimentally. The same heat exchanger is also investigated with use of vibration. The experiment is done on three different vibration intensities. Effects of different vibration intensities on heat transfer are observed and compared with different heat transfer characteristics like overall heat transfer coefficient, effectiveness and heat transfer rate in absence of vibrations. It is found that with increase in vibration intensities, heat transfer characteristics can be improved to some extent.*
***Keywords:*** *Heat Transfer Enhancement, Rectangular Channel, Triangular Baffles, Vibration Intensity.*

## I. Introduction

Heat exchangers are used in different processes like conversion, utilization & recovery of thermal energy in various industrial applications which include steam generation & condensation in power plants; sensible heating & cooling in thermal processing of chemical, pharmaceutical & agricultural products etc. Increase in heat transfer enhancement can lead to more economical design of heat exchanger which can help to make energy, material & cost savings related to a heat exchange process. The need to increase the thermal performance of heat exchangers has led to the development & use of many active and passive techniques which leads to increase in heat transfer co-efficient at the cost of increase in pressure drop. Therefore proper analysis of heat transfer rate & pressure drop has to be performed while designing a heat exchanger using any of these techniques. To achieve high heat transfer rate in an existing or new heat exchanger while taking care of the increased pumping power, several techniques have been proposed in recent year.

Thundil Karuppa Raj [1] investigated the effects of various inclination angles of baffles on heat transfer characteristics. Inclination angles were 0$^o$, 10$^o$ and 20$^o$. Also, CFD software tools were used to study temperature fields. Investigations were done on various mass flow rates and baffle angles for a baffle cut of 36%. The parameters like shell side outlet temperature, pressure drop etc were determined from CFD simulation and concluded that maximum mass flow rate found was 2 kg/s as pressure drop would increased beyond this with little variation in outlet temperature and pressure drop is decreased by 16%, with baffle angle of 20°(maximum) and 4% with baffle angle 10°. Parkpoom Sriromreun et al. [2] investigated the impact of Z-shaped (as placed in zig-zag manner) baffles in a rectangular channel on heat transfer augmentation. For finding optimum thermal performance, Z-baffle height (inclined at 45$^o$ to flow direction) and pitch spacing length effects were examined for various Reynolds number ranges from 4400 to 20400. Three baffles to channel height ratio (e/H=0.1, 0.2 and 0.3) and pitch ratios (P/H =1.5, 2 & 3) were examined. Heat transfer characteristics like Nusselt number, friction factor & thermal performance factors for in phase 45$^o$ Z-baffles were found better than those at out phase 45$^o$ Z-baffles. S. Pethkool et. al. [3] experimentally investigated the augmentation of heat transfer in a concentric tube heat exchanger using helically corrugated tubes. The effects of pitch to diameter ratio (P/D=0.18,0.22 and 0.27) and rib height to diameter ratio (e/D=0.02,0.04 and 0.06) on heat transfer, isothermal friction factor and thermal performance factor for Reynolds number range from 5500 to 60000 was examined and found mean increase in heat transfer between 123% to 323%. It was also found that maximum thermal performance factor was 2.3 at P/D=0.27 and e/D=0.06 at low Reynolds number. S. S. Shinde et. at. [4] showed the comparative thermal analysis of Helixchanger with segmental heat exchanger. Thermal analysis for conventional shell and tube heat exchanger and helixchanger for five different baffle inclination angles (α) was observed that continual helical baffles can eliminate dead regions in shell side. Pressure drop was found very small at $\alpha>35^o$. Heat exchangers with continual helical baffles had higher heat transfer coefficient as compared to segmental heat exchanger. Jeong and Kwon [5] investigated experimentally the effect of ultrasonic vibrations on critical heat flux (CHF). CHF has been measured on flat heated surface with and without applying ultrasonic vibration to the fluid. They examined the water subcooling at various temperatures and angles. Also, these angles of the heated surface and water subcooling were varied. The data so collected showed that ultrasonic wave enhanced the CHF. The range of CHF had varied with the inclination angles of the heated surface. Further it was observed that as the water subcooling values increased, CHF rate also increased and shows its linear nature. However CHF decreased with an increase in inclination angle. In experimental investigation by Kim et al [6] the effect of tube vibration on critical heat fluxes (CHF) was observed to find the variation of the relationship between CHF and flow-induced vibration (FIV) was found. The experiment was carried out for different values of mass flux, amplitude and frequency. They used the frequency range from 0 to 70 Hz. They also proposed an empirical correlation in presence of tube vibrations which predicted the CHF enhancement ratio (En) with reasonable accuracy, with an average error rate of 27.75%. Lee et al [7] carried out experiments with vertical annulus tube. They examined the effects of mechanical vibrations on CHF under electrically heated condition and find the total increase of 16.4% in CHF under mechanical vibrations. It was observed that reinforced turbulent mixing effect of vibration enhanced the CHF value. Go [8] studied the effect of microfins oscilating due to flow induced vibration. The fluid taken was air and velocities of air was 4.4m/s and 5.5 m/s. Also microfin array was fabricated over the heat sinks. As the fluid moves over them, a vibration was induced which causes heat transfer enhancement. Data so obtained was compared to plain heat sink. It was concluded that microfins provided upto an 11.5% enhancement over a plain heat sink. Oscillatory motions generally enhance the heat and mass transfer in a fluid. For instance, Ni and Rama Rao[9] reviewed various concepts of mixing enhancements through pulsation and oscillations. They had used the vibrations for heat transfer enhancement at different periods. Yasir[10] also investigated experimentally the effects on heat transfer coefficient and heat flux characterstics for both subcooled process and saturated boiling process. He used the acoustic vibration levels having ranges of 5 kHz to 15 kHz and the results shows increase in heat transfer coefficeint at higher mass fluxes for subcooled boiling. It increase upto 14% from lower to higher frequencies used in experiment. Similarly for saturated boiling tested at two different heat flux of 15kW/m$^2$ and 29 kW/m$^2$ and found that increase in frequency increases the heat transfer coefficient at increse in mass flow.

