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Comparison of Heat Transfer Through a Circular Pipe Using Different Geometry Inside the Pipe

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Abstract— The purpose of this paper is to observe different rate of heat transfer while changing the surface area at different condition inside the circular pipe section. Insulation was given to compare the heat transfer rate with non-insulated ones. The main objective was to construct an Experimental setup with which it can be experimented that increase in the surface area would have an effect on the rate of heat transfer. Heat transfer through a circular pipe is investigated while using different geometries inside the pipe. The material of the pipe used is Stainless Steel and the working fluid is water. 4 pipes in a series were used in the experiment and each of them was 4 feet (1.2192 meter) long and the inner and outer diameter of the pipes is 2 inch (0.0508 meter) and 2.016 inch (0.0512 meter) respectively. Three of the four pipes were insulated with glass wool. A spring and a wire mesh, both of stainless steel material, was inserted in two insulated pipes. Then hot water with different temperature was flown through the pipes. The experiments were conducted for five different flow rates of the water and for each flow rate; five inlet temperatures of the water were taken. The temperature readings were taken at different locations of each pipe and calculated the heat transfer. The results are compared with other published papers. The results show that the internal surface area, fluid flow rate and even the initial fluid temperature play major role on heat transfer.

Index Terms— Heat Transfer, Heat Transfer Rate, Heat Transfer through circular pipe, Steel Net, Spring

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1 Introduction

Heat is a form of energy and Heat transfer is flow of energy from higher temperature object to lower temperature object. Heat transfer rate may vary with geometry, material property and with other parameters. For example, a bucket full of water cools slower than the same amount of water poured in the ground, because the surface area of hot water increases when it poured in the ground. Heat is transferred in three different methods. They are:

i. Conduction heat transfer
ii. Convection heat transfer
iii. Radiation heat transfer

When a temperature gradient exists within a body, then there is an energy transfer from the high temperature region to the low temperature region. This phenomenon of transfer of energy is known as conduction heat transfer. Convection is heat transfer by mass motion of a fluid such as air or water when the heated fluid is caused to move away from the source of heat, carrying energy with it. Radiation is the only heat transfer process in which no medium is required. This process involves electromagnetic waves to transfer heat.

The Reynolds number can be defined for different situations where a fluid is in relative motion to a surface. The equation for the Reynolds number is written as:

$$Re = \frac{\rho * v * d}{\mu}$$

Where,
ρ = density of the fluid, v = mean velocity of the object relative to the fluid, d = diameter, and μ = dynamic viscosity of the fluid.

As long as Re is less than approximately 2300, the flow is laminar. Above this value, turbulence would invariably occur.

The objective of this work is to observe the different rate of heat transfer while increasing the surface area at different condition inside the circular pipe section. The main objective was to construct an Experimental setup with which it can be experimented that increase in the surface area would have an effect on the rate of heat transfer. The major objectives of this project are:

1. To construct an experimental setup with necessary conditions
2. Provide different conditions for four different pipe section

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3. Compare the heat transfer result for four different pipe section
4. Calculate the rate of heat transfer for an increase in the surface area of the pipe section.

2 LITERATURE REVIEW

Number of investigations has been carried out by using various inserts and tube geometries for heat transfer augmentation. Naphon [1] experimentally investigated the effect of coil-wire insert on heat transfer enhancement and pressure drop of the horizontal concentric tube. It was observed that as the Reynolds number increases heat transfer rate decreases. Further Naphon in 2011 [2] changed the geometry of insert, it was found that the swirl flow is generated as fluid flowing through the plain tube with twisted wire brush insert and in the presence of swirl flow, the convective heat transfer obtained is higher. Eiamsa-ard [3] experimentally investigated the heat transfer characteristics in a tube fitted with helical screw-tape with/without core-rod inserts. It was observed that the heat transfer rate obtained by using the tape without core-rod is found to be better than that by one with core-rod around 25–60% while the friction is around 50% lower. Eiamsaard in 2008, [4] used double pipe heat exchanger with different arrangement of louvered strip inserts, experimental results showed that the forward louvered strip arrangements can promote the heat transfer rate by approximately 150% to 284%, while the backward arrangements could improve the heat transfer by approximately 133% to 264%. It was observed that Louvered strip insertions can be used efficiently to augment heat transfer rate because the turbulence intensity induced could enhance the heat transfer. Murugesan [6] experimentally investigated the heat transfer and pressure drop characteristics in a circular tube fitted with and without V-cut twisted tape insert. It was observed that the V-cut twisted tape offered a higher heat transfer rate, friction factor and also thermal performance factor compared to the plain twisted tape. Thianponga [7] experimentally investigated the effect of perforated twisted-tapes with parallel wings on heat transfer enhancement in a heat exchanger tube. The result showed that as compared to plain twisted tube, PTT increases heat transfer rate up to 208%, and compared with [5,6] showed good result.

