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Heat Transfer Enhancement in Double Pipe Heat Exchanger using Ultrasonic Vibrations

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Abstract – *In this work heat transfer enhancement in double pipe heat exchanger under the ultrasonic vibration is studied experimentally and CFD. CFD simulation is carried out in Ansys fluent 2019 R3. Experiment is performed using homemade double pipe heat exchanger. Ultrasonic vibration is applied to part annulus for length of 250 mm. Ultrasonic power of 50 W and frequency of 42 kHz is used. Water is used as working fluid. Study is carried out by varying mass flow rate of cold water in annulus and keeping hot water flow rate in inner tube constant for parallel flow configuration. It shows that overall heat transfer rate is increased by 39% & Enhancement factor is 1.51 for annulus cold water flow rate of 0.01 kg/s and Enhancement in heat transfer rate is higher at lower flow rate.*

Key Words: Double pipe heat exchanger, Heat transfer enhancement, experimental setup, Ultrasonic transducer, Ultrasonic vibration etc.

1. INTRODUCTION

Industrial development and demand for higher heat transfer rate have made the heat transfer enhancement issue more attractive and important. Smaller space with higher heat transfer rate is always better. Reducing thermal resistance as much as possible is important for any Heat exchanger. Surface & geometrical modification such as fins, inserts, surface treatment etc are passive enhancement method. It does not require external power. The method which require external power for working for example mechanical aids, surface/fluid vibration, Ultrasonic vibrations etc are active enhancement methods. Ultrasound waves are sequences of compressions and rarefactions that propagate in media, such as water or air. Ultrasonic waves refer to frequency above 20 kHz. 20 kHz-1 MHz frequency is called power ultrasound or low frequency ultrasound and above 1 MHz frequency called high frequency ultrasound.

Legay et al [1] designed, built and studied a double pipe heat exchanger. Ultrasonic vibration of frequency 35 kHz is applied to annulus. Heat transfer rate is increased by 80% in laminar flow. M. Setareh et al [3] studied Heat transfer enhancement of double pipe heat exchanger in the presence of ultrasonic vibrations is experimentally and numerically at 26.7 kHz with varying ultrasonic power. Ultrasonic vibration is applied to inner tube. They carried effect of Ultrasonic vibration at different mass flow rate. It shows that at lower mass flow rate heat transfer coefficient is higher. Their result shows that the flow generated by propagation of ultrasonic waves into the cold fluid in annulus is responsible for heat transfer enhancement. J. L. Laborde et al. [4] studied effect of ultrasonic vibration at 500 kHz inside cylinder with liquid. They made mathematical model to study the bubbles and cavitations. Dynamic mesh fluent6.1 is used for wall motion. It establish link between acoustic pressure and cavitations. It shows cavitations pattern & acoustic streaming pattern. M. Abolhasani et al. [6] They study the effect of high frequency ultrasonic waves on heat transfer rate for cylindrical heater surrounded by water. CFD modelling of ultrasound wave propagation was carried out to predict the fluid flow pattern and heat transfer inside the water. k-ε model is used for CFD simulation. Alessandro Franco et al. [7] This paper gives review to understand the potential of ultrasonic vibration in heat transfer improvements and fouling reduction. Fouling resistance is depends upon ultrasonic frequency as well as ultrasonic power and initial hardness of water. Bergles A. E. et al. [8] They performed experiment to study effect of high intensity ultrasonic vibration on a heat transfer to water flowing in annuli. Inner tube of annulus was heated by electricity. It shows 40% increases in local heat transfer coefficient at low flow velocities. Sudarmadji et al. [12] They investigate the effect of 20 kHz, 30 kHz, 40kHz frequency on double pipe heat exchanger in parallel configuration experimentally. The higher overall heat transfer coefficient enhancement was about 44% for 20 kHz followed by 40% for 40 kHz.

1.1 Effect of Ultrasonic vibration on liquid

There are four effects of ultrasonic wave propagation in liquid [7].

i. Heating: Heating in the medium occurs due to dissipation of the introduced vibration energy.

ii. Acoustic cavitations: When ultrasonic power attains a threshold & rarefaction cycle exceed the attractive forces then cavitations bubbles could appear from existing gas nuclei. The implosion of these bubbles results in microscopic hydrodynamic phenomena such as micro-jet formation, shockwave propagation and thereby micro-mixing of the liquid which increase the local heat transfer coefficient.

iii. Acoustic streaming: The streaming generated by propagation of ultrasonic waves through a fluid is called acoustic streaming. It is a steady circular flow generated by friction between a vibrating fluid medium adjacent to a solid.

iv. Nebulization: It occurred at the high-frequency ultrasonic vibration and called as the acoustic fountain.

