# Advancement in Triple Flow Heat Exchanger Using Vibration

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*Abstract*- **In this, the performance and advancement of triple flow heat exchanger is determine and presented graphically in terms of temperature, effectiveness of two of the fluids. The effectiveness is determined as a function of heat exchanger size for sets of fixed operating temperature condition. In this experiment were performed to investigate the effect of vibration on the heat transfer characteristic of flow in circular heated pipe. Water is used as working fluid with inlet Reynolds number between the range of 400 to 1100 and vibration acceleration is varying from 1g to 5g. The results demonstrated that mechanical force vibration significantly influences the heat transfer in a cold pipe flow. The Nusselt number increases with the vibration acceleration. The Nusselt number increases rapidly when the vibration frequency increases but change in Nusselt number increasing first then start decreasing. Effectiveness and efficiency parameter are determined for a wide range of operating parameter for counter flow.**

*Index Terms*- **triple flow, counter flow, vibration, nusselt number, and heat transfer coefficient;**

## INTRODUCTION

Heat exchanger is a device that offer the exchange of heat between two or more fluids that are at different temperature and keeping them from mixing with one another. It differs from mixing chamber that it does not allow any fluids to mix, they are separated by a different walls or chamber, or we can say that heat transfer is a device that is used for transfer of internal thermal energy between two or more fluids available at different temperature. Common example of heat exchanger familiar to us day to day use are automobile radiator, condenser, evaporator, air-pre heater and oil coolers.

The heat exchanger running with two fluid doesn't give much temperature difference because the fluids interaction, momentum and temperature exchange is not uniform to every particles or molecules or layers of fluid flowing. Disadvantages of double tube heat exchanger is that, it would have to be very long and to solve that the design can be folded over for better compactness, but this would result in higher pressure losses and mechanical problems. It would also amenable to periodic cleaning.

Parallel or counter flow heat exchanger involving three or more distinct fluid have been of interest and received attention. Recently, interest has been generated in the possible use of multi flow, cross flow heat exchanger. In triple flow heat exchanger three fluid simultaneously crossing each other in single pass, out of the three fluid one may hot which is at the middle then other two fluid will cold crossing each other either in parallel or in counter direction or cross flow direction.

Leyarovski et.al. [7] Heat exchanger of two tube is less effective in the presence of second cold flow with low gas pressure and other physical parameter, because of the necessity of third tube. LI Ya-xia et.al. [9] The results show that the spiral corrugation can further enhance heat transfer of the smooth helical tube due to the additional swirling motion. Decrease of the pith of spiral corrugation can increases heat transfer between the tube. The results show that the spiral corrugation can further enhance heat transfer in smooth helical tube due to the additional swirling motion and decrease of the pith of spiral corrugation makes heat transfer enhance higher. Klaczak et al. [4] delivered a report concerning the influence of forced vibration on the heat transfer in a horizontal laminar flow steam–water exchanger. It was demonstrated that a vibration with a high acceleration generally boosts the heat transfer efficiency. Barigou et al. [2,] used computational fluid mechanics methods to study sinusoidal transverse mechanical vibrations on an internal viscous flow in a pipe; a distinct enhancement in heat transfer, more uniform radial temperature profile, and faster heating of the core region of the fluid flow were observed owing to the vibration. Cheng et al. [5] performed an experimental and numerical study on the relationship between flow induced vibration and heat transfer enhancement in a heat exchanger. It was concluded that the heat transfer could be enhanced and the fouling resistance could be decreased under the flow induced vibration condition. Hosseinian, et. al. [11] The forced vibration on the outer surface of the heat exchanger is imposed by electro-dynamic vibrators. Result demonstrates that imposing the vibration increase the heat transfer coefficient remarkably, while decrease the nano-particles deposition.

