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Heat Transfer Analysis of Cone Shaped Helical Coil Heat Exchanger of Different Pitches and Diameter

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ABSTRACT

Heat exchanger is a device in which both hot and cold fluids exchange heat between themselves without absorbing or losing heat from ambient.In the present study an experimental investigation of heat transfer in cone shaped helical coil heat exchanger ireported for various Reynolds number. The purpose of this article is to compare the heat transfer in cone shaped helical coil and simple helical coil. The pitch, height and length of both the coils are kept same for comparative analysis. The calculations have been performed for the steady state condition and experiments were conducted for different flow rates in laminar and turbulent flow regime. The coil side flow rate is kept varying while the coil side flow rate is kept constant. It was observed that the effectiveness of the heat exchanger for the cone shaped helical coil is more than that for the simple helical coil. Results show that the heat transfer rates for the cone shaped helical coil are comparatively higher than that of the simple helical coil.

I. INTRODUCTION

Heat exchanger is a device in which both hot and cold fluids exchange heat between themselves without absorbing or losing heat from ambient. Examples are -Steam condenser (steam or vapour to water), Economizer (flue gases to feed water), Super heater (flue gases to steam), Cooling tower (hot water to ambient air), Air pre heater (hot flue gases to combustion air), Oil cooler (hot oil to coolant), etc.

Heat exchangers are broadly used in process industries for ample variety of applications including refrigeration and air-conditioning, nuclear reactors, chemical processing, food industries, steam power plant and medical equipment. By improving coefficient of heat transfer, the heat exchanger dimensions will reduce and its performance will improve. At present various techniques of heat transfer augmentation are used by researchers. These are classified into three groups: active, passive and compound techniques [1]. In active techniques external force are required for improvement like electric field, surface vibration and fluid vibration, where as in passive techniques various tube insert or unique surface geometries are used. If two or more of these techniques are used for augmentation in heat transfer they are called as compound enhancement. In industries shell and coil tube configuration are frequently used which is a significant passive technique. In equipments like heat exchangers and reactors, helical coil arrangement is very effective because of compact structure which produces large heat transfer surface area in a small space [2].

In laminar and turbulent flow system broad research on experimental and numerical investigation on simple helical coils was done by different researchers. However, fluid flow through helical coil of cone shape is still under investigation. In process industries heat exchangers of helical coil are hugely used. Heat transfer

IJARSE
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characteristic with numerical replication method was investigated by Pei-qi (2011) for conical spiral tube package. They observed that cross section and cone angle have major effect while helical pitch has little effect on heat transfer augmentation. At constant cross section area, circular section has larger heat transfer coefficient than elliptical section [3]. Salimpour (2009) investigated heat transfer coefficient for three heat exchanger of different pitch and found that larger pitch have higher heat transfer coefficient than smaller pitches [4]. Pawar et al. (2011) carried out a survey of heat transfer through circular helical coils. They developed correlation in terms of M number to determine pattern of flow in helical coils [5].

Classification of Heat Exchanger

Heat exchanger are mainly classified into three group

Direct transfer type H.E. - In any direct transfer type H.E. there is no contact between both the fluids but heat transfer takes place by pipe wall of separation e.g.- economizer, surface condenser, air pre heater. Direct transfer type heat exchangers are sub classified as:

a. Parallel flow H.E.

b. Counter flow H.E.

c. Cross flow H.E.

Direct contact type H.E. – In this type of H.E both hot and cold fluid mix up in one another while transferring heat between them. Examples- cooling tower, jet condenser.

Regenerative or storage type H.E. –Both types of hot and cold fluids were alternately passed through the cellulose matrix, one heats the matrix and other picks the heat from it. e.g. Ljungstorm air preheater.

Log. Mean Temper. Difference (LMTD)

LMTD is the temperature difference which, if kept constant, will lead to the same rate of heat transfer that actually takes place under varying conditions of temperature difference.

$$LMTD=\frac{\theta_1-\theta_2}{\ln(\frac{\theta_1}{\theta_2})}$$

Where θ_1 =inlet temp. Difference and

θ_2 =outlet temp. Difference

Effectiveness of Heat Exchanger – Effectiveness of H.E. is defined as the ratio of actual heat transfer rate to maximum possible heat transfer rate between hot and cold fluids.

$$\varepsilon=\frac{\text{Actual heat transfer}}{\text{Maximum heat transfer}}$$

Number of Transfer Units- The **'NTU'** in a heat exchanger is given by

$$NTU=\frac{U_O*A}{C_{min}}$$

Where, U_O =Overall heat transfer coefficient

C= Heat capacity

ε = Effectiveness of H.E.