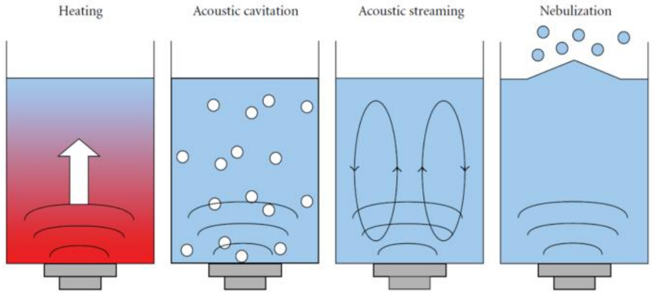

Fig -1: Four effects resulting from ultrasonic vibration on a liquid [7].

Ultrasound waves are sequences of compressions and rarefactions that propagate in media, such as water or air. The ultrasound waves cover wave frequencies higher than human hearing (higher than 20 kHz).The sound pressure is given by the following relation [6].

$$P_{US}=P_a \cos(\omega t+z/c)$$

Where, c is sound velocity(m/s) in liquid, z is the space coordinate(m), t is time(s), Pa is acoustic amplitude(Pa), and is ω angular frequency(rad/s). The acoustic amplitude can be found from the following relation

$$P_a= \sqrt{(2IZ)}$$

Where, I is the sound intensity (W/m^2) of ultrasound & Z is the acoustic impedance of water (kg/m^{2}s).

A time-dependent velocity equation, calculated from the following equation [6], was used a.

$$V_o=\omega A_o*\sin(\omega t) \quad m/s$$

Where, A_o is face displacement (m).

1.2 Performance parameter formula

Heat removed from hot water

$$Q_h = m_h \times C_{ph} \times \Delta Th$$

Heat carried out by cold water

$$Q_c = m_c \times C_{pc} \times \Delta Tc$$

Average heat transfer rate

$$Q_{avg} = \frac{Q_h + Q_c}{2}$$

Log Mean Temperature differences

$$LMTD = \frac{(Thi-Tci)-(Tho-Tco)}{ln\frac{(Thi-Tci)}{(Tho-Tco)}}$$

The Outer surface area of inner tube

$$A_o = \Pi \times d_o \times L$$

Overall heat transfer coefficient

$$Uo = \frac{Qavg}{Ao \times LMTD}$$

Maximum possible heat transfer $Q_{max} = C_{min} \times (Thi - Tci)$

Effectiveness

$$\varepsilon = \frac{Qactual}{Qmax}$$

Enhancement factor

$$EF = \frac{U_o\ With\ ultrasonic\ vibrtion}{U_o\ Without\ ultrasonic\ vibrtion}$$

Where, Thi= hot water inlet temperature (K)
Tho= hot water outlet temperature (K)
Tci= cold water inlet temperature (K)
Tco= cold water outlet temperature (K)
L= Length of Heat Exchanger (m)
d_o= outer dia of inner pipe (m)
m_c= cold water mass flow rate (kg/s)
m_h= hot water mass flow rate (kg/s)

2. Experimental Setup

Homemade Double pipe heat exchanger is made. Steel 316 is used for inner pipe. Parallel flow arrangement is used. Hot water is passed through inner pipe. Hot water is heated by Heater. Cold water is passed through annulus. The heat exchanger is well insulated so as to avoid the heat loss to the surrounding. Temperature is measure with Thermometer. Flow rate is adjusted with flow control valve and measured with volume beaker and timer.
Hot water Inlet & Cold water Inlet temperature is kept constant at 325 K & 303 K respectively. Hot water flow rate is kept constant at 0.0333kg/s & Cold water flow rate is varied. Vibration applied to middle part of heat exchanger at annulus of length 250 mm.