3 METHODOLOGY

3.1 Design

Initially, copper pipe was given priority for the experiment for its various useful properties, like- higher thermal conductivity, corrosion resistance, lightweight, long lasting, low co-efficient of linear expansion etc. But, the required thickness of the pipe was not available and so stainless steel pipe was used. Then the pipe with 2 inch (50.8 mm) diameter was selected so that the flow rate could be varied to a greater range and to get greater volume for the experiment. After that, the length of the pipes was selected to be 4 feet (1219.2 mm) each for the experiment. Pipes with greater length than the used ones were given priority for the experiment to observe more accurate and better result. But for the limited space in the lab, pipes longer than the used ones could not be experimented. Inside the pipes, some profiles were inserted in two of them. One had spring and the other one had steel net. Both were made of stainless steel material. The steel spring was made of a stainless steel string which was 3mm thick. The reason was to observe the difference in heat transfer due to these irregular profiles. The thickness of the profile increasing means that the solid material density is increasing. So the conduction heat transfer rate through it will increase.

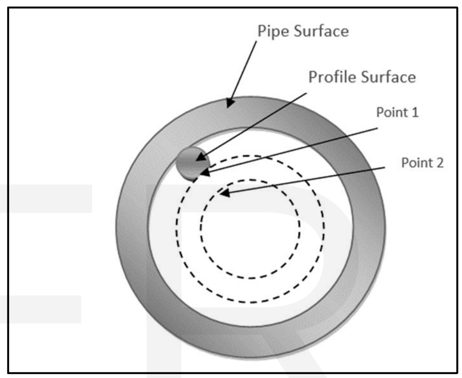


Fig. 1. Profile & Pipe Contact

In the figure 1, the surface contact between the inner surface of the pipe and the profile is shown. As it can be seen in the figure, if we go far from the center of the pipe to the outer surface, the temperature will gradually decrease though it will be very small amount. But if we take that in consideration, then point 1 will be cooler than point 2. So the more the thickness of the profile, the more it will get heat from the water. The more it gets heated, the more heat will be transferred by conduction through the profile to the pipe surface. This is why a standard thickness of 3mm was chosen to be the thickness of the spring profile.

3.2 Construction

Stainless steel pipes were used in this experimental setup instead of the copper pipe because of joining advantages. Firstly, the pipes were threaded for joining two pipes together with joints like 90° elbow, T joint, Union. Then zig-zag shape was given to maintain a constant mass flow rate through all pipes within a short space.

Fig. 2: Zig-zag shape in the pipe by using different joints

The temperature sensors were inserted by drilling a hole at the inlet and outlet portion of each pipe. Two tanks were used. One was the delivery tank and the other one was a heating chamber. The heating chamber was used to heat the water to reach to a certain temperature and the delivery tank was used to maintain a constant head at the delivery tank throughout the whole experimental process. Two water flow meters were connected, one at the delivery line of the heating chamber to the delivery tank and the other one at the outlet of the whole pipe arrangement. Flow rate at this two points were kept same. So, while the experiment was done, the delivery tank was refilled with the same amount of water that it lost while the delivery of water through the pipes. So the head at the delivery tank remained constant throughout the whole experiment. And so the flow rate at outlet remained constant.

Fig. 2: Heating Chamber

Fig. 3: Delvery Tank

In the heating chamber, two heaters 9KW and 2KW were used for uniform heating. For fully developed flow, the exit of water was slightly upwards so that the hot water touches the whole circular surface of the pipe.

3.3 Apparatus used

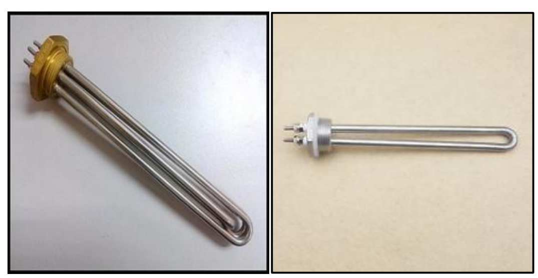
i) Water tank: Two kinds of the water tanks are used in the setup: a) Delivery Tank and b) Heating Chamber

ii) Steel pipe: In this experiment, Stainless steel pipe is used for it's remarkable attributes including corrosion resistance, high strength, durability, and machining-ability.