A= Heat exchanger area.

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II. LITERATURE REVIEW

Ghorbani et al. (2010) gives experimental analysis of mixed convection heat transfer at different Reynolds and Rayleigh number, different tube to coil diameter ratio and pitch coil in a coil in shell heat exchanger. Purpose of this article was to determine the flow rate and coil pitch over the modified effectiveness and performance coefficient for vertical coil tube heat exchanger. They found that LMTD decreases as mass flow ratio increases.

Mujumdar et al. (2011) evaluated the heat transfer performance of non circular helical coil tubes. They investigated the conical, helical, and in-plane spiral configuration and their performances are compared with the straight duct. It is reported coiled ducts gave higher heat transfer rates, at the cost of high pressure drop.

Kumar et al. (2012) gives a detailed experimental study in laminar and transition regime on five wire coils of different pitches insert. They concluded that as pitch decreases, efficiency increases. It is highest for conical sets. At Reynolds number of 2200-3000, friction factor is maximum.

Elazm et al. (2012) compared the performance of helical cone coil heat exchanger to ordinary helical coil and introduced the concept of helical cone coils. They found the Nusselt number, heat transfer coefficient and coil exit temperature are directly proportional to the taper angle. The increase in the coil taper angle leads to a lower space requirement for the setup.

Marko et al. (2012) studied heat transfer coefficient of 3 heat exchangers with helical coils. Prime focus was on shell-side heat transfer coefficient that is highly affected by geometric/construction parameters e.g. as winding angle, radial pitch, axial pitch, etc. It was reported that the shell-side heat transfer coefficients should be based on shell side hydraulic diameter as it includes the number of shell side construction parameters.

Shinde and Danger (2013) performed experiments on cone shaped helical coil H.E. at various Reynolds number. Comparison between cone and simple helical coil is the main focus taking pitch, height and length of both coils constant. For cone shaped coil heat transfer rate are up to 1.38 times higher than simple helical coil. Also overall heat transfer coefficient, convective heat transfer and Nusselt number increases when fluid flow rate increases.

Farhadi et al. (2013) carried outthe experimentalanalysis to increase the heat transfer rate in shell and coiled tube heat exchanger. Shell and tube side heat transfer coefficients are calculated by Wilson plots. From experimental analysis they found that by increasing the flow rate of shell side, Nu increases. As Dean number increases, overall heat transfer coefficient and Nusselt number increases.

Ray et al. (2014) performed paper reviews on experimental works using passive heat transfer technique, on this technique wire coil insert in tubes to augment heat exchanger efficiency. It also useful for designers in implement of passive enhancement techniques. For strengthen heat transfer efficiency here various developed wire coil insert are researched.

Purandare et al. (2015) gives thermal analysis of conical coil H.E. through experimental investigation. The analysis indicates that Nu and f are function of curvature ratio, cone angle, tube diameter and flow rates. They found effectiveness of H.E. is a function of Re. As Re increases effectiveness decreases. The Nu increases as Re increases inside tube taking constant cold water flow. As Re increases friction factor f reduces also f increases for increasing cone angle for same Re.

III. OBJECTIVES

The objectives of present study is to determine

IJARSE
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i. average heat transfer rate
ii. overall heat transfer coefficient
iii. effectiveness

For various pitches and to analyze the effect of pitch variation and to establish mathematical relation for LMTD by taking coil tube diameter and coil pitch as input parameters.

IV.EXPERIMENTAL DETAILS AND SETUP

This chapter provides schematic diagram (Figure 3.1) and actual diagram (Figure 3.2) of experimental setup, list of equipment with specification, formation of a conical coil for experimental setup and experimental procedure of proposed system.

