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Comparative Analysis of Convective Heat Transfer Enhancement in Different Metal Ducts with Internal Threads

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Abstract: **The present paper focuses on Experimental analysis of heat transfer and experimental investigation of Heat Transfer enhancement through circular duct of aluminium and carbon steel using internal threads of pitch 5 mm and 10 mm with air as the working fluid. The experimental data obtained were compared with those obtained from plain duct.The effects of internal threads of varying depth on heat transfer and friction factor were presented for different metal (aluminium and carbon steel) as test metals. The heat transfer coefficient enhancement for internal threads is higher than that for plain duct for a given Reynolds number. The use of internal threads improved the performance of circular duct.**

Keywords: **compare heat transfer enhancement, carbon steel duct, and internal threads.**

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1. INTRODUCTION

The heat generated within the system must be dissipated to its surrounding in order to maintain the system at its recommended working temperature and functioning effectively and reliably. Increase in Heat exchanger's performance 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, thereby effecting energy, material & cost savings have led to development & use of many techniques termed as Heat transfer Augmentation.

These techniques are also referred as Heat transfer Enhancement or Intensification. Augmentation techniques increase convective heat transfer by reducing the thermal resistance in a heat exchanger. Use of Heat transfer enhancement techniques lead to increase in heat transfer coefficient but at the cost of increase in pressure drop. So, while designing a heat exchanger using any of these techniques, analysis of heat transfer rate &pressure drop has to be done. Apart from this, issues like long-term performance & detailed economic analysis of heat exchanger has to be studied. 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 years.

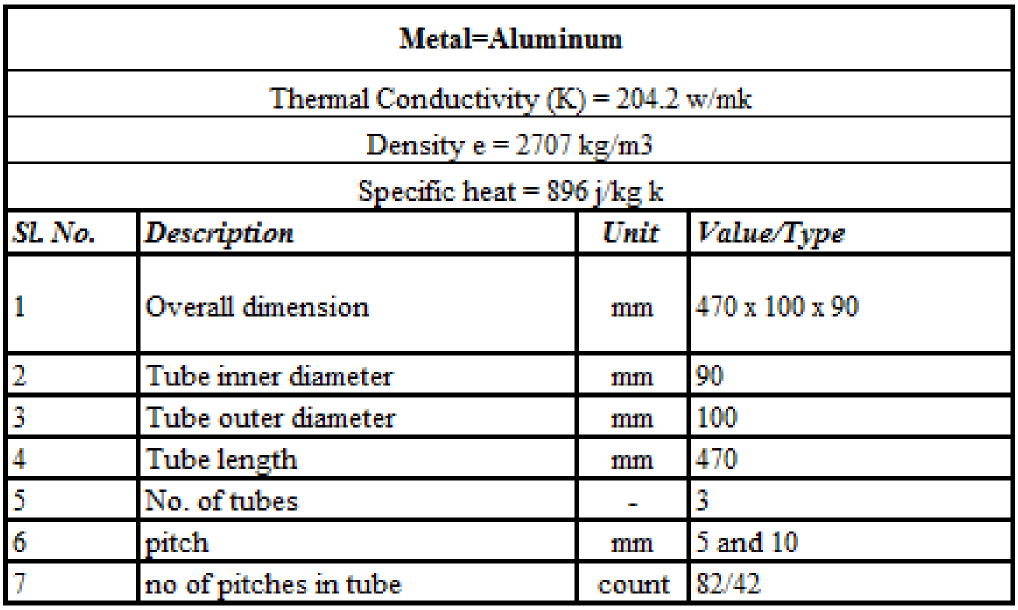
Turbulent flow in complex geometries receives considerable attention due to its importance in many engineering applications and has been the subject of interest for many researchers. Some of these include the energy conversion systems found in some design of process industries, cooling of evaporators, thermal power plants, air conditioning equipment radiators of space vehicle and automobiles and modern electronic equipment's. The present experimental study investigates the increase in the heat transfer rate betweenpipes heated with a constant uniform heat flux with air flowing inside it using internal threads of varying pitch. As per the available literature, the enhancement of heat transfer using internal threads in turbulent region the present work has been carried out with turbulent flow (Re number range of 17,000-30,000) as the flow problems in industrial heat exchangers involve turbulent flow region. The experiments are conducted on test rig of Aluminum and carbon steel duct initially without using any internal threads and with using internal threads of different pitches (p= 1cm & 0.5 cm) and various heat transfer characteristics are calculated.