Fig 4: Stainless steel pipe

iii) Working fluid: One of the most important factors behind choosing water as the working fluid is the compatibility of the heat transfer fluid with the wetted surfaces of the components or system. Water is compatible with S.S pipe which was used as a fluid path.

iv) Heater: In this experiment, two heaters are used to heat the water. Two coil type heater is placed at the bottom of the heating chamber. The input power of the heater is electricity. One is 9kW and other one is 2kW heater, being used for the experiment.



Capacity: 9kW Capacity: 2kW

Fig. 5: Heater

v) Flow meter: In this experiment, two water flow meters were used to maintain constant head at the delivery tank as described earlier.

Fig. 6: Flow meter

vi) Joints: For sealing leakage at the drilling points, M-seal is used. M-seal is an Epoxy resin which is used for sealing metal pipe joint.

vii) Temperature sensors: Thermocouple: Pen type, Range: 50 to 300° C, Accuracy: ±1°C/ ±2°C Between -20°C to 120°C

Fig. 7: Pen type Thermocouple

4 Experiment Statement

This experiment is about the comparison between four section of the pipe. The heat loss will be compared between that four section. The four sections are as follows:

i) Normal pipe section (Pipe1): It is the section of the pipe where heat loss will be maximum because there is no insulation. The heat supplied from the hot water will be convected out because there is no insulation on the pipe surface and also the Stainless steel is a moderated conductor of heat.

ii) Adiabatic and with insulation pipe section (Pipe2): It is the section of the pipe where heat loss will be minimum because there is insulation on the surface of the pipe and there is no external or internal surface added to increase the heat transfer and that is why the loss will be minimum in this section of the pipe.

iii) Adiabatic and internal profile (Steel net- Pipe3): In this section of the pipe, there is insulation on the surface of the pipe to prevent the heat loss and a profile is added which is steel net, to increase the heat transfer so this is the condition which will help to distinguish the heat losses between the two pipes. Specification of steel net: Material: Stainless Steel, Thickness = 2 mm, 2 holes per 1 inch².

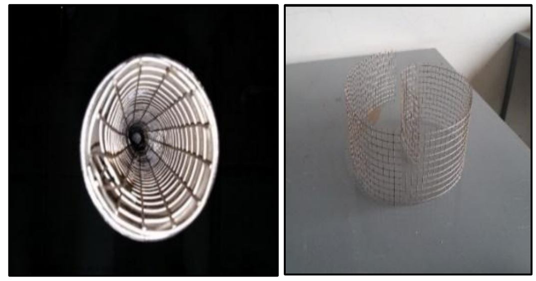


Fig. 8: Internal profile (steel net)

iv) Adiabatic and internal profile (Spring- Pipe4): With increase in surface area, the heat transfer will also increase. In this section of the pipe, the heat loss will increase than the third pipe because of the surface area which has been increased and so the heat transfer should increase as well. Specification of spring: Material- Stainless Steel, Length = 4 feet, Wire dia = 3 mm, Outer dia = 2 inch= 50.8 mm, Inner dia = 50.2 mm.

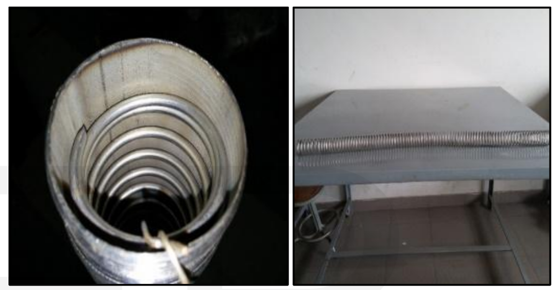


Fig. 9: Internal profile (Spring)

Power supply unit for first heater:
Type: AC, Voltage: Up to 420 volts, Current: 32 A, Frequency: 50 Hz.
Power supply unit for second heater:
Type: AC, Voltage: Up to 220 volts, Current: 10 A, Frequency: 50 Hz.

5 Experimental Set Up

To calculate the heat loss per section of the pipe, eight Pen type thermocouples are used. These thermocouples are placed at the inlet and outlet portion of the pipes to measure the temperature of the hot water passing through that section. The temperature sensors are denoted by T1, T2, T3, T4, T5, T6, T7, T8 and two IR sensors are used to measure the water tank and pipe surface temperature. One 9KW and one 2KW heater is used to heat the water to a desired temperature. When the water reaches the desire temperature the heaters is manually switch off. The whole setup is then mounted on a steel table. The pipe is supported by wooden frame to avoid undesirable heat loss by conduction.