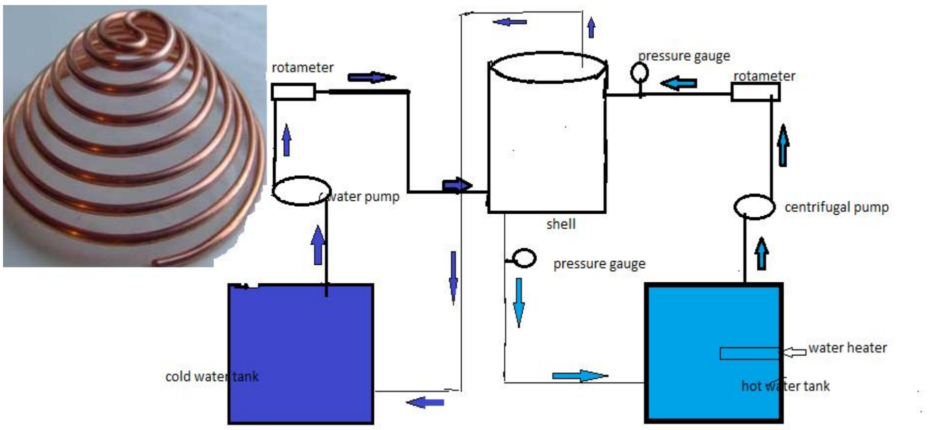

Figure 4.1 Schematic diagram of experimental set up

Figure 3.2 Actual diagram of experimental set up

LIST OF EQUIPMENTS OF EXP SET UP WITH SPECIFICATION

- Water storage tank-2, (100 lts.)
- Water heater-1, (1500 W)
- Discharge pump-2, (1/12 hp capacity)

IJARSE
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- Flow control valve
- Rotameter-2, (0-5 LPM)
- Micro manometer
- Shell-dia-300 mm, height-250 mm
- Thermocouple-4 (j type)

EQUIPMENT

- Water discharge pump or centrifugal pump
- Water tank
- Water heater
- Rotameter
- Pressure gauge (Manometers & Mechanical gauges)
- Thermocouple (j-type)

V. EXPERIMENTAL PROCEDURE OF THE PROPOSED SYSTEM

i. Initially water is filled in both the tanks and then heater was switched as to heat water in hot water tank.

ii. Centrifugal pump of hot water side was started after desired temperature of water was achieved to circulate hot water through coil. The flow rate is measured by rotameter and controlled by flow control valve (FCV).

iii. At same instant, centrifugal pump of cold water side was started. Cold water flow rate is controlled by FCV and measure by rotameter in a manner similar to previous one.

iv. The above test was carried out in counter flow configuration.

v. Once steady state is achieved, inlet and outlet temperature of shell side and coil side are measured by thermocouple.

vi. Keeping shell side flow rate constant, the temperature was recorded for different hot water mass flow rate.

vii. Repeat the procedure for other coil.

VI. FORMULA USED IN CALCULATIONS

LMTD $= (\theta_1 - \theta_2)/\ln\left(\frac{\theta_1}{\theta_2}\right)$

Where LMTD=Logarithmic mean temperature difference

θ_1 = At inlet temperature difference

θ_2 = At outlet temperature difference

U_0 = Overall heat transfer coefficient

U_0 = q / (A*ΔT_m) W/m^2K

- Hot water heat transfer rate

$q_h = m_h * c_{ph} *$(Tin-Tout)

- Cold water heat transfer rate

IJARSE
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$q_c = m_c * c_{pc} *$ (Tout-Tin)

- Avg. heat transfer rate

q = (q_h +q_c)/2 W

- Effectiveness of Heat Exchanger (ε)
- If $m_c*c_{pc}<m_h*c_{ph}$

ε = (T_{co}-T_{ci}) / (T_{hi}-T_{ci})

- If $m_h*c_{ph}<m_c*c_{pc}$

ε = (T_{hi}-T_{ho}) /(T_{hi}-T_{ci})