NOMENCLATURE

| | |
|---|---|
| $T_{co}$ | Temperature of cold water outlet |
| $T_{ci}$ | Temperature of cold water inlet |
| $T_{hi}$ | Temperature of hot water inlet |
| $T_{ho}$ | Temperature of hot water outlet |
| $T_1$ | Temperature of inlet for tube-1 |
| $T_2$ | Temperature of outlet for tube-1 |
| $T_3$ | Temperature of inlet for tube-2 |
| $T_4$ | Temperature of outlet for tube-2 |
| $T_5$ | Temperature of inlet for tube-3 |
| $T_6$ | Temperature of outlet for tube-3 |
| $C_{pc}$ | Specific heat capacity at constant pressure for cold fluid |
| $C_{ph}$ | Specific heat capacity at constant pressure for hot fluid |
| Re | Reynolds number |
| Nu | Nusselt number |
| LMTD | Logarithmic Mean Temperature Difference |
| Pr | Prandtl Number |
| L | Length of the tube |
| D | Diameter of the tube |
| A | Cross sectional area |
| h | Heat transfer coefficient |
| $\dot{m}_c$ | Mass flow rate for cold water |
| $\dot{m}_h$ | Mass flow rate for hot water |
| a | Diameter of tubes |
| Rc | Radius of spiral |
| Q | Heat flux that is transferring |
| ρ | Density of fluid flowing |
| g | Gravity |
| **ν** | Velocity at which fluid if flowing |
| $f_n$ | Natural frequency |
| f | Operating frequency |
| $\delta$ | Displacement under gravity |

EXPERIMENTAL SETUP AND PROCEDURE

In this, there is three tube tube-1, tube-2 and tube-3, tube-3 is the outer tube and the tube-1 and 2 are middle one. Inside the tube-2 the hot fluid will flow and in tube-1 and tube-3 colder fluid will flow which gain energy and temperature for the next cycle. The shape of middle tubes are in helical shape and shape of outer tube is cylindrical, helical tubes are joined by soldering and put inside the tube-3. The helical shape of tube-1 and 2 give turbulence to the inside fluid and due to counter flow there is increase in heat transfer. But the fluid inside the tube-3 will may be or may not be in turbulent so, to increase the heat transfer tube -3 are attach with the vibrator. As the vibration increases the heat transfer will increase up to the resonance and after that there is decrement in the heat transfer. The mass flow inside the tube-1 will be the inlet for the pipe-3, as the diameter of the pipe-3 is larger in dimension, hence it has low Reynolds's number compared to pipe-1

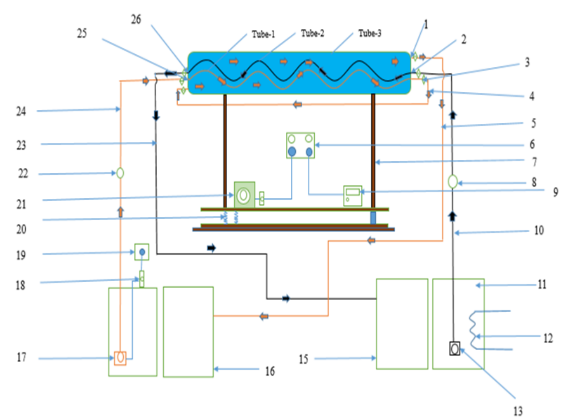


Fig. no. 1 -Schematic Diagram of experimental setup

| | |
|---|---|
| 1 | Outlet of tube-3 |
| 2 | Inlet of tube-2 |
| 3 | Thermocouples |
| 4 | Outlet of tube-1 |
| 5 | Hose for cold fluid outlet |
| 6 | Power supply |
| 7 | Stand of heat exchanger |
| 8 | Valve to regulate the flow of hot fluid |

| | |
|---|---|
| 9 | Temperature indicator |
| 10 | Hose for hot fluid inlet |
| 11 | Reservoir, Hot fluid to tube-2 inlet |
| 12 | Heating source |
| 13 | Pump for hot fluid |
| 15 | Reservoir, hot fluid from tube-2 outlet |
| 16 | Reservoir, cold fluid from tube-3 outlet |
| 17 | Pump for cold fluid |
| 18 | Voltage regulator |
| 20 | Spring support |
| 21 | Motor with eccentric load |
| 22 | Valve for cold fluid |
| 19 | Power supply to cold fluid's pump |
| 23 | Outlet hosing for hot fluid |
| 24 | Inlet hosing for cold fluid |
| 25 | Inlet of cold fluid |
| 26 | Outlet of hot fluid |

The flow inside the tube-3 run with the fully developed flow and will give the good temperature difference. Tube-1 and 3 having same direction but fluid inside tube-2 having counter direction to enhance the heat transfer. After gaining the energy from the tube-2 both the tube-1 and tube-3 will get joined for the next system.