2. REAL TIMEWORK ENVIRONMENT

The apparatus consists of a blower unit fitted with aaluminum and carbon steel duct, which is connected to the testsection located in horizontal orientation. Nichrome bend heater encloses the test section to alength of 47 cm. Three thermocouples T2, T3 and T4 at a distance of 15 cm, 30 cm and 45 cmfrom the origin of the heating zone are embedded on the walls of the duct and twothermocouples are placed in the air stream, one at the entrance (T1) and the other at the exit(T5) of the test section to measure the temperature of flowing air as shown in Fig. 1. The ductsystem consists of a valve, which controls the airflow rate through it and an orifice meter tofind the volume flow rate of air through the system. The diameter of the orifice is 1.4 cm andcoefficient of discharge is 0.64. The two pressure tapings of the orifice meter are connected toa water U-tube manometer to indicate the pressure difference between them. Input to heateris given through dimmer stat. The test tube of 18 mm thickness was used for experimentation.Display unit consists of voltmeter, ammeter and temperature indicator.

Design Specification:

Here is the design specification to build pipe/duct of different metal for this experimental analysis.



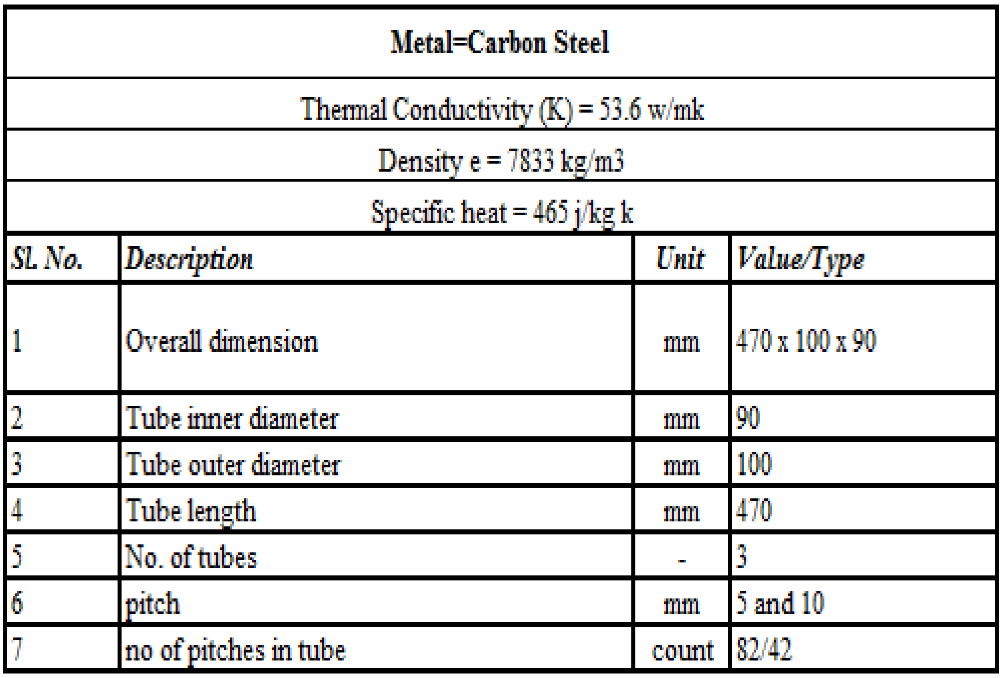
Metal=Aluminum

Thermal Conductivity (K) = 204.2 w/mk

Density e = 2707 kg/m3

Specific heat = 896 j/kg k

SL No.	*Description*	*Unit*	*Value/Type*
1	Overall dimension	mm	470 x 100 x 90
2	Tube inner diameter	mm	90
3	Tube outer diameter	mm	100
4	Tube length	mm	470
5	No. of tubes	-	3
6	pitch	mm	5 and 10
7	no of pitches in tube	count	82/42



