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Experimental Analysis of Screw Heat Exchanger for Non- Newtonian Fluids

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Abstract- Experimental analysis and developmental methodology of screw type heat exchanger has been explained in detail also investigation of heat transfer characteristics for non-Newtonian fluid in screw heat exchanger with effect of different operating parameters such as speeds of rotation, Reynolds number etc. The experimental results obtained for inner tube with spiral fins on outer surface when this tube is kept stationary are compared with Dittus Boelter Equation results for variation of Nu for range of Re. It is seen that as Re increases the Nu increases both for plain tube in tube and for finned inner tube heat exchanger. The Nu obtained in case of finned inner tube heat exchanger is higher than plain tube in tube heat exchanger (Dittus Boelter Equation). The percentage enhancement in case of finned inner tube is around 100 % than that of plain tube heat exchanger.

Index Terms- Heat exchanger; heat transfer coefficient; Coefficient of Performance; Nusselt number.

1. INTRODUCTION

The heat exchanger is widely used equipment in various industries such as process, power generation, petroleum refining, chemicals and paper. Energy and material saving considerations as well as environmental challenges in the industry have stimulated the demand for high efficiency heat exchanger. To improve the efficiency of heat exchanger one must think of heat transfer enhancement in heat exchanger. Moreover heat transfer enhancement enables the size of heat exchanger to be considerably decreased. The enhancement techniques are divided into three groups as active, passive and compound techniques. Active methods involve complexity in design. Passive methods lead to drop in fluid pressure. Compound methods are hybrid methods in which both active and passive methods are used in combination.

The heat exchanger industry has been striving for improved thermal contact and reduced pumping power in order to improve the thermo hydraulic efficiency of heat exchangers. In the proposed work, compound technique which minimizes pressure drop of passive method and reduces the complexity of active method is considered. The concentric tubes with this compound technique give arrangement of screw heat exchanger. The arrangement is studied for heat transfer characteristics and enhancement for non-Newtonian fluids. It is essential because of growing technological applications of non-Newtonian fluid. In many chemical and processing industries, the products such as polymer, The experiments are carried out by using two different fluids at outer tube side as hot fluid viz. water and Glycerol. The secondary fluid flowing through inner tube as cold fluid is water in both cases.

2. THE VARIOUS HEAT TRANSFER ENHANCEMENT METHODS

Methods of heat transfer can be classified as active,passive, and compound.

i. Active enhancement techniques

ii. Passive enhancement techniques

iii. Compound enhancement techniques

2.1Active enhancement techniques:

The active methods are more effective than the passive methods but still rarely used due to complicated design. Different active enhancement techniques are available for different applications. Descriptions for the various active techniques have been given below

i. Mechanical aids are those that mix the fluid by mechanical means or by rotating the surface. These methods enhance the heat transfer rate by 100 to 400 % than the system without enhancement technique. The more prominent examples include rotating tube heat exchangers and scraped-surface heat and mass exchangers. It is widely used with the high viscous fluids.

ii. Surface vibration has been applied primarily at either low or high frequency in single-phase flows to obtain higher convective heat transfer coefficients.

iii. Fluid vibration or fluid pulsation, with vibrations ranging from 1.0 Hz to ultrasound (~1.0 MHz), used primarily in single-phase flows. It is considered to be the most practical type of vibration enhancement technique.

iv. Electrostatic fields, which could be in the form of electric or magnetic fields or a combination of the two, from DC or AC sources, can be applied in heat exchange systems. It is applicable only when the working fluids in heat exchanger are dielectric fluids. Depending on the application, they can promote greater bulk fluid mixing and induce forced convection (corona "wind") or electromagnetic pumping to enhance heat transfer.