TABLE 1
DATA TABLE FOR CONSTANT FLOW RATE OF 0.00003558 M3/S

Delivery Tank Water Temp(°C)	Sensor 1 Temp T_1	Sensor 2 Temp T_2	Sensor 3 Temp T_3	Sensor 4 Temp T_4	Sensor 5 Temp T_5	Sensor 6 Temp T_6	Sensor 7 Temp T_7	Sensor 8 Temp T_8
45.8	45.6	45.1	45.0	44.9	44.7	44.5	44.4	44.0
55.0	54.8	54.0	54.1	53.9	53.9	53.6	53.5	52.9
65.2	65	64.1	64.0	63.6	63.4	63.0	63.0	62.4
70.2	69.9	68.8	68.7	68.2	68.1	67.6	67.6	66.7
76.0	75.7	74.3	74.2	73.7	73.8	73.2	73.0	71.9

TABLE 2
CALCULATION DATA FOR DIFFERENT TEMPERATURES

SL	Temperature	Water Density, ρ (kg/m3)	Specific heat. Cp (kJ/Kg-K)	Mass Flow Rate (kg/s)	Q1 (KW)	Q2 (KW)	Q3 (KW)	Q4 (KW)
1	45.8°C	990.2	4.181	0.032	0.06689	0.01337	0.02675	0.0535
2	55°C	986	4.183	0.03507	0.11735	0.02933	0.044009	0.088
3	65.2°C	980	4.188	0.03485	0.13135	0.05838	0.05838	0.08757
4	70.2°C	978	4.191	0.03478	0.16033	0.07288	0.07288	0.13118
5	76°C	974	4.195	0.03464	0.2034	0.0726674	0.087188	0.159846

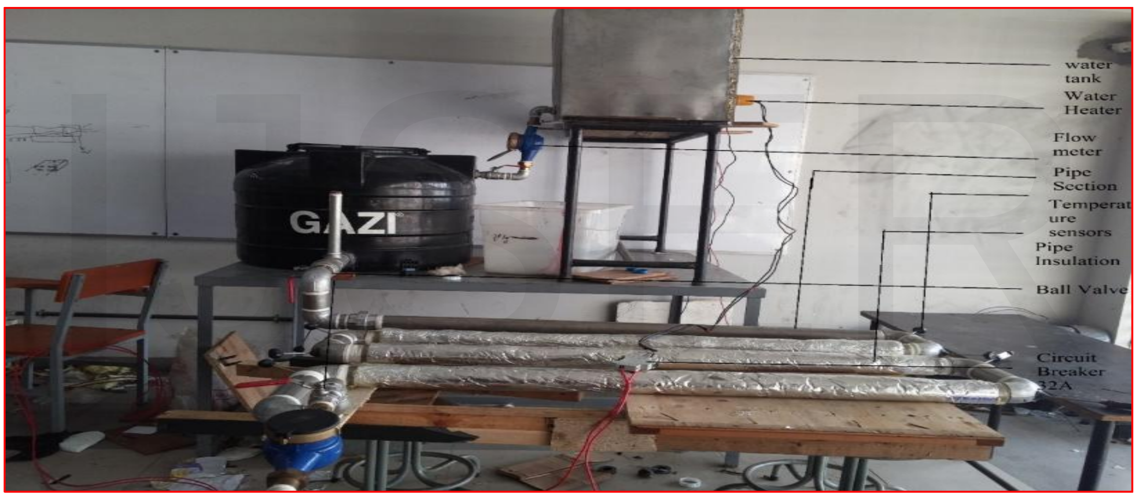


Fig. 10: Experimental Setup

6 CALCULATION

Calculation for Constant Flow Rate of 0.00003558 m3/s:

Flow rate =0.00003558= A*V
or, 0.00003558= (¼) *3.1416* (0.0254)2 *V
or, V =0.0702 m/s

6.1 Sample Calculation for 45.8°C:

Water density at 45.8°C, ρ = 990.2 kg/m3
Specific heat at 45.8°C, Cp = 4.181 kJ/Kg-K

Mass Flow Rate, m = ρ * V * A
= 990.2 * 0.0702 * 0.0005067
= 0.0320 kg/s

Reynolds number through circular pipe for sample data:

$$Re = \frac{\rho * v * d}{\mu}$$

$$= \frac{990.2 * 0.0702 * 0.0254}{0.5 * 10^{-3}}$$

= 3531.21

So, the flow is turbulent.