Metal=Carbon Steel

Thermal Conductivity (K) = 53.6 w/mk

Density e = 7833 kg/m3

Specific heat = 465 j/kg k

SL No.	*Description*	*Unit*	*Value/Type*
1	Overall dimension	mm	470 x 100 x 90
2	Tube inner diameter	mm	90
3	Tube outer diameter	mm	100
4	Tube length	mm	470
5	No. of tubes	-	3
6	pitch	mm	5 and 10
7	no of pitches in tube	count	82/42

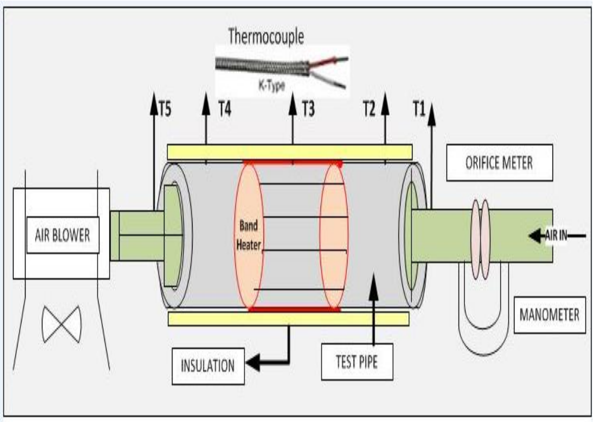


Fig.1: Experimental Setup Layout

Fig.2: Test Duct with internal pitches

3. WORKING PROCEDURE

A series of experiments carried out with Circular duct. A suction mode blower is used to draw the air in Circular duct. The heated test section is 47cm long. At the inlet Tb1 is the inlet bulk temperature measured by thermocouple and Tb5 exit bulk temperature.

Experiments were carried out in two steps (1) with Aluminum duct and (2) carbon steel

3.1 Without Internal threads:

Initially, the experiment was carried out on plain duct without internal threads. The working fluid air flows through the duct section with least resistance.

3.2 With Internal threads of varying depth:

The internal threads were done on duct as shown in Fig. 2. The three different test ducts of varying depth were used for experimentation. The presence of the internal threads in the duct causes resistance to flow and increases turbulence. The mass flow rates of air and the heat input were kept constant as that of plain duct experiment.

4. DATA REDUCTION

The data reduction of the measured results is summarized in the following procedures:

The duct surface and in/out temperature:-

$Ts = (T2 + T3 + T4)/3$ - (Equation I)

$Tb = (T1 + T5)/2$ - (Equation II)

Discharge of air:-

$Q = Cd *A1 *A2\sqrt{ 2ghair)}/\sqrt{ (A12 – A22)}$ - (Equation III)

Equivalent height of air column:-

$hair = (\dot{\rho}\ w *hw) /\dot{\rho}w$ - (Equation IV)

Velocity of air flow:-

$V = (Q/A)$ - (Equation V)

Where A =convective heat transfer area (II*D*L)

$Re = (\dot{\rho} * V * D) /\mu$ - (Equation VI)

Where D = inner diameter of duct and L= Length of duct

Total Heat Transfer:-

$Q = Qc + Qr$ - (Equation VII)

Q = m Cp (T1 – T5) - (Equation VIII)

Where m= mass flow of air

Qc = Convective Heat Transfer

Qr = Radiation Heat Transfer

$Qr = \sigma\, A\, \varepsilon\, (Ts^4 - Tb^4)$ - (Equation IX)

h= (Q-Qr) / (A (Ts -Tb) - (Equation X)

Experimental Nusselt number:-

Nu = h* (D/ K) - (Equation XI)

Nusselt numbers calculated from the experimental data for plain tube were compared with the correlation recommended by Dittus-Boelter.

Theoretical Nusselt number:-

$Nu = 0.023\, Re^{0.8} pr^{0.4}$ - (Equation XII)

In straight duct lengths, Pressure drop (ΔP) can be calculated using the Darcy Equation

f = Darcy friction factor

$$\Delta P_{Friction} = \frac{f.L_{Pipe}}{d_{Pipe}} \frac{\rho.u^2}{2}$$

5. RESULT ANALYSIS

Result with Aluminum duct:

From the Fig.3, it is observed that the heat transfer coefficient increases with increase in Reynolds no. As Reynolds no. increases, the air flow will cause more turbulence so due to which the heat transfer rate will increase. From the Fig.4 it is observed that the circular duct without using any internal threads gives the less heat transfer coefficient with the use of internal threads of pitch 1cm create more turbulence in duct which increases the heat transfer coefficient. An internal thread of pitch 0.5 cm gives maximum value of heat transfer coefficient as compared to internal threads of pitch 1cm.