VII. OBSERVATION TABLE

Table-7.1 Observation table for tube diameter 10mm*12mm and pitch 20 mm

	S.N	T_{hi} (°c)	T_{ho} (°c)	T_{ci} (°c)	T_{co} (°c)	ΔT_m (°c)	q In KW	U_o KW/m^2K	ε
Mh=1 Mc=4	1	39	27	14	17	17.11	0.71	0.61	0.54
	2	34	25	17	19	11.14	0.75	0.57	0.50
	Avg					14.13	0.73	0.59	0.52
Mh=1.5 Mc=4	1	48	33	11	17	26.24	0.86	0.63	0.43
	2	34	28	18	20	11.89	0.90	0.59	0.39
	Avg.					19.07	0.88	0.61	0.41
Mh=2 Mc=4	1	47	35	15	21	22.87	0.90	0.66	0.42
	2	35	29	19	22	11.43	0.94	0.62	0.38
	Avg.					17.15	0.92	0.64	0.40
Mh=2.5 Mc=4	1	45	34	12	19	23.94	0.96	0.78	0.37
	2	30	26	19	21	7.96	1.00	0.74	0.33
	Avg.					15.95	0.98	0.76	0.35
Mh=3 Mc=4	1	44	35	16	23	19.98	1.02	0.92	0.36
	2	34	30	21	24	9.49	1.06	0.88	0.32
	Avg.					14.74	1.04	0.90	0.34
Mh=3.5 Mc=4	1	46	38	15	22	23.50	1.16	1.00	0.32
	2	32	29	21	23	8.50	1.20	0.96	0.28
	Avg.					16	1.18	0.98	0.30
Mh=4 Mc=4	1	41	31	9	19	22	1.55	1.20	0.30
	2	33	27	14	20	13	1.59	1.16	0.26
	Avg.					17.5	1.57	1.18	0.28

IJARSE
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Table 7.2 Observation table for tube diameter 7mm*9mm and pitch 20 mm

	S.N	T_{hi} (°c)	T_{ho} (°c)	T_{ci} (°c)	T_{co} (°c)	ΔT_m (°c)	q In KW	U_o KW/m^2K	ε
Mh=1 Mc=4	1	41	34	24	26	12.33	0.53	0.47	0.45
	2	37	32	26	27	7.83	0.49	0.43	0.41
	Avg.					10.08	0.51	0.45	0.43
Mh=1.5 Mc=4	1	41	35	23	25	13.90	0.55	0.53	0.37
	2	36	32	25	26	8.41	0.51	0.49	0.33
	Avg.					11.16	0.53	0.51	0.35
Mh=2 Mc=4	1	44	37	22	25	16.92	0.71	0.60	0.33
	2	38	34	24	26	10.97	0.67	0.56	0.29
	Avg.					13.95	0.69	0.58	0.31
Mh=2.5 Mc=4	1	42	36	20	24	17	0.82	0.74	0.29
	2	35	32	24	26	8.5	0.78	0.70	0.25
	Avg.					12.75	0.80	0.72	0.27
Mh=3 Mc=4	1	41	36	20	24	16.5	0.86	0.83	0.28
	2	35	32	24	26	8.5	0.82	0.79	0.24
	Avg.					12.5	0.84	0.81	0.26
Mh=3.5 Mc=4	1	42	37	17	21	20.5	0.91	0.94	0.22
	2	31	29	21	22	8.5	0.87	0.90	0.18
	Avg.					14.5	0.89	0.92	0.20
Mh=4 Mc=4	1	43	38	19	24	19	1.20	1.18	0.20
	2	37	34	22	25	12	1.16	1.14	0.16
	Avg.					15.5	1.18	1.16	0.18

Table-7.3 Observation table for tube diameter 4 mm*6 mm and pitch 20 mm

	S.N	T_{hi} (°c)	T_{ho} (°c)	T_{ci} (°c)	T_{co} (°c)	ΔT_m (°c)	q In KW	U_o KW/m^2K	ε
Mh=1 Mc=4	1	45	34	18	21	19.73	0.42	0.67	0.43
	2	40	32	20	22	14.80	0.38	0.63	0.39
	Avg.					17.27	0.40	0.65	0.41
Mh=1.5 Mc=4	1	43	35	18	21	19.39	0.47	0.81	0.35
	2	39	33	21	23	13.90	0.43	0.77	0.31
	Avg.					16.65	0.45	0.79	0.33
Mh=2 Mc=4	1	43	36	18	21	19.93	0.59	0.87	0.29
	2	37	33	21	23	12.97	0.55	0.83	0.25
	Avg.					16.45	0.57	0.85	0.27
Mh=2.5	1	43	37	20	24	17.98	0.67	1.04	0.28

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

Mc=4	2	36	33	24	26	9.49	0.63	1.00	0.24
	Avg.					13.74	0.65	1.02	0.26
Mh=3 Mc=4	1	41	37	22	25	15.49	0.69	1.10	0.24
	2	34	32	25	26	7.49	0.69	1.06	0.20
	Avg.					11.49	0.67	1.08	0.22
Mh=3.5 Mc=4	1	41	37	22	25	15.49	0.78	1.19	0.20
	2	35	33	26	27	7.49	0.74	1.15	0.16
	Avg.					11.49	0.76	1.17	0.18
Mh=4 Mc=4	1	40	35	16	21	19	1.05	1.37	0.18
	2	34	32	22	24	10	1.01	1.33	0.14
	Avg.					14.5	1.03	1.35	0.16