Due to the laminar flow the flowing fluid will flow one over another which result in there will be existence of velocity gradient, but there is transfer of heat flux which result in temperature gradient as well which is not at all desirable for efficient heat transfer. The function of the vibrator is to disturb the laminar flow and allow the proper mixing of the layer of the fluid and there will not be existence of temperature gradient. But continuously increment in vibration force affect the flow of the fluid and try to restrict the passage of the flow.

In this study, experiment were performed with water as working fluid with Reynolds's number between the range of 400 and 1100 and acceleration varying between 1g to 5g. The mechanical vibration significantly influence the heat transfer in cold pipe.

The other advantage of providing vibration in flowing fluid result in decrement in scale formation and decrease the settlement of pit which indirectly increases the resistance between the two flowing fluid and due to this advantage it increases the life cycle of the tube.

Dimension of the tubes

| | a(mm) | $R_c$ (mm) | Inlet temp. (°C) | No of turns | pitch |
|---|---|---|---|---|---|
| Tube-1 | 5 | 30 | 30 | 16 | 62.5 |
| Tube-2 | 12 | 30 | 60 | 16 | 62.5 |
| Tube-3 | 81 | - | Depends on the outlet of tube-2 | - | - |

MATHEMATICAL MODELLING

Assumptions: -

- The heat exchanger is considered to be adiabatic.
- Steady flow exists for all three fluids.
- Fluids properties are constant.
- There are no temperature gradients in the fluids in the direction normal to the heat transfer surface.
- There is no mixing of any fluids.
- Heat transfer in one direction.

Heat transferred to fluid-1 from fluid-2 across elemental area dx, dy are given by

Rate of heat transfer = overall heat transfer coefficient * area * temperature difference

$dQ1=U1,2*(T2-T1)*dx*dy$ … (1)

$[dQ = U * A * dT]$

The above expression can be equated to the energy equation of element as it move from x - x+dx and y - y+dy

$\Delta Q=m1*Cp1*\Delta T$

$\therefore dQ=m1*Cp1*dT$

In 2-D the temperature difference is the function of X- direction and Y-direction. So, complete differentiation will be;

$T=f(x,y)$

$\therefore dT=\partial T/\partial x \ \partial x+\partial T/\partial y \ \partial y$

$dQ1 = m1*Cp1*(\partial T/\partial x \ \partial x+ \ \partial T/\partial y \ \partial y)$ (2)

Equating the above two equation 1 and 2.

$U1, 2*(T2-T1)*dx*dy = m1*Cp1*(\partial T/\partial x \ \partial x+ \ \partial T/\partial y \ \partial y)$

As the fluid is passing in X- direction there will be greater change in temperature in X- direction as compared to Y-direction

$U12*(T2-T1)*dx*dy = m1*Cp1*\partial T/\partial x \ \partial x$

$\partial T1/\partial X =U12/(m1*Cp1) \ *(T2-T1)*dx*dy$ (3)

Similarly, for the heat exchange between fluid-2 and fluid-3 is given by;

Rate of heat exchange = Overall heat transfer coefficient between fluid-2 and fluid-3 * area of

The tube * temperature difference between fluid-2 and fluid-3

dQ3=U3, 2*(T2-T3)*dx*dy (4)

The above expression can be equated to the energy equation of element as it move from x - x+dx and y - y+dy

Δ Q=m3*Cp3*ΔT

∴dQ=m3*Cp3*dT

dQ3 = m3*Cp3*(∂T/∂x dx+ ∂T/∂y dy) (5)

Equating the above two equation,

U3, 2*(T2-T3)*dx*dy = m3*Cp3*(∂T/∂x dx+ ∂T/∂y dy)

As the fluid is passing in X- direction there will be greater change in temperature in X- direction as compared to Y-direction.