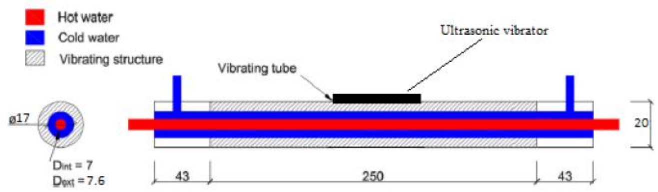

Fig -2: Sketch of Double pipe heat exchanger (all dimensions are in mm)

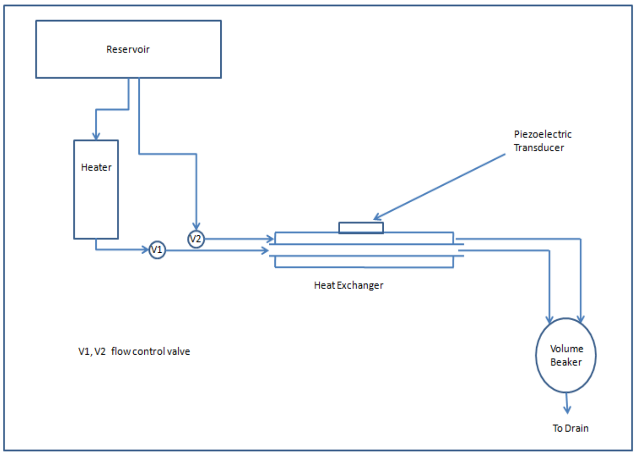

Fig -3: Schematic diagram of Experimental setup

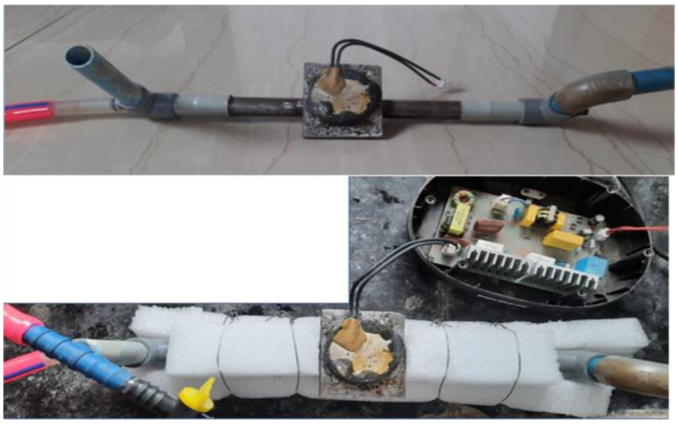

Fig -4: Double pipe Heat exchanger with & without insulation with Transducer

3. CFD Simulation

In this chapter, Simulation in parallel flow arrangements with & without ultrasonic vibration is discussed. For the simulation process, ANSYS 2019 R3 version used.

3.1 Geometry

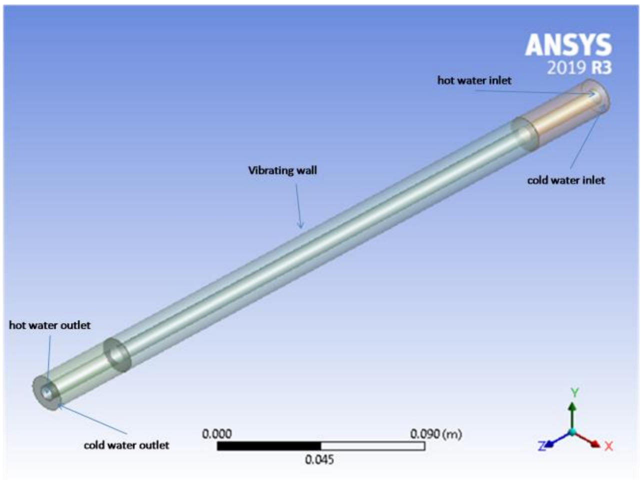

Fig -5: Double pipe heat exchanger geometry

3.2 Meshing

The meshing of the model is done in ANSYS WORKBENCH The value of orthogonal quality of for this model is 0.80 and the value of the skewness is 0.29.