Table-7.4 Observation table for tube diameter 10 mm*12mm and pitch 15mm

	S.N	T_{hi} (°c)	T_{ho} (°c)	T_{ci} (°c)	T_{co} (°c)	ΔT_m (°c)	q In KW	U_O KW/m^2K	ε
Mh=1 Mc=4	1	45	38	26	28	14.36	0.53	0.44	0.51
	2	38	32	28	30	5.77	0.49	0.40	0.47
	Avg.					10.07	0.51	0.42	0.49
Mh=1.5 Mc=4	1	44	37	25	28	13.90	0.55	0.50	0.40
	2	36	33	28	29	5.94	0.51	0.46	0.36
	Avg.					9.92	0.53	0.48	0.38
Mh=2 Mc=4	1	42	36	24	27	13.44	0.69	0.58	0.38
	2	37	35	29	30	6.49	0.65	0.54	0.34
	Avg.					9.97	0.67	0.56	0.36
Mh=2.5 Mc=4	1	46	37	20	26	18.5	0.82	0.62	0.33
	2	35	31	25	27	6.95	0.78	0.58	0.29
	Avg.					12.73	0.80	0.60	0.31
Mh=3 Mc=4	1	43	36	18	23	18.98	0.98	0.69	0.30
	2	35	32	24	26	8.49	0.94	0.65	0.26
	Avg.					13.74	0.96	0.67	0.28
Mh=3.5 Mc=4	1	46	38	16	23	22.49	1.20	0.89	0.27
	2	36	32	23	26	9.49	1.16	0.85	0.23
	Avg.					15.99	1.18	0.87	0.25
Mh=4 Mc=4	1	45	35	9	19	26	1.97	1.20	0.24
	2	36	31	19	24	12	1.93	1.16	0.20
	Avg.					19	1.95	1.18	0.22

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

Table-7.5 Observation table for tube diameter 10 mm*12mm and pitches 25 mm

	S.N	T_{hi} (°c)	T_{ho} (°c)	T_{ci} (°c)	T_{co} (°c)	ΔT_m (°c)	q In KW	U_O KW/m^2K	ε
Mh=1 Mc=4	1	45	39	20	23	17.11	0.37	0.42	0.59
	2	37	33	22	25	5.77	0.33	0.38	0.55
	Avg.					11.44	0.35	0.40	0.57
Mh=1.5 Mc=4	1	42	34	19	22	26.94	0.44	0.47	0.47
	2	35	32	20	23	11.89	0.40	0.43	0.43
	Avg.					19.42	0.42	0.45	0.45
Mh=2 Mc=4	1	42	35	19	22	17.93	0.56	0.51	0.44
	2	34	30	21	23	9.97	0.52	0.47	0.40
	Avg.					13.95	0.54	0.49	0.42
Mh=2.5 Mc=4	1	43	40	24	26	16.5	0.64	0.54	0.41
	2	33	29	26	28	3.92	0.60	0.50	0.37
	Avg.					10.21	0.62	0.52	0.39
Mh=3 Mc=4	1	42	39	20	22	19.5	0.89	0.60	0.38
	2	36	34	23	24	11.5	0.85	0.56	0.34
	Avg.					15.5	0.87	0.58	0.36
Mh=3.5 Mc=4	1	50	43	14	20	29.5	1.04	0.75	0.36
	2	37	35	21	22	14.5	1.00	0.71	0.32
	Avg.					22	1.02	0.73	0.34
Mh=4 Mc=4	1	46	41	13	18	28	1.45	0.94	0.33
	2	30	29	19	20	10	1.41	0.90	0.29
	Avg.					19	1.43	0.92	0.31

VIII. RESULTS AND DISCUSSION

The results obtained from the experimental analysis of conical coil heat exchanger operated at different conditions are studied in detail and are presented below

8.1 Thermal analysis

The thermal performance of conical coil heat exchanger is determined on the basis of heat transfer rate, overall heat transfer coefficient and effectiveness. The coil side flow- rate was varied between 60 LPH to 240 LPH and during this flow rate through shell side was kept constant. The experiments are carried out only for counter flow arrangement.