U32*(T2-T3)*dx*dy = m3*Cp3*∂T/∂x dx

∂T3/∂X =U32/(m3*Cp3) *(T2-T3)*dx*dy (6)

A differential volume element of fluid-2 is bounded by two surface and is in heat transfer with both fluid-1 and fluid-3. The energy transferred to this element of fluid-2 from the outer fluid is.

Rate of heat transfer = overall heat transfer coefficient between fluid-1 and fluid-2 * area * temperature difference between fluid-1and fluid-2 + overall heat transfer coefficient between fluid-2 and fluid-3 * area * temperature difference between fluid-2 and fluid-3.

dQ2=U12*(T1-T2)*dx*dy + U23*(T3-T2)*dx*dy(7)

The above expression can be equated to the energy equation of element as it move from x - x+dx and y - y+dy

Δ Q=m2*Cp2*ΔT

∴dQ=m2*Cp2*dT

dQ2=m2*Cp2*(∂T2/∂x dx+ ∂T2/∂x dy) (8)

by equating the above two equation,

U12*(T1-T2)*dx*dy + U23*(T3-T2)*dx*dy = m2*Cp2*(∂T2/∂x dx+ ∂T2/∂x dy)

As the fluid is passing in X- direction there will be greater change in temperature in X- direction as compared to Y-direction.

∂T/∂X=U12/(m2*Cp2)*(T1-T2)*dx2*dy2+ U23/(m2*Cp2)*(T3-T2)* x2*y2 (9)

Therefore the final equation for the all the three tubes is;

dT1/dX= U12/(m1*Cp1)*(T2-T1)*dx1*dy1 (10)

dT2/dX= U12/(m2*Cp2)*(T1-T2)*dx2*dy2+ U23/(m2*Cp2)*(T3-T2)*dx2*dy2 (11)

dT3/dX= U23/(m3*Cp3)*(T2-T3)*dx3*dy3 (12)

RESULT AND DISCUSSION

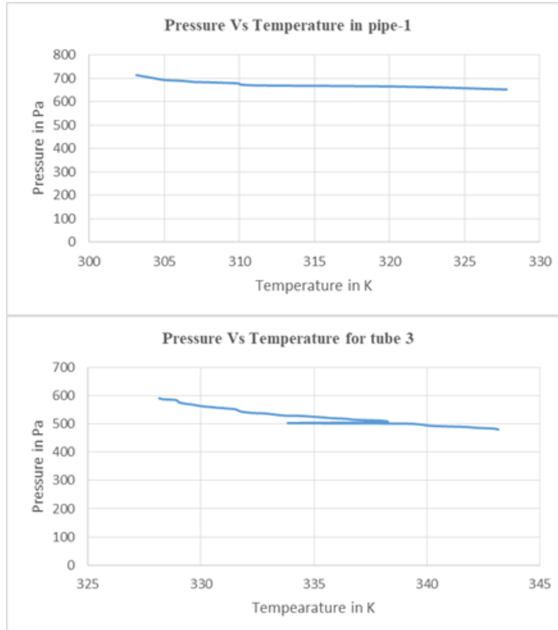


Fig no.2: - pressure and temperature graph for cold fluids

From the figure no.: -2, as the temperature is increasing there is increase in molecular momentum which increases the kinetic energy and hence velocity increases. As the velocity increases there is decrease in pressure because according to Bernoulli's equation.

$$\frac{P}{\rho g} + \frac{v2}{2g} + Z = constant$$

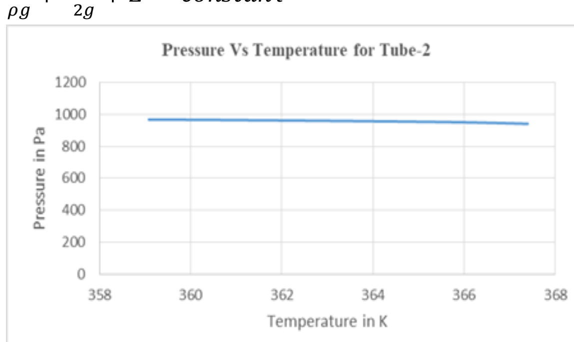


Fig no. 3: - pressure and temperature graph for hot fluid

From right to left in fig. no.-3, as the temperature is decreasing because of heat transfer between the fluid-1 and fluid-3 there is loss in kinetic energy which increase the pressure energy. The reason behind is that according to Bernoulli's equation summation of pressure energy, kinetic energy, and potential energy is always constant.