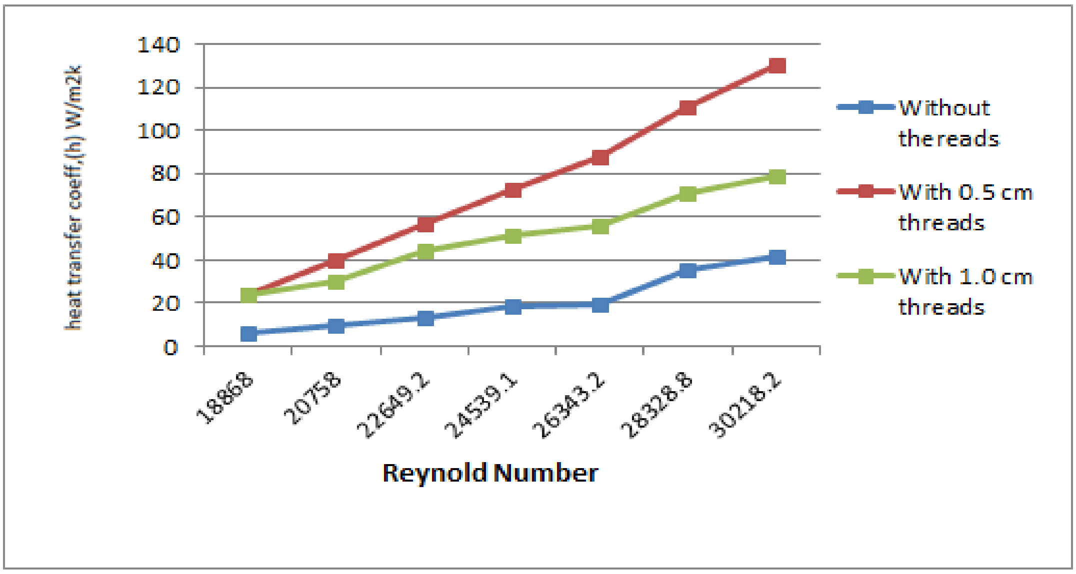


Fig.3: Heat transfer coefficient Vs Reynolds Number

From the Fig.4. it is observed that there is increase in Nusselt number as increase in Reynolds number .As Reynolds number increases the air flow will cause more turbulence due to which heat transfer rate will increase in heat transfer coefficient (h) and Nu=hDh/k i.e increase in heat transfer coefficient increases the Nusselt number. From fig 4.it is observed that maximum Nusselt number is obtained for internal thread of pitch p= 0.5 cm as compared to p= 1cm and without internal threads.