Figure 8.1 shows the variation of average heat transfer rate with hot water mass flow rate for three different tube diameter 10mm*12mm, 7mm*9mm, and 4mm*6mm taking constant pitch of 20 mm. The average heat transfer

IJARSE
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rate increases with fluid flow rate. It also indicated that the heat transfer rate was maximum for tube diameter 10 mm*12 mm due to more surface area.

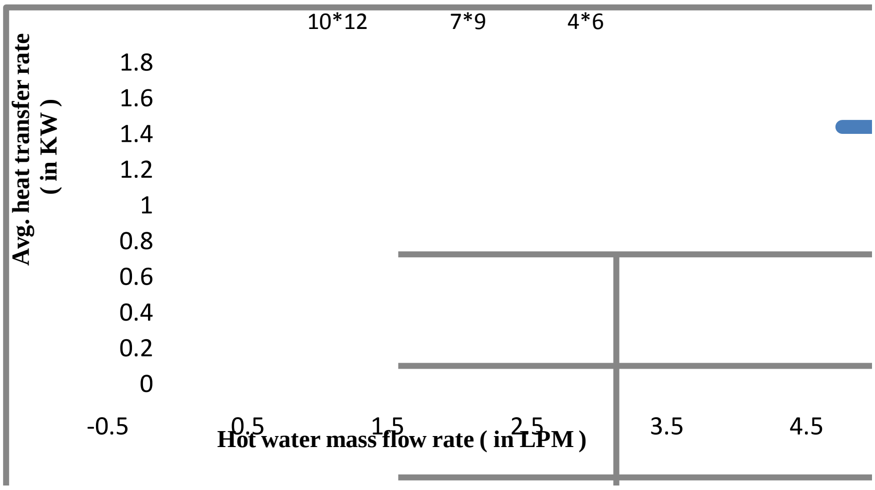

Figure 8.1. Variation of avg. heat transfer rate with hot water mass flow rate for coil pitch 20 mm

Figure 8.2 indicate the variation of overall heat transfer coefficient with hot water mass flow rate for three different tube diameter 10mm*12mm, 7mm*9mm, and 4mm*6mm taking constant pitch of 20 mm. The overall heat transfer rate increases with fluid flow rate. The U value was found maximum for 4 mm*6 mm tube diameter, due to least surface area. Increase in tube and coil diameter decreases the secondary which reduces the heat transfer coefficient [6].

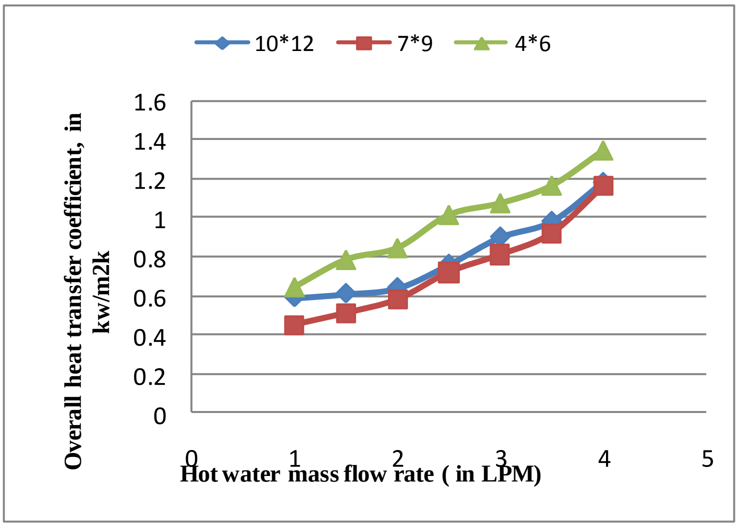

Figure 8.2 Variation of overall heat transfer coefficient with hot water mass flow rate for coil pitch 20 mm

Figure 8.3 indicate the variation of effectiveness of heat exchanger with hot water mass flow rate for three different tube diameter 10mm*12mm, 7mm*9mm, and 4mm*6mm taking constant pitch of 20 mm. The heat exchanger effectiveness decreases as fluid flow rate increases. As fluid flow rate increases the contact time between fluids decreases so that effectiveness of heat exchanger decreases with increasing fluid flow rate.