$$\frac{P}{\rho g} + \frac{v2}{2g} + Z = constant$$

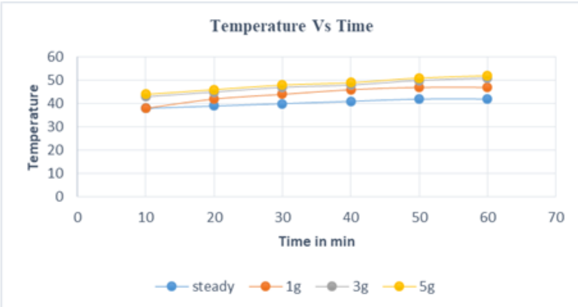


Fig. no.4:- temperature vs. time

From the figure no.4, we can observe that as the time increases the temperature keeps increasing because of fact that at beginning of experiment all tubes are at room temperature, cold fluid at 31°C and hot fluid at 60°C. So, at the beginning of experiment when experiment started there is temperature difference between the running fluids and copper tubes which take time for copper tube to become equal to running fluid's temperature and there is more time required for heat flux from hot tube to cold tube and then cold tube to cold fluid. But once the temperature difference and heat flux become steady the heat exchanger shows significant result.

In the above graph we see that when the fluid is flowing without any disturbance it shows less temperature difference because in this case the flowing fluid is running layer by layer and there is no any mixing of fluid which causes the heat transfer coefficient to be less but in case of vibration there is much temperature difference we get at the outlet of the cold fluid because due to vibration it causes the fluid to mix properly and enhance heat transfer coefficient.

We can also see that temperature difference between the vibration acceleration 3g and 5g is not so much because of as the vibration force increases there is back forth motion occur which causes and disturb the flow motion and start decreasing value of heat transfer coefficient.

From the figure no-5, once the temperature difference and heat flux is established the effectiveness graph shows the constant value. From the above graph we can see that, the effectiveness value for the flow without vibration is become constant at before 50 minutes because as the flow is smooth and layer by layer the fluid at the wall surface reaches easily to its saturation value between the temperature(31°C-60°C).

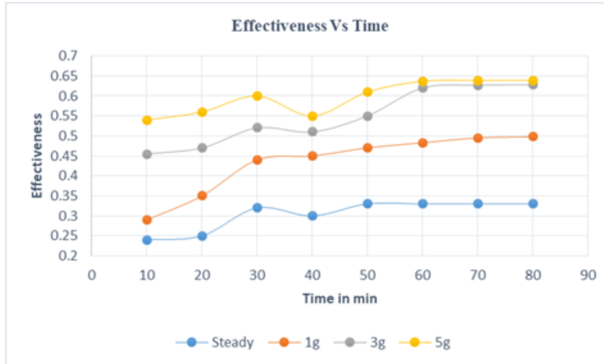


Fig. no.5: - Effectiveness vs. time

But for the fluid which is under the vibration is continuously vibrating and due to this the fluid which is at the wall goes up and loses its temperature and cools down and therefore the bulk mean temperature takes more time that's why the effectiveness under the vibration take more time to stable and gives significant result.

