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CFD Based Evaluation Of Effectiveness Of Counter Flow Heat Exchanger

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Abstract
Engineers are continually being asked to improve effectiveness of heat transfer equipments. These requests may arise as a result of the need to increase profitability or accommodate capital limitations. Processes which use heat transfer equipment i.e. heat exchanger must frequently be improved for these reasons. Artifical roughness is important technique for enhancing the effectiveness of heat exchanger. In this work effectiveness of smooth as well as roughened tube in heat exchanger is theoretically investigated by using ring type roughness geometry. The performance obtained is then compared with smooth tube. Ringed tube has a significant effect on effectiveness of heat exchanger. The effectiveness is 3.2 times as compared with plane tube was reported. The effectiveness found to be increased with increasing roughness and decreasing pitch between the rings.
Keywords*- Heat exchanger, Effectiveness, CFD, Relative roughness.*

NOMECLATURE

A	Cross sectional area, m^2
C_p	Specific heat of water, kJ/kg K
D	Diameter of inner tube, m
e	Height of roughness element, m
e/D	Relative roughness height(dimensionless)
L	Length of test section, m
$\dot{m}$	Mass flow rate, kg/s
p	Pitch of roughness element, m
p/D	Relative roughness pitch (dimensionless)
q	Heat transfer rate, KJ/s
Re	Reynolds number (dimensionless)
T_{hi}	Hot water temperature at inlet, °K
T_{ho}	Hot water temperature at outlet, °K
T_{ci}	Cold water temperature at inlet, °K
T_{co}	Cold water temperature at outlet, °K
V	Velocity of water, ms^{-1}
Greek letters	
ρ	Density of water, kg m^{-2}
ε	Effectiveness of heat exchanger,%
μ	Dynamic viscosity of water, $kg/s^{-1}m^{-1}$

I. INTRODUCTION

Heat transfer enhancement techniques are frequently using in heat exchanger systems in order to enhance heat transfer rate and to increase its thermal performance. Heat transfer enhancement techniques are divided into two categories active method and passive method. In active method heat transfer is improved by supplying extra energy to fluids and to its equipment's by use of mechanical auxiliary elements i.e. rotating the surface, mixing fluid with mechanical accessories and constituting electrostatic in flow area. In passive method heat transfer is improved by without any external energy and including rough surfaces, extended surfaces and coated surfaces. Among them coiled wire or twisted tape inserts in swirl flow are most commonly used in order to enhance heat transfer rate. The coiled wire or twisted tape causes redevelopment of boundary layer and increase the heat transfer surface area by increasing turbulence. Numerous researches have been carried out concerning effect of coiled wire, twisted tape, dimpled tubes, sand grain roughness etc. Taji et al. investigated heat transfer characteristics and friction factor of horizontal double pipe heat exchanger with coil wire inserts made up of different materials. Effect of coil wire inside a horizontal tube is studied by Garcia et al. in laminar, transition and turbulent region with different pitch and wire diameter. Heat transfer and friction correlations are developed by Webb R.L et al. for turbulent flow in tubes having a repeated-rib roughness.

CFD based theoretically evaluation of heat exchanger effectiveness with plane tube and roughened tube has been carried out in this work by inserting ringed type tubes in wall of inner tube of heat exchanger.

II. METHODOLOGY

The system consists of a counter flow heat exchanger of stainless steel with smooth tube and ringed tube shown in Fig. 1. The external surfaces of heat exchanger are properly insulated. Flow rate in both channels was adjusted to maintain same Reynolds number. The effectiveness of heat exchanger was calculated on the basis of temperature drop. Solidworks flow simulation 2013 tool was used in investigation.

Following assumptions has been used:

1. The fluids are in steady state conditions.

2. Fluids do not undergo any phase change.
3. No slip boundary conditions in solid, fluid interface.
4. Viscous and external heat transfer is neglected.
5. Thermo physical properties are constant.