1] Number of nodes =183006

2] Number of elements =671492

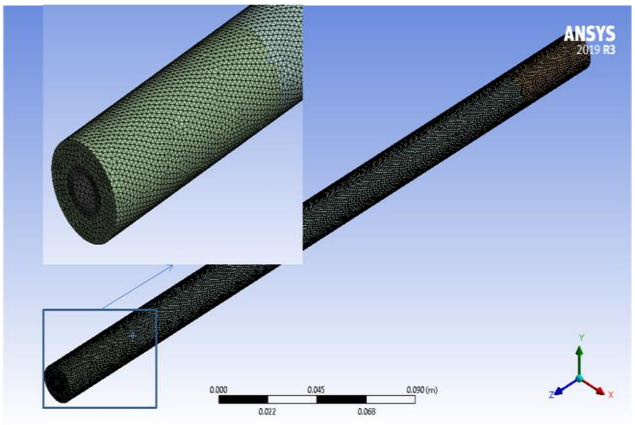

Fig -6: Meshing quality

3.3 CFD setup

The current problem is assumed as 3 D, Pressure-based transient. Energy on, Multiphase mixture with cavitation on, Realizable k-ε model is used. The following boundary conditions are used.

Table -1: Cell zone conditions

Zone	Type
Annulus fluid	Fluid (liquid water)
Tube fluid	Fluid (liquid water)
Inner tube	Solid (steel)

Table -2: Boundary conditions

Zone	Type
Tube Inlet	Mass flow Inlet
Tube outlet	Pressure Outlet
Annulus Inlet	Mass flow Inlet
Annulus Outlet	Pressure Outlet
Vibrating wall	Velocity inlet with $v_o=\omega A_o*\sin(\omega t)$ [6]

4. Result and Discussion

Temperature contour & velocity vector without and with ultrasonic vibration is obtain from CFD simulation for cold flow rate of 0.01 kg/s & hot water flow rate 0.0333 kg/s.

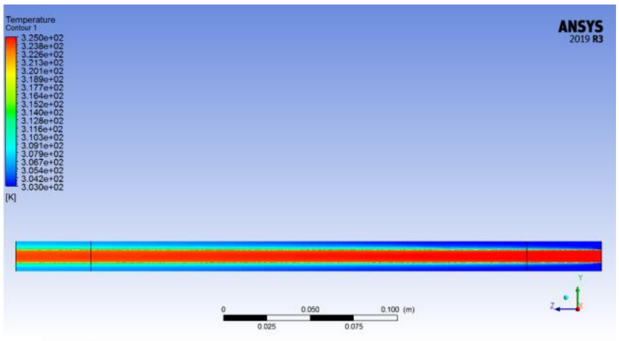

Fig 7. Temperature contour without ultrasonic vibration

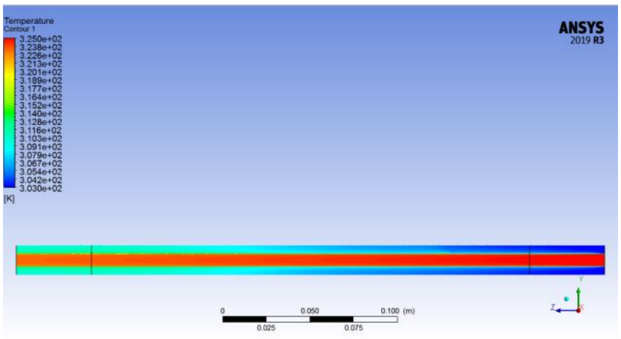

Fig 8. Temperature contour with ultrasonic vibration

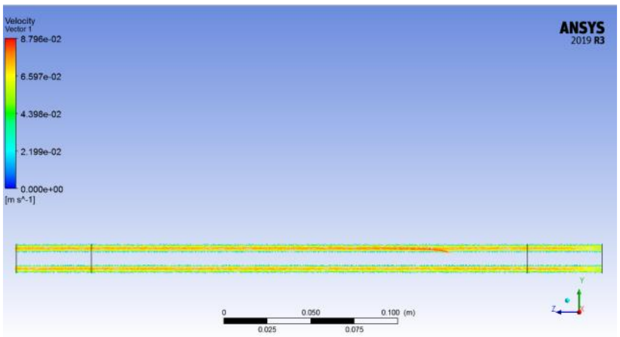

Fig 9. velocity vector without ultrasonic vibration

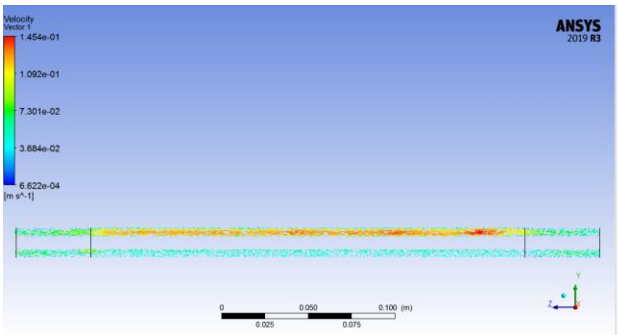

Fig 10. Velocity vector with ultrasonic vibration

Temperature contour shows that heat is higher with ultrasonic vibration. Velocity vector shows that magnitude of velocity is more with ultrasonic vibration so fluid mixing is increased.