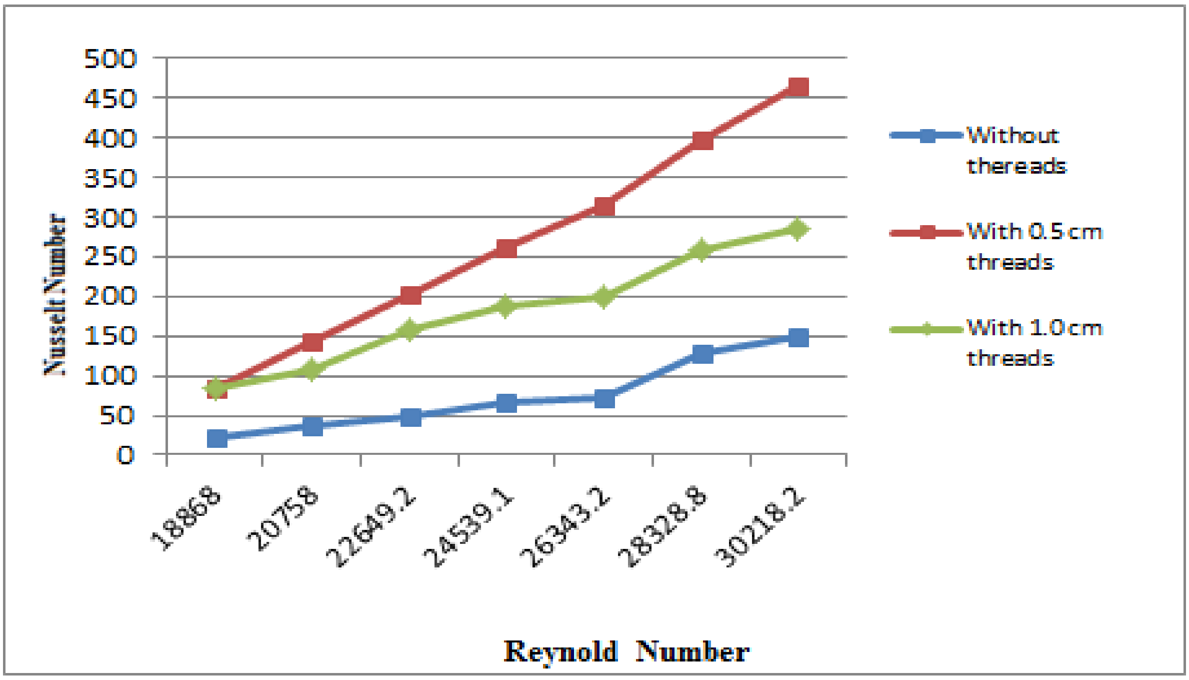


Fig.4: NusseltNumber Vs Reynolds Number

From the Fig.5 it is observed that as the Reynolds increases there is decrease in friction factor. As the velocity goes on increasing with Reynolds number and friction factor is inversely proportional to the velocity. From fig.5 it is observed that least friction factor is obtained in duct without internal threads and maximum friction factor is observed in with internal threads of pitch(p=0.5cm).

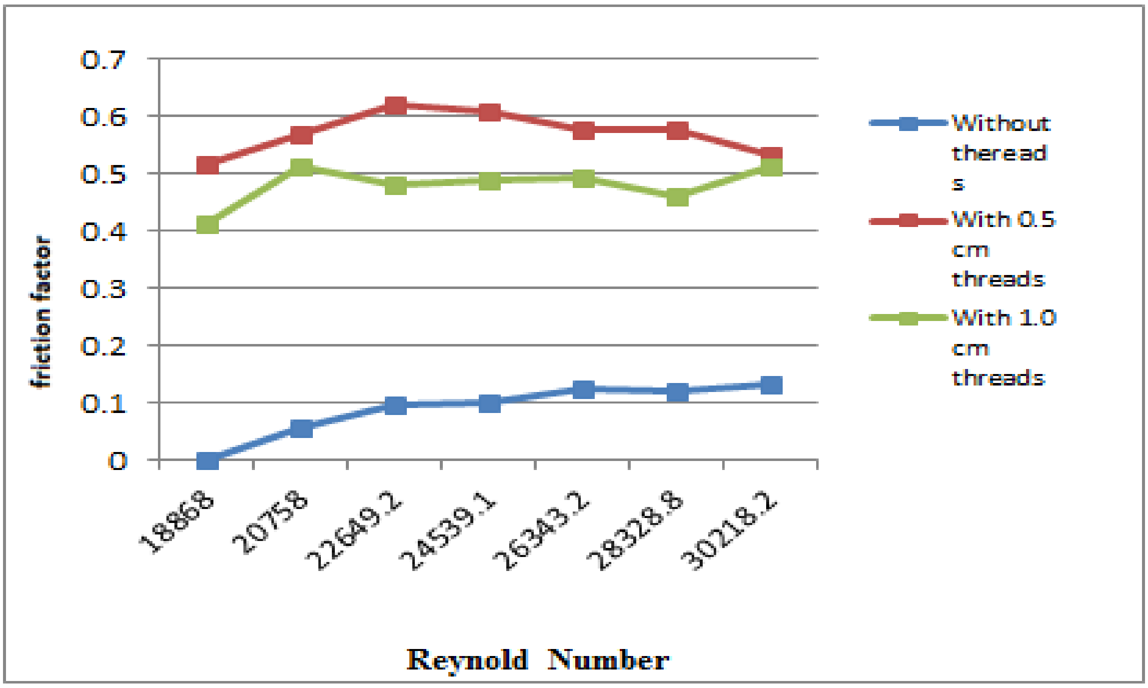


Fig.5: Friction FactorVs Reynolds Number

Result of Carbon steel duct:

From the Fig.6, it is observed that the heat transfer coefficient increases with increase in Reynolds no. As Reynolds no. increases, the air flow will cause more turbulence so due to which the heat transfer rate will increase. From the Fig.4 it is observed that the circular duct without using any internal threads gives the less heat transfer coefficient with the use of internal threads of pitch 1cm create more turbulence in duct which increases the heat transfer coefficient. An internal thread of pitch 0.5 cm gives maximum value of heat transfer coefficient as compared to internal threads of pitch 1cm.

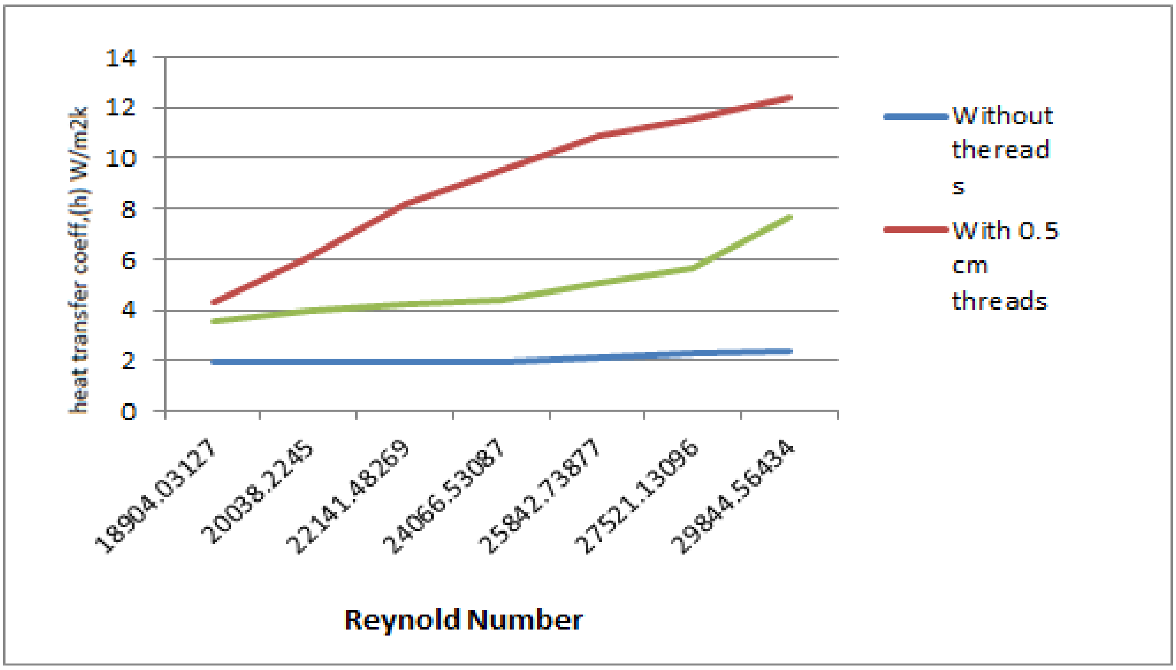


Fig.6: Heat transfer coefficient Vs Reynolds Number

From the Fig.4. it is observed that there is increase in Nusselt number as increase in Reynolds number .As Reynolds number increases the air flow will cause more turbulence due to which heat transfer rate will increase in heat transfer coefficient (h) and Nu=hDh/k i.e increase in heat transfer coefficient increases the Nusselt number. From fig 4.it is observed that maximum Nusselt number is obtained for internal thread of pitch p= 0.5 cm as compared to p= 1cm and without internal threads.