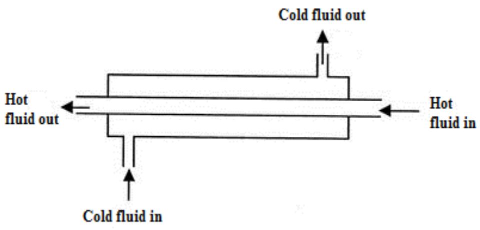

Fig. 1. Counter flow heat exchanger

Boundary conditions:
Inlet temperature of cold fluid
298K
Inlet temperatures of hot fluid
348K
Internal diameter of inner tube (di)
0.017 m
Outer diameter of inner tube (do)
0.0214 m
Internal diameter of outer tube (Di)
0.042 m
Pitch (in mm)
10,20,30,40,50
Length
1.5m

Table 1: The range/value of operating parameters

S No.	Operating parameter	Range/value
1.	Reynold number (Re)	3000-20,000
2.	Relative roughness height (e/D)	0.029-0.117
3.	Relative roughness pitch (p/D)	0.588-2.94
4.	Mass flow rate (□)	0.016-0.1 kg/s
5.	Temperature of hot water (^{o}K)	348 ^{o}K
6.	Temperature of cold water(^{o}K)	298 ^{o}K

III. DATA REDUCTION

In this work, effectiveness and heat transfer rate was calculated by using the following equation:

$$\varepsilon = \frac{q}{q_{\max}} \quad (1)$$

$$q_{\max} = c_{\min}(T_{hi} - T_{ci}) \quad (2)$$

$$q = m_c C_{pc}(T_{hi} - T_{co}) = m_c C_{ph}(T_{co} - T_{ci}) \quad (3)$$

$$q_c = m_c C_{pc}(T_{co} - T_{ci}) \quad (4)$$

$$q_h = m_h C_{ph}(T_{ho} - T_{hi}) \quad (5)$$

IV. RESULT AND DISCUSSION

Results obtained w.r.t. in analyzing the effect of relative roughness height (e/D), Effectiveness, Relative relevant pitch (p/D), Mass flow rate and Reynolds number under the said theoretical study have been presented.

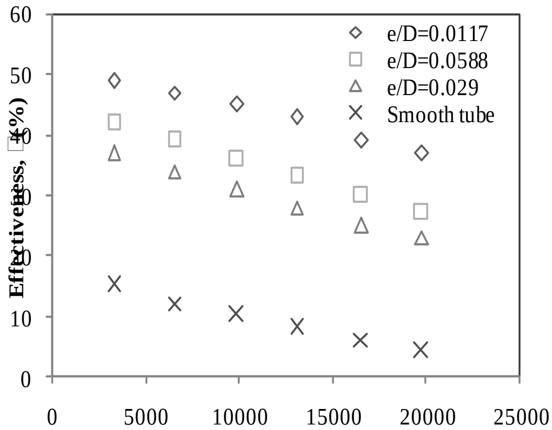

Fig. 2: Variation of effectiveness as a function of Reynolds no. for range of relative roughness height (e/D).

Fig. 2 shows the variation of effectiveness as a function of Reynolds number of smooth and roughened tube. It can be seen that effectiveness increases monotonously with decrease in mass flow rate of water for smooth as well as roughened tube. It can be seen that effectiveness for the tube fitted with coil wire insert are higher than that of plain tube for given Reynolds number.

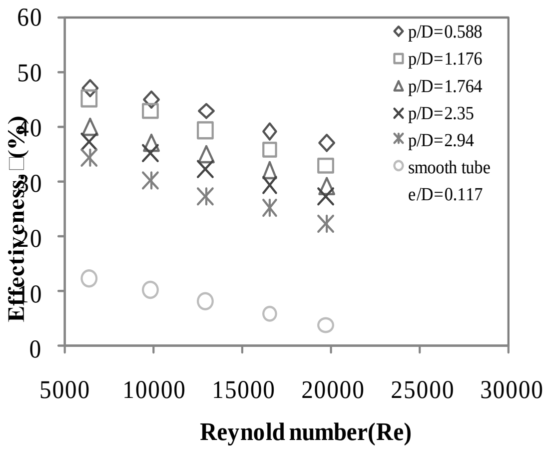

Fig. 3: Variation of effectiveness as a function of Reynolds number.