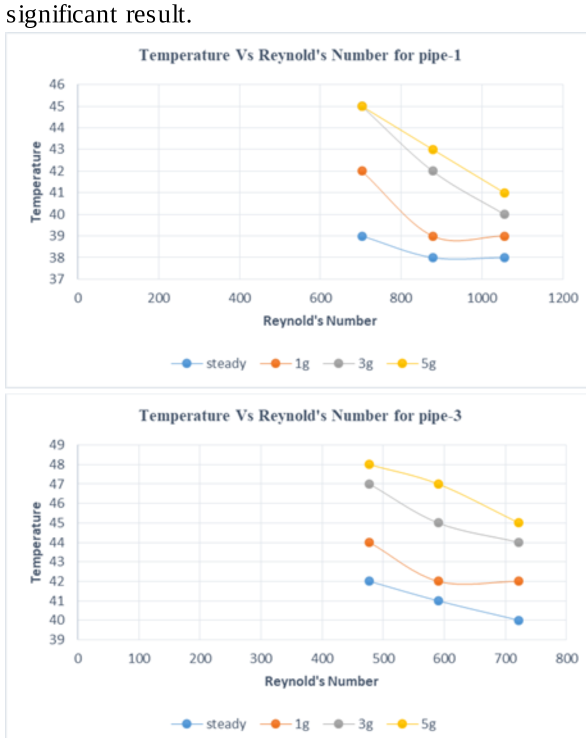


Fig. no.6: - temperature vs. Reynolds number

From the above two figure we can say that as the Reynolds number increases the temperature difference is keep decreasing because of the fact that when the mass flow inside the tube increasing its increasing the heat capacity(ṁ*Cp) of the fluid which indirectly suppress the effect the temperature difference of the fluid. One more thing that we can observe form the above graphs is that the temperature difference between the fluid under the vibration of 3g and 5g is less compared to difference between the 1g and 3g, because of the fact that, when the fluid is passing through inside the tube at the vibration acceleration 1g and 3g there is only the bulk fluid disturbance and the laminar sub-boundary layer remain adhere to boundary roughness which support the conduction and convection but in case when the fluid running under the vibration force of 5g, the fluid under the excessive vibration which causes the fluid under the turbulent flow but simultaneously it disturb the laminar sub-boundary layer at entry of the cold fluid because of phenomenal action there at some of the point only convection happens instead of conduction and convection.

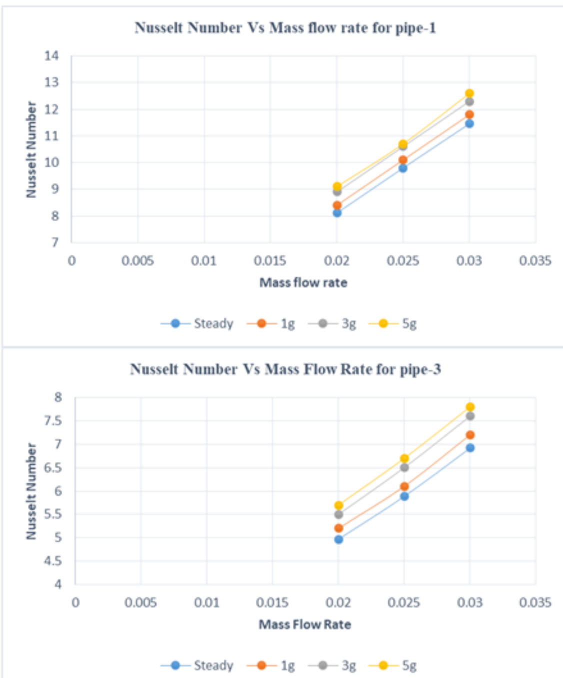


Fig. no.7: - Nusselt Number vs. mass flow rate

From the above graph we can see that as the mass flow increases the nusselt number increases because of the fact that as the mass flow increases there is increase in velocity for same density and cross sectional area, and as the velocity increases Reynolds number increases because these two parameter are directly proportional to each other. As the Reynolds number increases nusselt number will increases because these two factor are directly proportional to each other.

But the other thing that we can observe from the graph is that the range between the line of 3g acceleration and 5g acceleration is very less compared to range between 1g and 3g because when the fluid flow under the vibration of 5g condition, its start suffering obstacle in flow and flow under this condition suffer back forth problem too. And there is one more problem, up to this excessive vibration very lowest layer also called as laminar sub boundary layer gets disturb which is not desirable. Nusselt number under the vibration are calculated by using the equation

$$\frac{Nu\ vibration}{Nu\ steady\ state} = \frac{0.455\left(\frac{gt}{g}\right)+1.713}{\sqrt{1+2.879\left(1+\frac{f}{fn}\right)2+2.879\left(1-\frac{f}{fn}\right)4}}\ Re^{-0.525}$$