Q1 = m * Cp * (T1-T2)
or, Q1 = 0.0320 * 4.181 * 0.5 kW
= 0.06689 kW

Q2 = m * Cp * (T3-T4)
or, Q2 = 0.0320 * 4.181 * 0.1 kW

= 0.01337 kW

Q3 = m * Cp * (T5-T6)
or, Q3 = 0.0320 * 4.181 * 0.2 kW
= 0.02675 kW

Q4 = m * Cp * (T7-T8)
or, Q4 = 0.0320 * 4.181 * 0.4 kW
= 0.0535 kW

6.2 Heat balance at 76°C:

Heat loss from the heater to water to the first pipe section
= Heat conducted transfer by first pipe
= Convective Heat Transfer of first pipe.
= 0.2034 kW

Heat transfer by conduction through a circular pipe:

$$Q_{conduction} = \frac{2\,\pi\, l\,(T1-T2)}{\frac{1}{k} ln \frac{r2}{r1}}$$

$$= \frac{2 * 3.1416 * 1.2192\,(76-75.5)}{\frac{1}{16} * ln\frac{0.0274}{0.0203}}$$

= 0.20433 kW

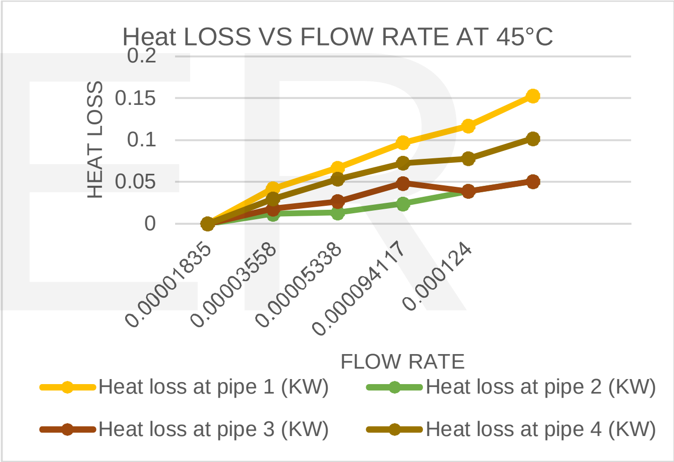
Here,
K=thermal conductivity of steel = 16W/m-K
l = length of pipe = 1.2192 m
T_1 = pipe internal surface temp = 76°C
T_2 = pipe external surface temp = 75.5°C
R_1 and R_2 are the inside and outside radius of the pipe.

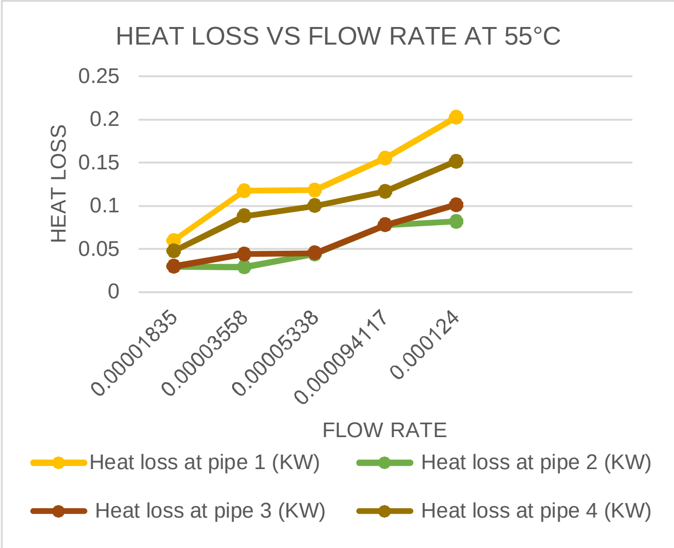
Heat transfer by convection through the circular pipe:
$Q_{convection} = 2 * \pi * r * h * l * (T_2-T_3)$
= 2 * 0.0274 * 3.1316 * 20 * 1.292 * (75.5-27.8)
= 0.200234 kW

Where,
h = Heat transfer co-efficient of air = 20 W/ (m^2K) (approximately)
T_3 = Environment Temp (°C)