Fig. 3 shows the variation of effectiveness as a function of Reynolds number of water for smooth and roughened tube for range of relative roughness pitch (p/D) at fixed relative relevant roughness (e/D) of 0.117.

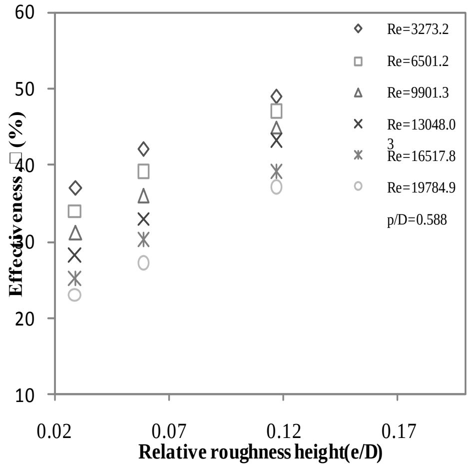

Fig. 4: Variation of effectiveness as a function of mass flow rate for range of relative roughness height (e/D).

Fig. 4 shows the variation of effectiveness as a function of Reynolds number of relative roughness height (e/D) in range of 0.029 -0.117.

Fig. 5 shows the effectiveness for roughened tube is considerably higher as compared to smooth tube.

Fig. 6 shows the variation of effectiveness as a function of relative relevant pitch (p/D) for range of Reynolds number and relative relevant roughness (e/D) is kept fixed at 0.117.

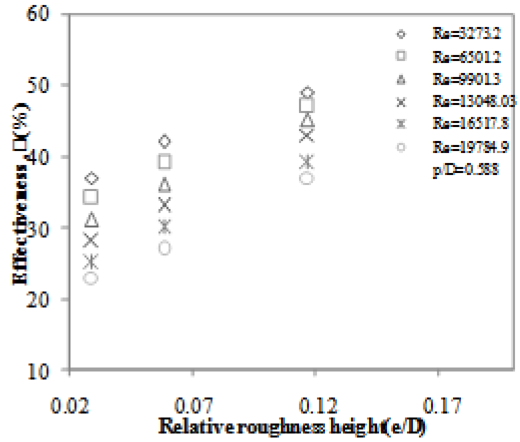

Fig. 5: Variation of effectiveness as a function of relative relevant height (e/D).

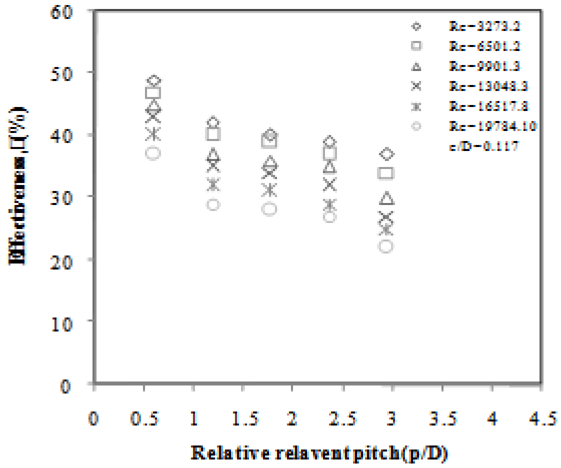

Fig. 6: Variation of effectiveness as a function of relative relevant pitch (p/D).

V. CONCLUSION

Numerical simulation of counter flow heat exchanger using computational fluid dynamics (CFD) is a very representative. This study offers a good understanding of temperature distribution and fluid flow under turbulent conditions for the range of Reynolds number. Effectiveness increases for the roughened tube as compared to that of the smooth tube.

- The effectiveness increases monotonously with decrease in mass flow rate of water for smooth as well as roughened tube. It can be observed that enhancement in effectiveness is considerably large at lower values of flow rate of water.
- Effectiveness increases with decrease in reynolds number of water for smooth as well roughened tube. It has been observed that effectiveness increases with decrease of reynolds number.
- The effectiveness increases with increase in relative roughness height (e/D) at fixed relative relevant pitch (p/D).
- The effectiveness increases at lesser value of pitch .i.e., at 10 mm is higher due to increase in number of rings which increases the turbulence in the region.

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