2.2 Compound enhancement techniques:

Some examples of promising compound enhancement techniques for varied practical applications are given below [1, 2].

i. Passive techniques applied in rotating tubes and ducts
ii. Dimpled tube fitted with a twisted tape swirl generator
iii. Converging-diverging tube with evenly spaced twisted-tapes
iv. Helical fins on outer surface of inner tube with some vortex generators
v. Corrugated (rough) tube with a hydrophobic coating (treated surface) to promote drop wise condensation of steam
vi. Application of Electro hydrodynamic (EHD) fields in pool boiling of refrigerant R-134a from micro finned and treated tubes
vii. Single-phase mass transfer enhancement in grooved (finned) channel with flow pulsations, and heat transfer in an acoustically excited flow field over a rough cylinder
viii. Gas–solid suspension flows in an electric field
ix. Fluidized-bed heat transfer with airflow pulsations and across finned tubes
x. Surfactant additive for seawater evaporation in spirally corrugated or doubly fluted (rough surface) tubes

2.3 Passive enhancement techniques

The descriptions of passive techniques are as follows.

i. Extended surfaces are more commonly also referred to as finned surfaces. These surfaces provide an effective heat transfer surface area enlargement. Plain fins have been used regularly in many heat exchangers. The newer developments, however, have led to modified finned surfaces which tend to improve the heat transfer coefficients by disturbing the flow field in addition to increasing the surface area. Sometime the extended surfaces are provided with smaller vortex generators.

ii. Swirl flow devices produce swirl or secondary recirculation in the flow through a tube. They include twisted tape or screw-type tube inserts, twisted ducts, and various forms of shape which are tangential to axial direction of flow. These methods can be used for single-phase as well as two-phase flows.

iii. Rough surfaces are generally surface modifications. These alternations promote turbulence in the flow field, primarily in single-phase flows. They do not increase the heat transfer surface area. Their geometric features range from random sand-grain roughness to discrete three-dimensional surface protuberances, micro fins on surface etc.

iv. Coiled tubes are curved tube what the name implies. They lead to relatively more compact heat exchangers. They are widely used in the chemical industries. The tube curvature due to coiling produces secondary flows or Dean vortices, which promote higher heat transfer coefficients in single-phase flows as well as in most regions of boiling.

3. PROCUDURE OF EXPERINMENT:

i. Heaters are switched 'ON' and water is heated for nearly 4 hours to get desired temperature. (In case of Glycerol as hot fluid, heating time is nearly 2 hours as temperature required is less than water).

ii. The valve at cold water inlet is opened. So that water flow in secondary circuit is started. The flow rate is adjusted to desired level by controlling valve opening and value is measured through rotameter.

iii. The valve at hot water inlet is opened and for water circulation the pump is switched 'ON'. The flow rate is adjusted to desired level by controlling valve opening and value is measured through rotameter. (For Glycerol circulation geared pump is started and flow is adjusted using bypass valve in case of Glycerol as hot fluid).

iv. The temperatures at four places viz. hot fluid inlet temperature, hot fluid outlet temperature, cold fluid inlet temperature and cold fluid outlet temperature are measured at regular intervals of 15 minutes for different outer fluid flow rates.

v. After noting each reading, the flow rate of hot fluid is changed using flow control valve positions. Such six readings are taken within decided Reynolds number range for first case.

vi. This experimentation is repeated for various speeds of D.C. motor viz. 0, 50, 100, 150 & 200. To change speed of motor control circuit is used.

Same procedure is repeated for non-Newtonian fluid. Here Glycerol is used as non-Newtonian fluid.

4. OBSERVATIONS:

i. Inner tube inner diameter in m = d_i =0.0214

ii. Inner tube outer diameter in m = d_o =0.0254

iii. Outer tube inner diameter in m = D_i =0.0680

iv. Outer tube outer diameter in m = D_o =0.0750

v. Length of heat exchanger in m = L = 0.970

vi. Thickness of inner tube in m = t_t

$$t_t = \frac{(d_o - d_i)}{2} = 0.002$$

viii. Thermal conductivity of inner tube material in W/m-K = k_t = 380

ix. Pitch of spiral fins in m = P_{fin} = 0.017

x. Thickness of fin in m = t = 0.001

xi. Height of the fin in m = h_{fin} = 0.016

4.1 OBSERVATION TABLE

4.2 Experimental data analysis:

Assumptions made for analysis are:

i. Fin efficiency is assumed 50 % as there is no mechanical contact between tube surface and fins.

ii. Losses in pipe connections are assumed negligible.