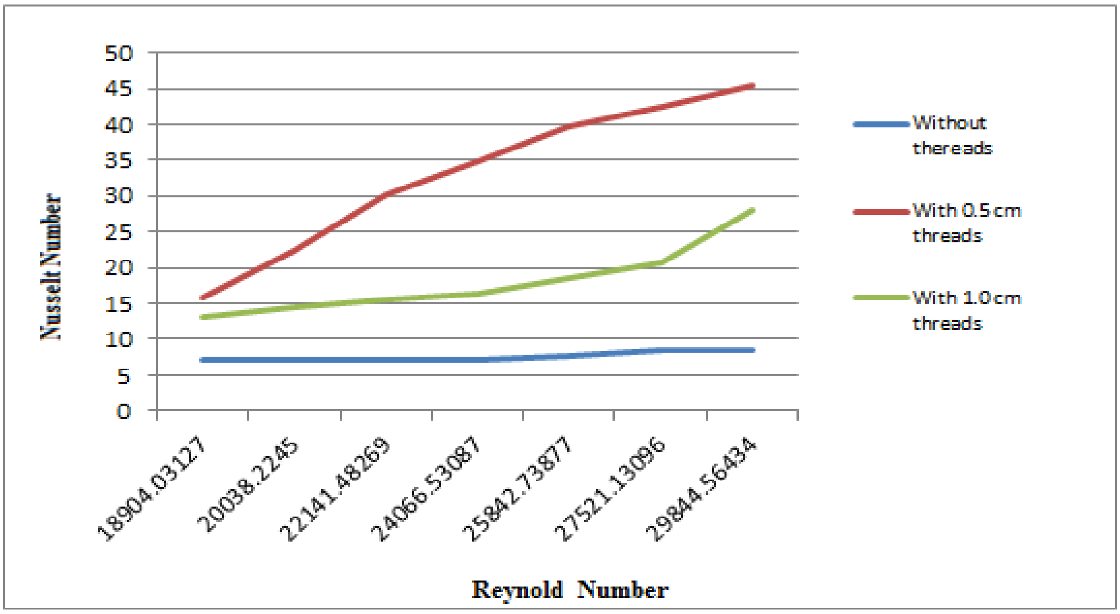


Fig. 7: Nusselt Number Vs Reynolds Number

From the Fig.5 it is observed that as the Reynolds increases there is decrease in friction factor. As the velocity goes on increasing with Reynolds number and friction factor is inversely proportional to the velocity. From fig.5 it is observed that least friction factor is obtained in duct without internal threads and maximum friction factor is observed in with internal threads of pitch(p=0.5cm).

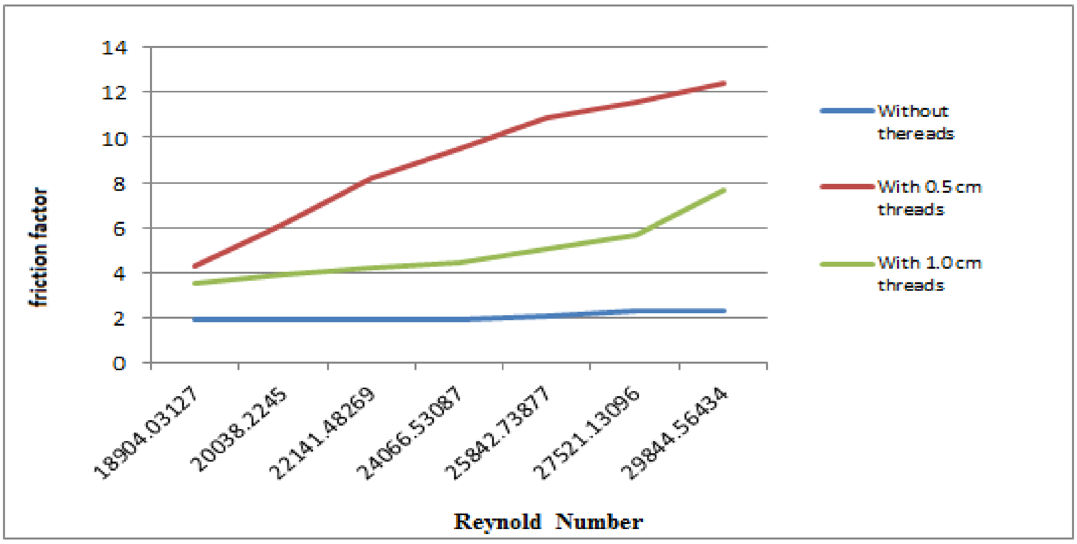
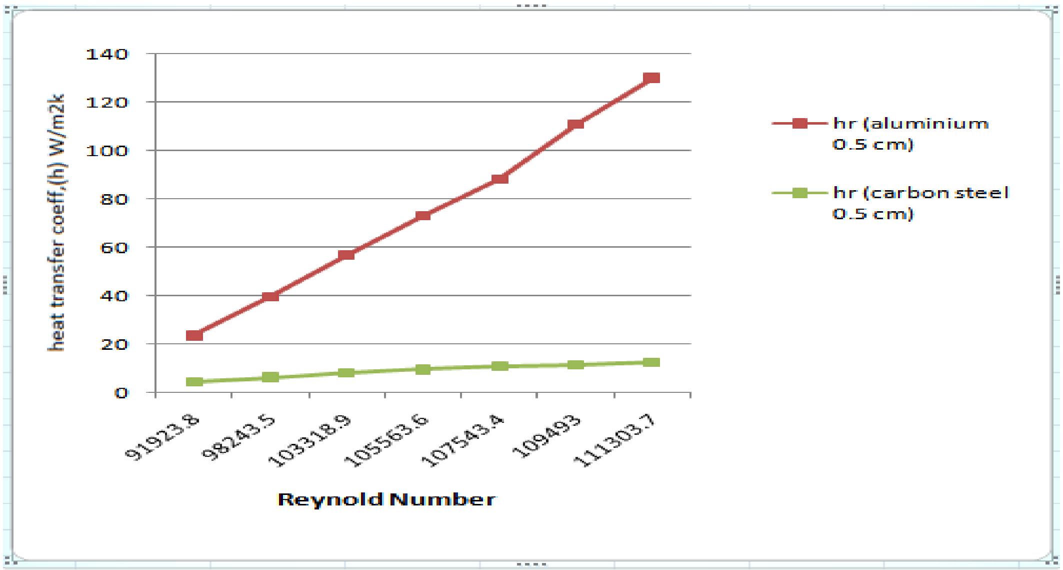