6.3 Heat loss vs Flow Rate Graph Analysis

The rate of heat transfer is directly proportional to mass flow rate. If flow rate is increased, it will increase the rate of heat transfer. Since we cannot mess with Mother Nature, it is very naive to think it works any other way. In these graphs, the temperature is constant at 45°C but with an increase of flow rate the heat transfer increase. The heat transfer is maximum in first pipe section which is not insulated so from the graph we can see heat transfer is maximum there. Heat transfer (Q) equals to the mass flow rate (m) times a constant (the specific heat of water) times Temperature difference. The temperature has increased from 45°C to 55°C and so, from the elemental heat transfer law, the heat transfer will increase in every section of the pipe. From the graph, it is clear that heat transfer has increased with increase in temperature while the flow rate remaining same. The flow rate remaining same, only the temperature has increased from 55°C to 65°C and the heat transfer has increased in every pipe section from the previous graph. The flow rate remaining same, only the temperature has increased from 65°C to 70°C and the heat transfer has increase in every pipe section, from the previous graph. If input and output point is constant, in this case input and output is Temperature of the pipe section, then with the increase in flow rate, the ∆T will decrease. But with increase in flow rate, the mass flow rate will also increase, as Q = m * Cp *∆T. In our case, the mass flow rate increased more than the decrease in ∆T, so overall heat transfer increases. From the below graphs, we can see that, with increase in mass flow rate the heat transfer increases. The maximum heat transfer occurs at maximum flow rate at 0.000125 m3/s.