By keeping hot flow rate constant at 0.0333 kg/s & varying annulus cold flow rate effectiveness & Heat transfer rate is compared.

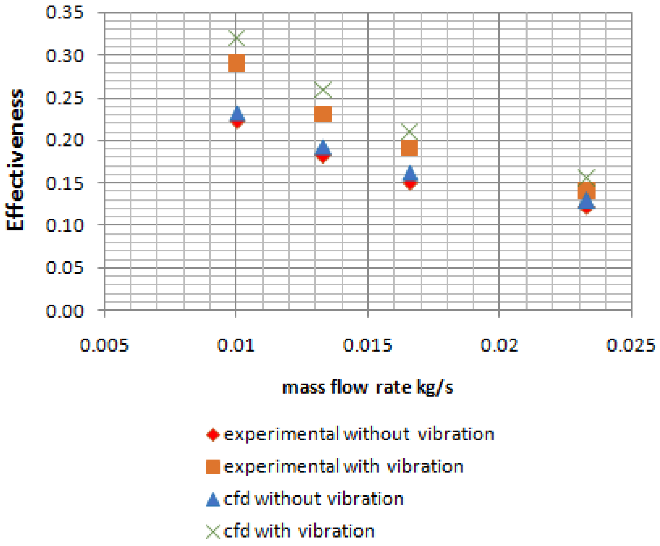

Chart -1: Mass flow rate vs Effectiveness

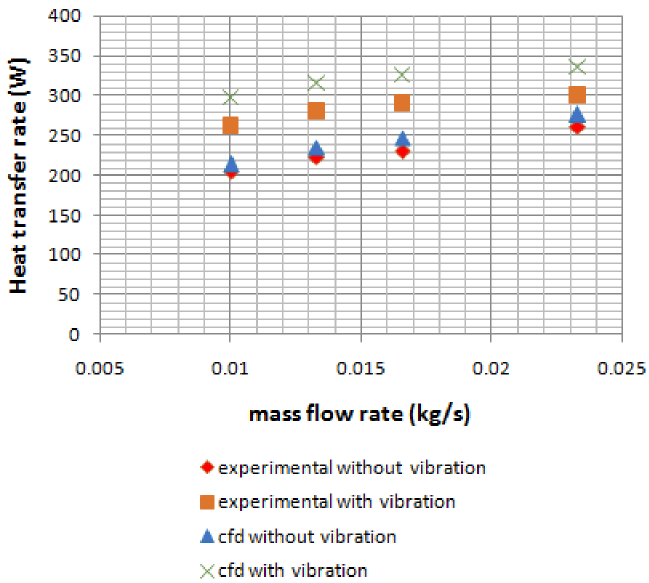

Chart -2: Mass flow rate vs Heat transfer rate

Chart-1 show that effectiveness is maximum at mass flow rate of 0.01 kg/s and it decreasing with an increase in mass flow rate. Chart-2 show that heat transfer rate is enhanced with application of ultrasonic vibrations.

5. CONCLUSIONS

Heat transfer enhancement in a double-pipe heat exchanger in the presence of ultrasonic vibrations was computationally and experimentally investigated. For this simple double pipe heat exchanger in parallel configuration is used and Numerical simulation is carried out in ANSYS FLUENT 19.3R with ultrasonic frequency at 42 kHz and 50W power.

1. Heat transfer rate increase 39% at annulus cold water mass flow rate of 0.01 kg/s.
2. Enhancement factor is 1.51 at 0.01 kg/s and decreases as flow rate increases.
3. As annulus flow rate is increases Enhancement in Heat transfer rate decreases.
4. CFD velocity vector shows that mixing of fluid is increased in presence of ultrasonic vibrations.

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