The present paper discusses the effect vibrations on the heat transfer in a rectangular channel having walls vibrating as standing waves. A vibrating wall next to a fluid at rest induces an unsteady motion in the fluids. In practical applications flexible walls vibrating as standing waves are also relatively easy to achieve compared to most other types of wall deformations.

## II. Experimental Set Up And Procedure

The experimental set up consists of a horizontal rectangular channel of cross-section 100mm×150mm and 1000mm in length which is insulated with layer of glass wool. Triangular baffles at a fixed inclination angle of 20$^o$ are placed along the length of the channel with baffle spacing of 0.2m. Two Cu tubes of outer diameter (O.D) 20mm are made three times to pass through the channel. These tubes are supported by baffles.

Vibration generating source, placed on the body of heat exchanger, is a motor having a cam with its eccentric weight attached to its shaft. A variac is used to regulate the vibration intensity. In the present experiment both the fluids used are water, cold water being circulated inside the tubes whereas hot fluid is made to pass through the channel. The mass flow rate of cold water is kept constant and mass flow rate of hot water is changed and noted for three different values viz. 1.5 kg/min, 1.75 kg/min & 2 kg/min. Inlet temperatures of hot water are also taken at three different values. Temperature variations at outlet are noted at each mass flow rate against every change in inlet hot water temperature. These temperature variations are taken in the absence of vibration. Various heat transfer enhancement characteristics are investigated experimentally such as outlet temperature, overall heat transfer co-efficient, effectiveness etc.