4.3 Calculation from the observations:

i. Temperature difference at one end for the counter flow arrangement (^oC),

$\theta_1 = T_{hi} - T_{co}$

ii. Temperature difference at other end for the counter flow arrangement (^oC),

θ2 = Tho - Tci

iii. Log Mean temperature difference (LMTD) in ^oC is given by

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

iv. Mean bulk temperature for outer side fluid in ^oC is

$$= \frac{(T_{hi} + T_{ho})}{2}$$

v. Mean bulk temperature for inner side fluid in ^oC is

$$= \frac{(T_{ci} + T_{co})}{2}$$

vi. Discharge through outer tube in m^3/s

$$Q_h = \frac{Q_{h(in\ LPH)}}{(1000 \times 3600)}$$

4.4 Properties of fluid at mean temperatures:

The following properties of the outer and inner fluids at respective mean bulk temperature are required.

i. Density of fluid = ρ in Kg/m^3

ii. Specific heat of the fluid = C_p in J/Kg K

iii. Dynamic viscosity of the fluid = μ in Ns/m^2

iv. Thermal conductivity of fluid = k in W/m K (4.1)

5. RESULTS AND DISCUSSIONS

Experiments were conducted to study the effect of following parameters:

i) Variation of flow rate between 228 LPH to 855 LPH.

ii) Variation of speed of rotation of inner tube from 0 RPM to 200 RPM.

Result are compared with the theoretical results obtained by using Dittus Boelter Equation which is applied for plain tube in tube heat exchanger. Two fluids are used for experimentation viz. water and Glycerol.

Obs. No.	Outer Fluid Temperature		Inner Fluid Temperature		Outer tube discharge Q_h (LPH)	Inner tube discharge Q_c (LPH)	h (m of CCl_4)
	Thi	Tho	Tci	Tco			
1	59.9	49.2	27.5	31.1	228	750	0.007
2	58.9	50.7	26.9	30.4	360	750	0.008
3	58.5	51.9	26.3	30.2	480	750	0.016
4	57.3	51.9	26.0	29.9	600	750	0.022
5	56.5	52.1	26.3	30.2	750	750	0.032
6	55.5	51.5	25.8	29.9	855	750	0.045

6. CONCLUSIONS

From the number of experiments carried out and calculated values following conclusions are made.

i. When water is used as hot fluid, there is increase of around 100.25 % in value of Nusselt number for finned tube when compared with the one obtained from Dittus Boelter equation (which is for plain double pipe heat exchanger).

ii. Nusselt number value increases by 4.7 % for rotating finned tube (at 50 RPM) when compared to stationary finned tube.

iii. As speed of rotation of inner tube increases, Nusselt number increases for same Reynolds number.

iv. Pressure drop minimises by 11.3 % as speed of rotation increases.

v. When Glycerol is used as hot fluid, value of Nusselt number is 8 times higher for finned tube when compared with the one obtained from Dittus Boelter equation (which is for plain double pipe heat exchanger).

vi. Nusselt number increases by 26.9 % for rotating finned tube (at 50 RPM) when compared to stationary finned tube.

vii. Nusselt number increases if speed of rotation of inner tube is increased for same Reynolds number.

viii. Pressure drop gets minimised by 37.7 % as speed of rotation is increased.

7. FUTURE SCOPE

i. To maintain constant fluid temperature inside tank continuous stirring can be used.

ii. Comparison of heat transfer behaviour can be done by changing fin pitch and fin height.

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