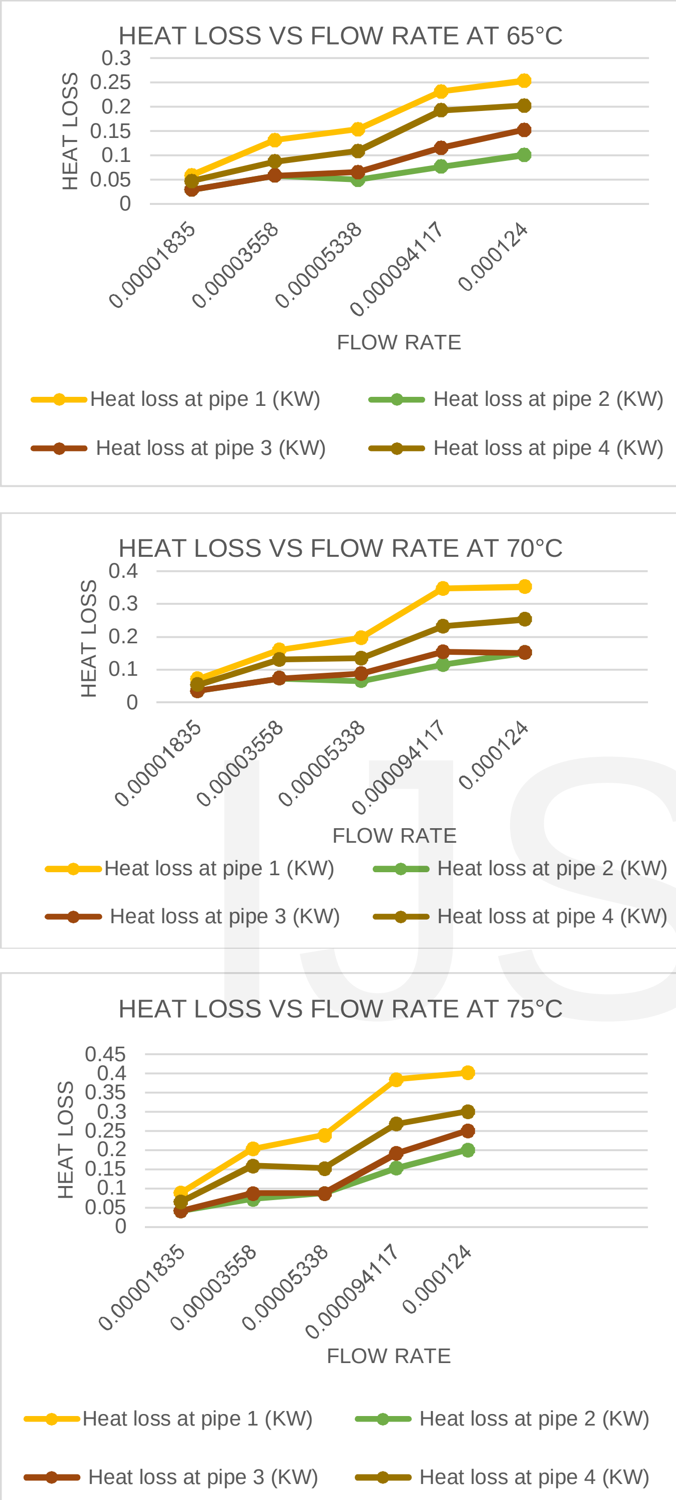


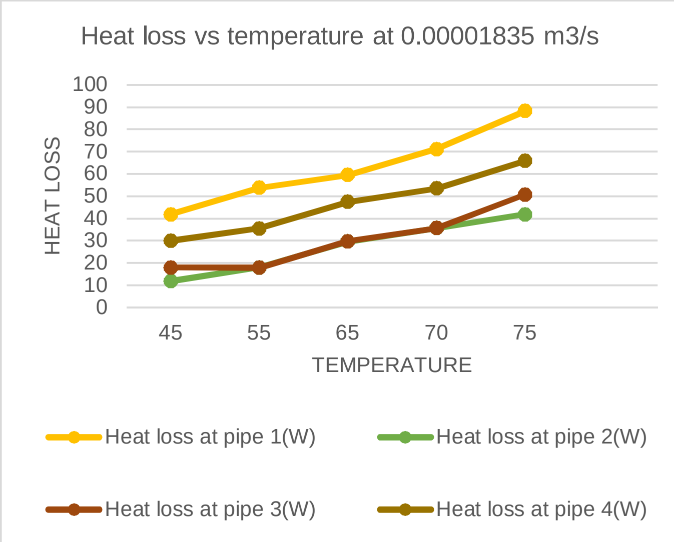
Fig. 11: Heat loss vs flow rate at different temperatures

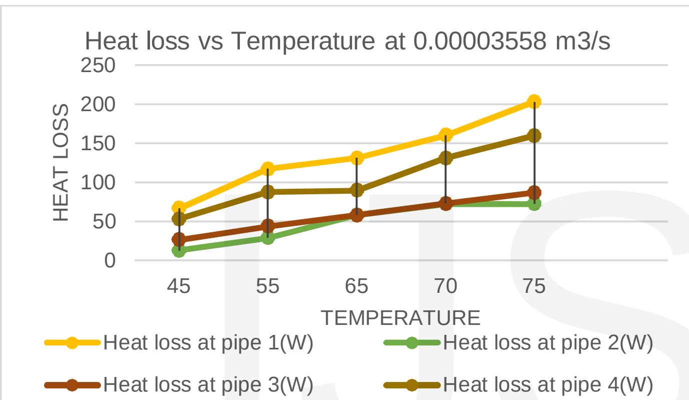
6.4 Heat Loss Vs Temperature Graph Analysis

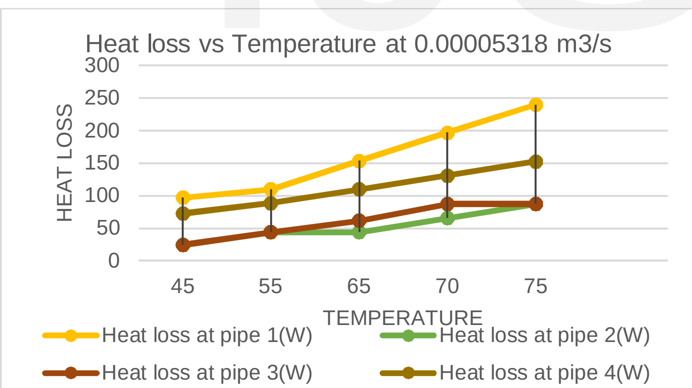
In below first graph, keeping the flow constant, with increase in temperature (Δt), the heat transfer increases. The minimun heat loss occurred in second pipe section because this section is insulated. Then the third pipe section which is insulated having an added internal profile as steel net which was placed to increase the heat transfer. Then the fourth pipe section which is insulated having staneless steel spring as an added internal profile. Maximum heat transfer occurs at the first pipe section which is not insulated. In second graph, the lowest amount of heat transfer occurs for the 2nd pipe which is insulated. As predicted, the amount of heat transfer of pipe 3 and pipe 4 are within the pipe 1 and pipe 2. Comparing between pipe 3 and pipe 4, pipe 4 exhibits better heat transfer i.e. heat loss from the fluid to the environment. As explained earlier, the spring is fitted inside the pipe and the wire diameter of the spring is much higher than the net which ultimately leads to conductive heat transfer from the fluid to the wall. Moreover, the fluid temperature at the center line to the pipe is higher and gradually decreases towards the wall. Therefore, the conductive heat transfer enhanced with the increase of the ΔT or the temperature gradient i.e. $\Delta T/\Delta x$. So, the heat transfer or the heat loss from the fluid to the environment for the 4 different pipes are as follows:

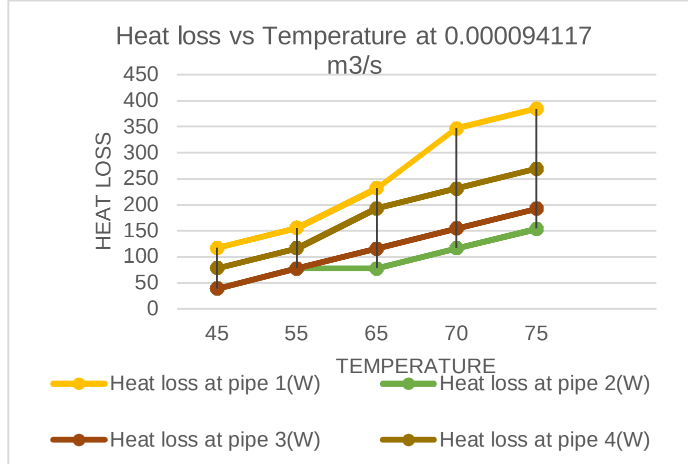
$$\text{So, } Q_{p1} > Q_{p4} > Q_{p3} > Q_{p2}.$$

In second graph, the flow rate has increased and it was maintained to be a constant flow rate of 0.00003558 m^3/s. So with the flow rate remaining same, with increase of temperature from 45°C to 75°C, the heat transfer has increased and it can be seen clearly from this graph. In the five graphs, with the increase in flow rate and temperature, the heat transfer maintained its theoretical law. Heat transfer at first pipe was highest at different temperatures and different flow rates. The other three pipe section was insulated. In order to increase the heat, transfer or compare those pipe sections, different kinds of condition were applied like steel net and spring and third pipe section was empty or had no added internal profile. The pipe section with stainless spring as the added internal profile, was the second maximum to transfer heat among three pipe section because of the surface area is being increased by the spring and then the pipe section with steel net as the added internal profile, and then the pipe section without any profile inserted in it but insulated.









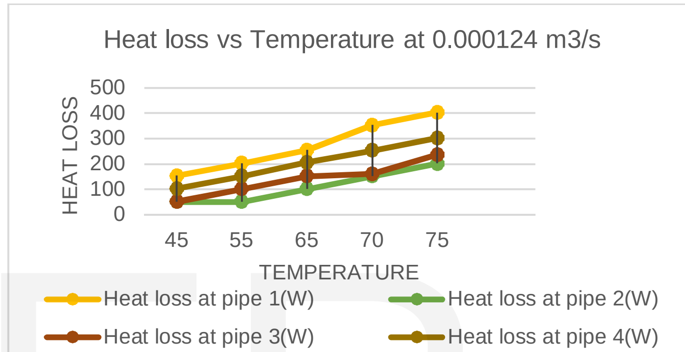


Fig. 12: Heat loss vs Temperature Graph Analysis

7 Discussion and Conclusion

7.1 Discussion

We can say that we have built an Experimental setup that can compare heat transfer through the circular pipe using internal profile and added different conditions that show suitable performance. Though we had some lacking in our construction, but we got good results from the setup. Better performance and result can be obtained if more precise temperature sensors are used and if the adiabatic sections were insulated perfectly. We had some errors in our reading while we measured the surface temperature of the pipe. If we could measure the inside temperature of the pipe, we could get more accurate and optimum results. Some errors were found in the reading due to the leakage in the joints and adhesive. Some errors occurred due to the fan and air conditional effect. Steel is not good conductor of heat so if we could use copper pipe, then the heat transfer would be much greater. The heat transfer co-efficient of copper is much greater than the heat transfer coefficient of stainless steel. As thickness of the copper pipe available is not too much to perform the threading operation on it, that is why stainless steel pipe was used.

7.2 Conclusion

Comparison of four pipe section, which shows the effect of insulation or adiabatic section pipe and the effect of increasing the internal fins or area. Although with an increase of the surface area or fins, the heat transfer should increase which can be seen from a comparison of the pipe section 2 and pipe section 4 but in the case of the pipe section 2 and pipe section 3, the result was not clearly shown. From above ten graphs, it can be seen that sometimes both results were equal which not the desired result is.

The following factors can be drawn from this experiment:

- With the increase of surface area, the heat transfer should increase.
- If input point and output point is constant, with increase in flow rate, the temperature difference will decrease.
- The effect of increase in flow rate and increase in temperature can be seen from the graph clearly.
- Instead of some errors in reading and faults in construction, the overall performance of the setup was good.

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