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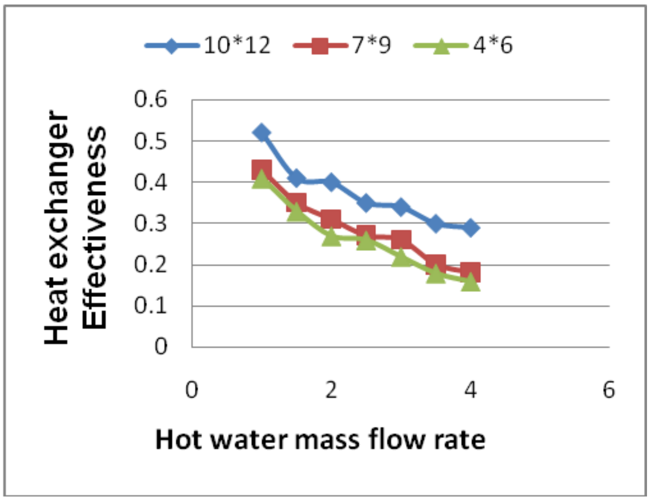

Figure 8.3 Variation of effectiveness of heat exchanger vs. hot water mass flow rate for coil pitch 20 mm

Figure 8.4 indicate the variation of average heat transfer rate with hot water mass flow rate for three different coil pitches 15 mm, 20 mm and 25 mm taking tube diameter 10 mm*12 mm constant. The Q value increases with fluid flow rate. From experimental observation it was concluded that heat transfer rate is maximum for 25 mm pitch coil than other two coils.

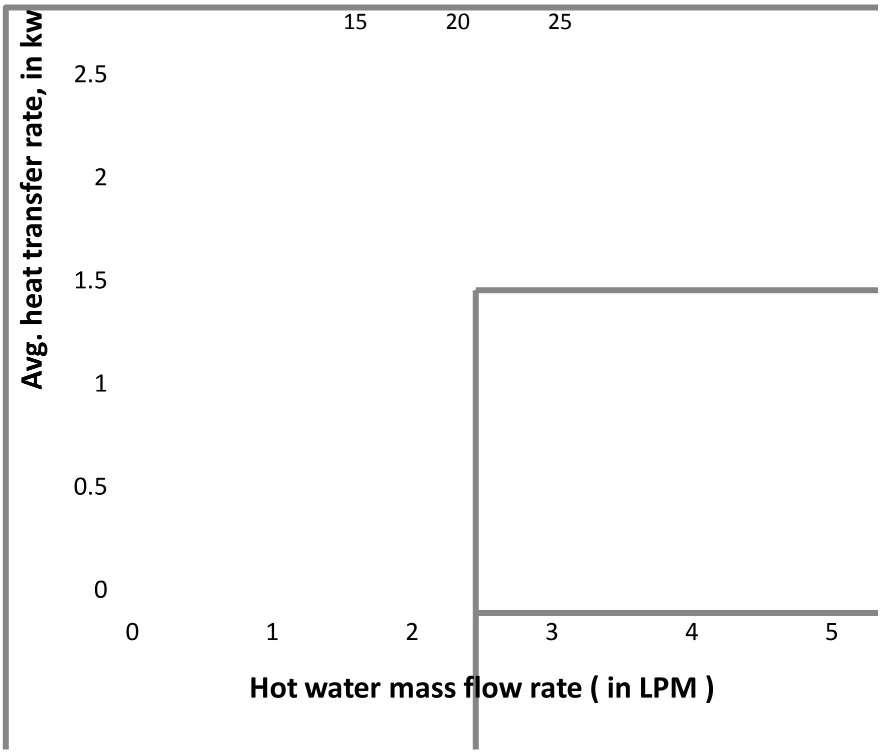

Figure 8.4 Variation of avg. heat transfer rate vs. hot water mass flow rate for tube diameter 10 mm*12 mm

Figure 8.5 indicates variation of overall heat transfer coefficient with hot water mass flow rate for three different coil pitches 15 mm, 20 mm and 25 mm taking tube diameter 10 mm*12 mm constant. Elazm et al. [7] also observed that heat transfer coefficient increases with increasing coil pitch.