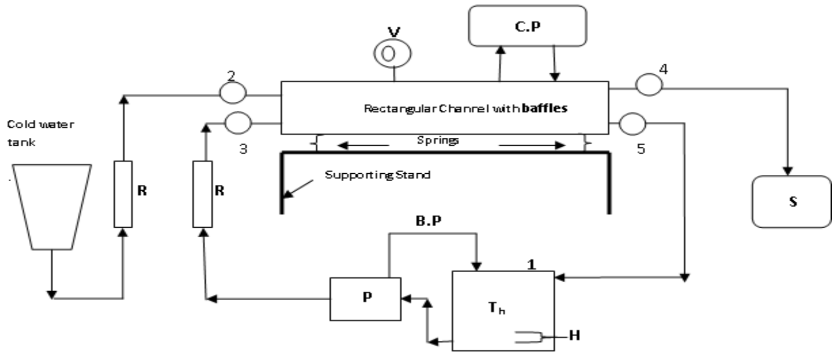
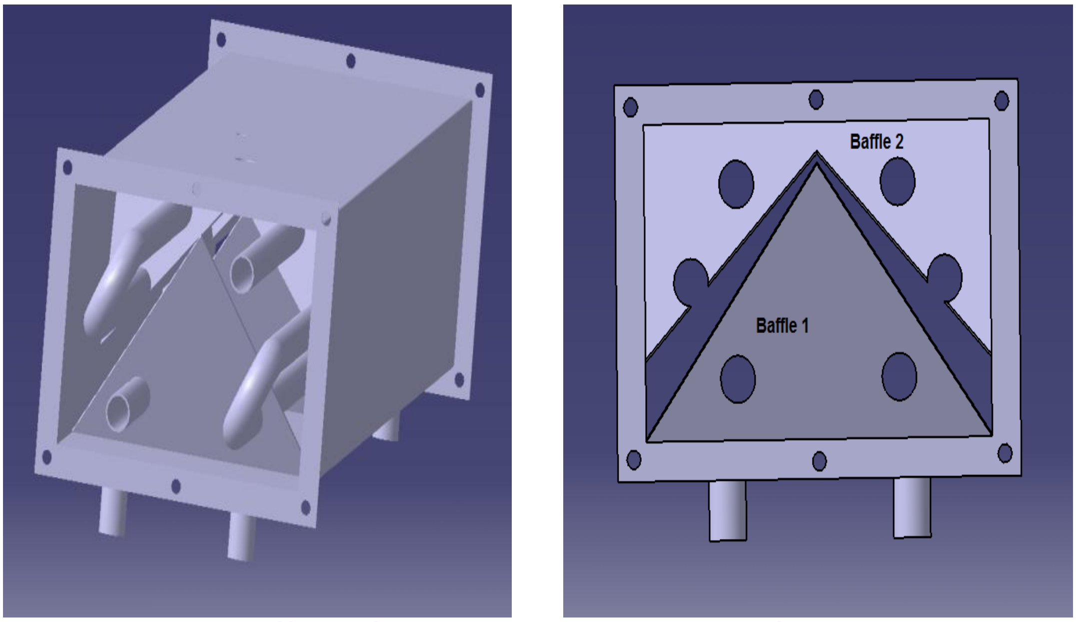



Fig. 1 Schematic diagram of rectangular heat exchanger with vibrator

The various abbreviations used in the above diagram are:

| | | | |
|---|---|---|---|
| 1,2,3,4,5 | Temp sensor | $T_h$ | Hot water tank |
| B.P | By-pass | V | Vibrator |
| C.P | Control Panel | R | Rotameters |
| H | Heater | S | Sink |




(a) Duct Assembly (opened) (b) Front View

Fig. 2 Different views of rectangular channel.

Different vibrations intensities are now used to find its effect on heat transfer enhancement. Here in this paper three different intensities of vibrations are shown and are correlated with those characteristics which had taken without any vibrations earlier. The vibration intensities are taken with intensities of 5, 5.5 & 6.5. The instrument used to measure the intensity of vibrations uses smart phone sensors having its reading in MMI (Modified Mercalli Intensity) scale that is similar with the Ritcher Magnitude scale and has no units.