[1]

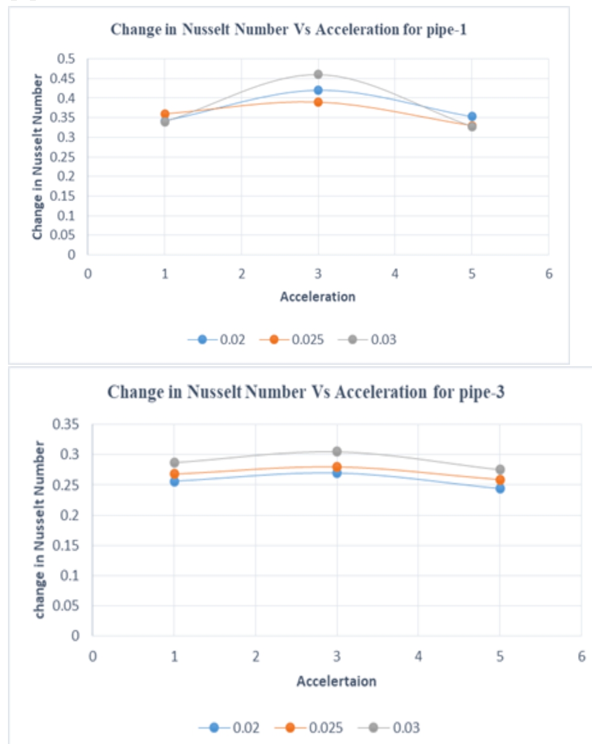


Fig. no 8: - change in Nu no. vs Acceleration

In previous graph we absorb that when the acceleration increases its increases the nusselt number which means its increases the heat transfer coefficient because the more the vibration force more will be the turbulence occur which enhance the value of Reynolds number or we can say nusselt number.

In above figure or graph we can see that change in nusselt number is higher at 3g acceleration force as compared to change in Nu number for 1g and 5g forces. It is true that when the acceleration increases, Nu number increases but increasing acceleration further or beyond 3g doesn't give considerable amount of difference.

## ERRORS

Errors defined as the difference between the actual values to the theoretical values

$\frac{dT}{dx} = \frac{u12}{m1*cp1}$ * ($T_2$-$T_1$) * area

$\frac{dT}{dx} = \frac{252.725}{0.025*4178}$ * (39-33) $* \pi * 0.005 * 1.5$

$\frac{dT}{dx}$ = 0.34205

$dT$ = 0.34205 dx

$\int_{Ti}^{Tf} dT$ = 0.34205 * $\int_{0}^{1.5} dx$

$Tf - Ti$ = 0.34205 * 1.5

Errors = $\frac{final-intial}{initial} = \frac{0.51308}{33}$ = 1.55% the above error for the cold fluid-1

$\frac{dT}{dx} = \frac{u32}{m3*cp3}$ * ($T_6$-$T_5$) * area

$\frac{dT}{dx} = \frac{283.25}{0.025*4178}$ * (42-39) $* \pi * 0.081 * 1.0$

$\frac{dT}{dx}$ = 1.847

$dT$ = 1.847 dx

$\int_{Ti}^{Tf} dT$ = 1.847 * $\int_{0}^{1.0} dx$

$Tf - Ti$ = 1.847 * 1.0

Errors = $\frac{final-intial}{initial} = \frac{1.847}{39}$ = 4.39% the above error for the cold fluid-2

For the entire system the error value varies from 1 to 5% of errors

## CONCLUSION

The above experiment are carried out of under the different vibration level which is varying from 1 to 5, varying mass flow rate from 0.020 to 0.030 and having Reynolds number changing from 400 to 1100 Re. The above experiment shows that as the vibration level increases it influences the heat transfer rate but up to some point and increasing beyond that point doesn't shows any much variation. The following conclusions are drawn based on the experiment.

1. As the Reynolds rate increases it decreases the rate of temperature difference
2. Increasing the mass flow rate increases the Nusselt number or heat transfer coefficient
3. Increasing the vibration level enhance the heat transfer rate
4. Increasing vibration beyond 3g doesn't give much difference to rate of heat transfer rate.

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