Fig.8: Friction FactorVs Reynolds Number

Experimental data:

Metal Name	Inlet temp (T1) °C	Surface temperatures °C			Outlet temp (T5) °C	Heat transfer coefficient (hr)	Reynolds No (Re)	Friction Factor(fr)
		(T2)	(T3)	(T4)				
Aluminum (5 mm)	39.3	88.8	89.2	86.3	44.3	23.5	18877.2	0.518
Aluminum (5 mm)	39.1	86.9	87.8	85	46.3	39.5	20774.5	0.569
Aluminum (5 mm)	39.3	85.5	86.3	84.9	48.3	56.7	22675.7	0.619
Carbon steel (5 mm)	35.4	53	59	58	35.9	4.29	18873.4	0.036
Carbon steel (5 mm)	35.6	55	59.7	59	36.3	6.10	20021.4	0.064
Carbon steel (5 mm)	35.6	56.9	61	60	36.5	8.20	22135.6	0.026

6. CONCUSSION



Experimental investigations have been carried out to study the effects of the internal threads of different pitches on different materials aluminum versus carbon steel (p= 1cm & 0.5 cm). Heat transfer coefficient and friction factor are analyzed with using passive heat transfer enhancement methods. From the graph plotted above following conclusions are made. The heat transfer rate increases in duct with the internal threads as compared to without internal threads.

Cutting threads in the metals of different conductivities results in increase of the rate of heat transfer. for metals having high conductivities the increase in rate of heat transfer is proportional .but in case of metals with lower conductivities there is increase in heat transfer rate but not as high as metals of high conductivities.

The result shows that the heat transfer rate increases as the Reynolds number increases.

➢ The internal threads of pitch p= 0.5 cm causes the maximum turbulence in the duct due to which maximum heat transfer to occur.

➢ As the pitch of internal threads decreases it is found that there is increase in heat transfer rate but increases in friction factor is observed. So it can be concluded that minimum the pitch of internal threads maximum the heat transfer rate but more frictional losses will occur.

➢ The performance of horizontal duct can be improved by the use of internal threads. The cost involved in making internal threads is minimal compared to energy efficiency improvement provided by this technique.

➢ Thus the Experiment conducted results in ,the fruitful use of internal threads as passive intensification technique

➢ one recommendation is made while using carbon steel as heat exchanger that is passivating it in order to avoid rusting and corrosion occurring due to environmental conditions.

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