## III. Experimental Results And Discussion

The calculation of variables for effective heat transfer is the real problem of the present work. Different parameters used to plot the graphs are mainly mass flow rate of hot water, hot water temperature at inlet, temperature difference at outlet and the calculated parameters are heat transfer rate of hot fluid, effectiveness, overall heat transfer co-efficient etc. These parameters are obtained at three different vibration intensities. From these parameters a number of variations in graphs can be draw but here we will discuss some of the graphs and are shown below.

### 3.1 Effects of vibrations on outlet hot water temperature and outlet hot water temperature difference at different inlet hot water temperature

Fig. 3.1 shows the effect of vibrations on outlet hot temperature at three different inlet hot water temperatures. This graph shows that at constant mass flow rate of 1.5 kg/min of both fluids, increase in inlet hot water temperature, the outlet hot water temperature also increased at each vibration level.

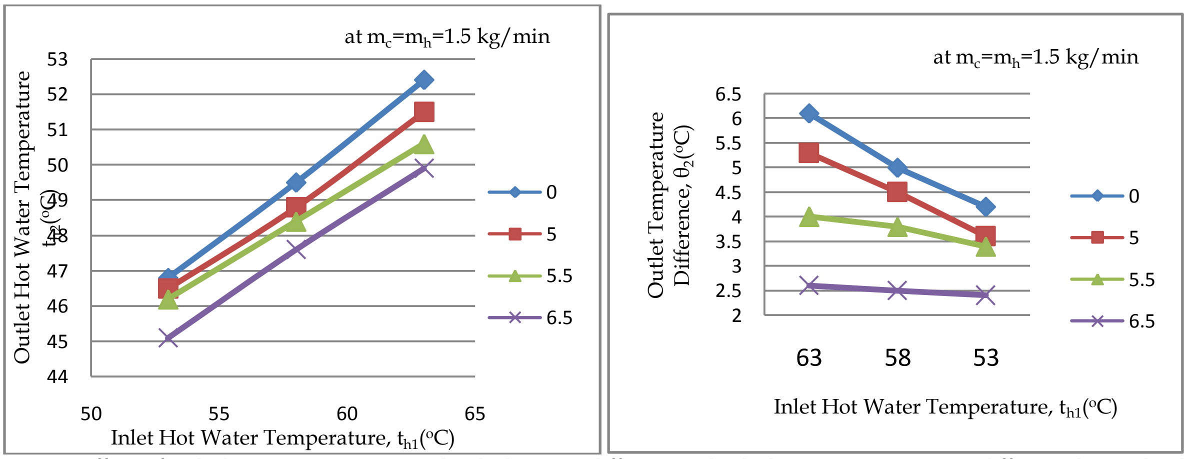



Fig. 3.1 Effects of outlet hot water temperature and outlet hot water difference with inlet hot water temperature at different vibration levels

This experiment is done on three inlet temperatures viz 53°C, 58°C and 63°C (constant difference of 5°C). Same is observed at different vibration levels. Graph clearly shows that higher the vibrations lower is the outlet hot water temperature. It shows that lower the inlet temperature lower will be the outlet difference. However, increase in vibration level drops the outlet temperature of hot water clearly indicates that heat is losing to cold water effectively. At different vibrations levels it is investigated that with decrease in inlet temperature, outlet temperature difference, $\theta_2$ tends to decrease which shows that vibration level shows positive effect on outlet temperature difference. On every increase in vibration levels this temperature difference decreases and minimum at higher vibration. This shows that vibrations have dropped the temperature difference from 6.1°C to 2.6 °C at constant inlet temperature of 65°C whereas it drops from 4.2 °C to 2.4 °C at minimum inlet temperature of 53 °C.

**3.2 Effect of vibrations on outlet temperature difference at different mass flow rates of hot water**

Variation of outlet temperature difference with increase in mass flow rate of hot water has also investigated in the presence of vibrations. As the Reynolds number for hot water has increased, outlet temperature difference has also increased in the absence of vibrations. But when intensity of vibrations has increased, it is found that outlet temperature difference decreases subsequently.