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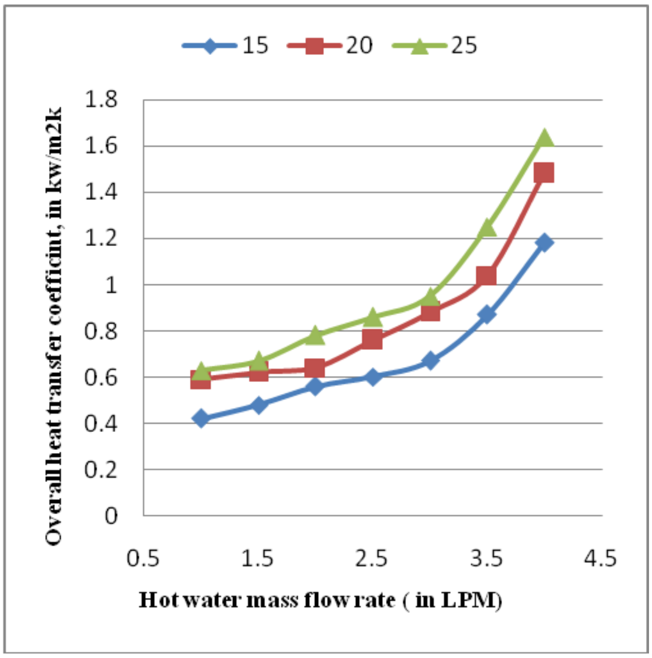

Figure 8.5 Variation of overall heat transfer coefficient vs. hot water mass flow rate for tube diameter 10 mm*12 mm

Figure 8.6 indicate variation of effectiveness of heat exchanger with hot water mass flow rate for three different pitches 15 mm, 20 mm and 25 mm taking tube diameter 10 mm*12 mm constant. Earlier we have known that effectiveness of heat exchanger decreases with increasing fluid flow rate. From observations it was found that coil pitch of 25 mm has more effectiveness than other two pitches.

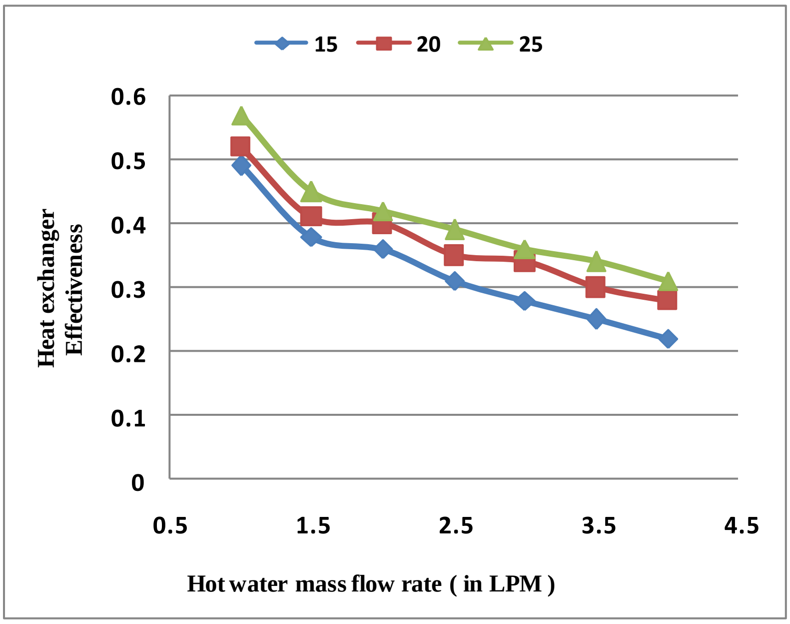

Figure 8.6 Variation of effectiveness of heat exchanger vs. hot water mass flow rate for tube diameter 10 mm*12 mm

Above results indicates that average heat transfer rate, overall heat transfer coefficient and effectiveness of conical coil heat exchanger of tube diameter 10 mm* 12 mm and coil pitch 25 mm is most suitable.

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Also after doing linear regression we obtained two mathematical relation as a result. They are:

1. ΔT_m = -0.63+1.21*D_o+1.49*M_h
2. ΔT_m = 4.78+1.95*P-9.62*M_h

Where, ΔT_m =LMTD

D_o=Outer tube diameter

P=Pitch of coil

M_h= Hot water mass flow rate

IX. CONCLUSION

The heat transfer characteristics of the conical coil heat exchanger with different pitches, tube diameters and mass flow rates were determined. The investigation leads to following conclusions for the present study:

1. Among three tube diameter 10mm*12mm, 7mm*9mm and 4mm*6mm, the tube diameter of 10*12mm is more effective.

2. For three different pitches of 15mm, 20mm and 25 mm, 25 mm pitch is more effective.

3. As mass flow rate increases avg. heat transfer rate and overall coefficient increases while effectiveness decreases.

4. Regression models were developed to predict LMTD.

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