Fig. 3.2 clearly shows the effect of vibrations. This graph has plotted for constant inlet temperature of 58°C. Big gap between vibration level 5.5 and 6.5 is due to fact that vibration intensity is not taken at constant level but taken at increase value of 5 and then 10. At mass flow rate of 1.5kg/min, 1.75kg/min and 2kg/min temperature difference drop from 4.9°C to 2.3°C, 5.2°C to 2.6°C and 6.2°C to 3.5°C when taken without vibrations to highest intensity of vibrations.

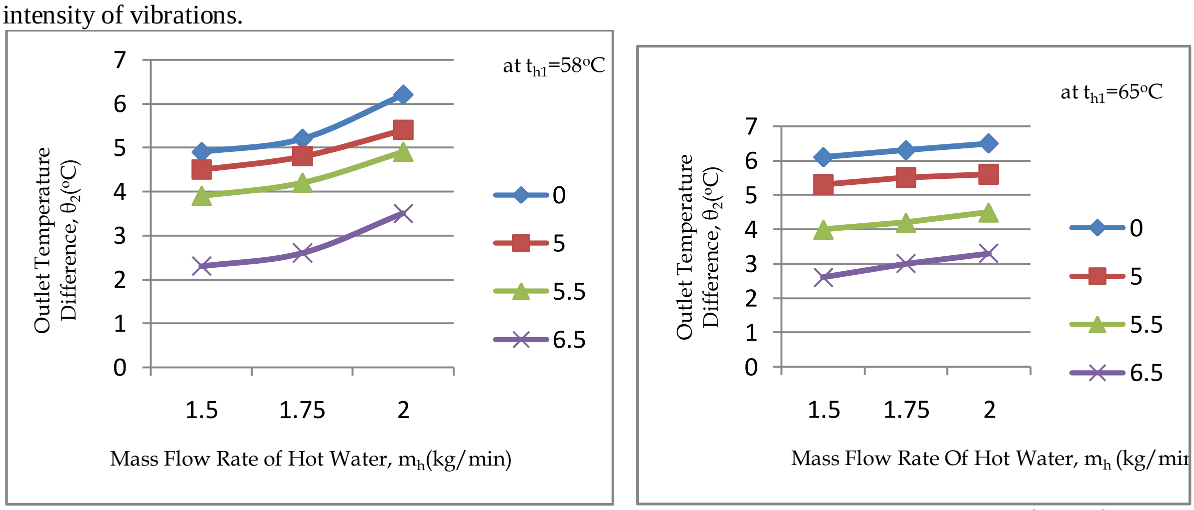



Fig. 3.2 Effects of vibrations on outlet temperature difference at different mass flow rate of hot water (at $t_{h1}$=58°C & 65°C)

The data so collected shows that vibrations decreases the outlet temperature difference and is found minimum at same mass flow rate of both fluids i.e. at 1.5kg/min. higher vibration levels means better results The outlet temperature difference is investigated on different mass flow rates of hot water where hot water temperature is kept constant at 65°C and Fig. 3.2 illustrates that at increase in intensities of vibration outlet temperature difference increases but with a lower slope due to increase in inlet temperature of hot water. Increase in mass flow rate increases the outlet temperature difference but on increasing vibrations intensities it.

**3.3 Effect of vibrations on heat transfer rate of hot water at different inlet hot water temperature**

Another graph (Fig. 3.3) is plotted between heat transfer rate of hot water and different vibration levels. The mass flow rate of hot water is increased to 2kg/min whereas mass flow rate of cold water is kept constant at 1.5kg/min. On all temperatures of inlet hot water, increase in vibration level increases the heat transfer rate. However irregularities in curves at inlet hot water temperature can be seen which may be due to experimental errors. Overall effect of vibrations can be clearly understood. Heat transfer rate is found maximum at high inlet temperature when taken at higher vibration intensity of 6.5 and is equal to 1591.06 Watt and minimum heat transfer rate is found at no vibration and low inlet hot water temperature is equal to 683.87 Watt. Graph clearly shows that increase in Q at increased vibrations shows heat transfer enhancement. At temperature 63°C, heat transfer rate increases from 1228.18 Watt with no vibration to 1591.06 Watt at highest vibration.

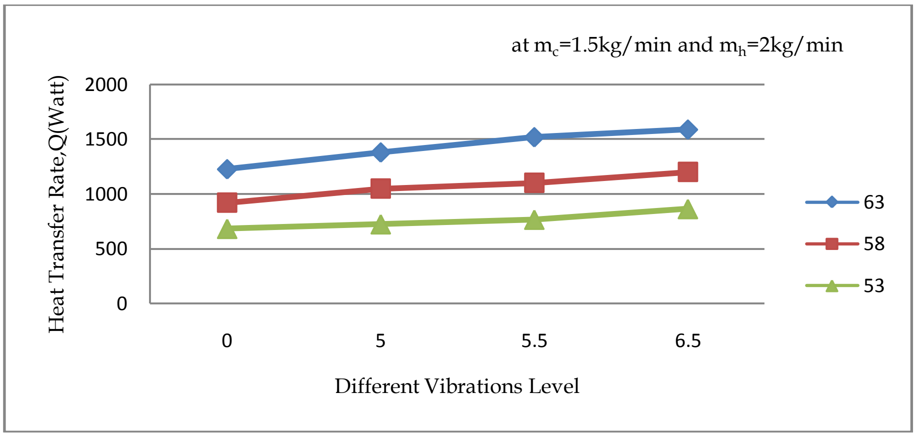



Fig. 3.3 Effect of heat transfer rate of hot water with vibration levels at different inlet hot water temperature.

**3.4 Variation of overall heat transfer co-efficient with vibration levels at different hot water inlet.**

The effect of vibrations on overall heat transfer coefficient (U) can be clearly understood with the help of Fig. 3.4. This graph shows that overall heat transfer coefficient increases with the increase in vibration levels. However, higher inlet hot water temperature leads to higher overall heat transfer coefficient and in the presence of vibrations it is found that overall heat transfer coefficient increases from 349.21 Watt (at no vibrations) to 594.68 Watt (at highest vibration level). Minimum value of overall heat transfer coefficient is found to be 291.39 Watt at no vibrations and at lowest inlet hot water temperature.

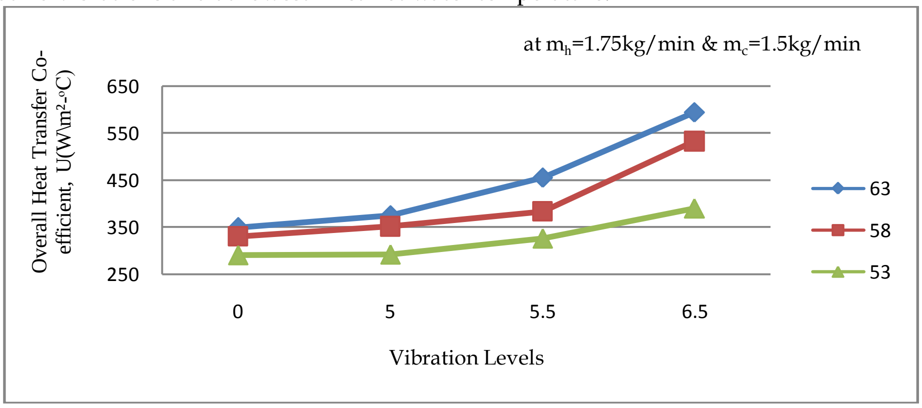



Fig. 3.4 Variation of overall heat transfer co-efficient with vibration levels at different hot water inlet.

This graph is plotted at fixed hot water mass flow rate of 1.75 kg/min and cold mass flow rate of 1.5 kg/min. The curves show that vibrations have increased the overall heat transfer coefficient for each hot inlet water temperature.

**3.5 Effect of vibrations on effectiveness at different hot water inlet temperature**

Here effectiveness is calculated at fixed mass flow rate of hot water equal to 2 kg/min and cold water equal to 1.5 kg/min. It is shown that increase in inlet hot water temperature actually increases the effectiveness and is shown by lowest curve. Other three curves indicate the different vibration levels. Graph simply illustrates the effect of vibration that higher the vibrations higher will be the effectiveness. At vibration level of 6.5, effectiveness increases from value 0.536 (i.e. 53.6%) to 0.6037 (i.e. 60.37%) when inlet hot water temperature increases and found to be highest among all values. At lower vibration levels, effectiveness increases when inlet hot water temperature increases but decreases with fall of vibration levels.

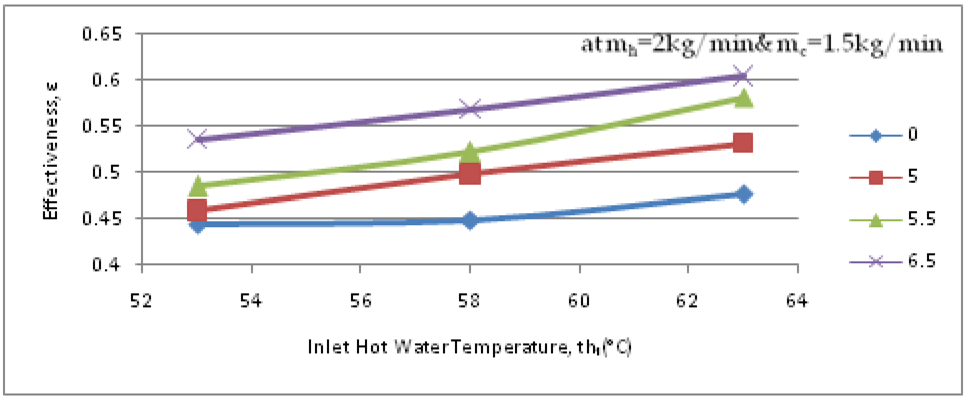



Fig. 3.5 Effect of inlet hot water temperature on effectiveness at different vibration levels

Also, increase in mass flow rate of hot water will also increase the effectiveness so it is evaluated that effectiveness is higher at high mass flow rate and varies with vibration level directly.

## IV. Conclusion

Hot water characteristics at outlet vary linearly to inlet, however on increasing vibration level outlet temperature decreased when taking at same mass flow rate of hot water. The outlet temperature difference is decreasing from 6.1°C to 2.6°C i.e. upto 57.3% at same inlet temperature, $t_{h1}$ and same mass flow rates of 1.5 kg/min. Vibrations shows the positive effect on outlet temperature difference. At temperature 63°C heat transfer rate increases from 1228.18 Watt with no vibrations to 1591.06 Watt at maximum vibration which ensures total increase of 29.5% in heat transfer rate of hot fluid. Similarly when calculated at inlet temperature 53°C it increases to 26.5% and is found minimum in all temperature ranges. Effect of vibration intensities on overall heat transfer co-efficient, U at same inlet temperature of 63°C shows the total increase of 70%. When investigated on different inlet hot water temperature of 58°C and 53°C, overall heat transfer co-efficient varies from approximately 34% to 60%. Variations of effectiveness with vibration levels also have some positive effects. The maximum effectiveness has found on vibration level of 6.5 and at maximum mass flow rate of hot water at 2 kg/min. It is calculated to be 60.37% at inlet hot water temperature of 63°C. Overall it can be concluded that with the use of vibration on heat exchanger, heat transfer enhancement can be achieved by some extent. However it is difficult to use such external vibration producing elements on large size heat exchangers. Also, increase of vibrations over a limit can cause corrosion in the heat exchangers, leakages, noise as it is found during this experiment.

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