Thermal Performance Ratio of Finned Tube Heat Exchanger with Wire Coil Inserts for Flow of Fe₃O₄-water Nanofluid

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ABSTRACT

This article reports an experimental study of forced convective heat transfer between hot water and Fe₃O₄ – water nanofluid in finned tube counter flow heat exchanger with wire coil inserts. The convective heat transfer rate, friction factor and thermal performance ratio are investigated for the flow of 0.4 % vol. Fe₃O₄ – water nanofluid in a tube with eight internal longitudinal fins under turbulent flow (7000 < Re < 49200) with the wire coil inserts of 2 mm, 6 mm and 12 mm pitch. Results indicate that the thermal performance ratio is higher for the wire coil insertion of 2 mm pitch compared to the finned tube without insert. Maximum Thermal performance ratios are 1.58, 1.15 and 1.13 for wire coil inserts with 2 mm, 6 mm and 12 mm pitch respectively at nanofluid flow rate of 10 LPM.

KEYWORDS

Enhancement, finned tube, nanofluid, wire coil, thermal performance ratio

INTRODUCTION

Heat exchangers find many applications and play an important role in industrial processes. Design of heat exchangers for heat transfer enhancement by using augmentation approach is having an increased impact on process industries. Apart from active and passive heat transfer augmentation methods, compound heat transfer methods rapidly growing applications in various industries due to higher heat transfer surface area and increased turbulence of fluid flow. Rajesh Babu et al.[1] performed the numerical simulation on tubes with three-row finned tube passes using helically wound fin geometries of partially serrated finned tubes are investigated. A k-ε turbulence model is employed to examine the effect of Reynolds number in the range of 8000 to 20000. The effect of a number of serrated segmented finned tubes per period on the performance of heat transfer enhancement is also investigated. Garcia et al. [2] performed the experiments on tubes with wire coil inserts with varied pitch and studied their effect on heat transfer and pressure drop.


In the present study, longitudinal internal fins are introduced on the inner pipe of double pipe heat exchanger (finned tube heat exchanger) to increase the heat transfer rate due to increase in effective heat transfer surface area. Compound heat transfer enhancement method is adopted by inserting wire coil in the finned tube heat exchanger along with the flow of Fe$_3$O$_4$-water nanofluid. It is evident that the heat transfer is higher in finned tube heat exchanger due to increase in area and the wire coil inserts also collectively contributes to the enhancement in heat transfer. Friction factor and pressure drop are very much higher due to the presence of fins and wire coil inserts which offers more resistance for the flow and also depends on the viscosity of working fluid. The major concern is the possibility of increased pressure drop along with heat transfer enhancement due to the adoption of augmentation method. The justifying parameter to adopt any enhancement method is thermal performance ratio (TPR) which compares the heat transfer and pressure drop with plain tube. The objective of the present study is to estimate the thermal performance ratio (TPR) of finned tube heat exchanger of eight internal longitudinal fins with wire coil inserts for the flow of 0.4 % vol. Fe$_3$O$_4$-water nanofluid at different volume flow rates of nanofluid.

**EXPERIMENTAL SETUP**

The experimental setup consists of double tube heat exchanger of 1.6 m long with inner tube of 26 mm inner diameter and 32 mm outer diameter with eight longitudinal internal fins of 2 mm thick and 4 mm width on the inner side of 26 mm inner diameter pipe (Fig. 1.a). The outer tube is of 50 mm inner diameter and 58 mm outer diameter and insulated with asbestos to minimize heat loss to the surroundings. The inlet and outlet bulk fluid temperatures are measured by resistance temperature detector. Pressure gauges are inserted into the inlet and outlet sections of the finned tube. Hot water at constant inlet temperature is circulated by using hot water pump through the annular space at constant flow rate. Fe$_3$O$_4$-water nanofluid is cooled by using cooling unit to recirculate through the finned tube heat exchanger. J-type thermocouples are used to measure the fluid temperatures in storage tanks. Copper wire of 2 mm diameter(d) is used as a coil with pitch of 2 mm(d), 6 mm(3d) and 12 mm (6d) (Figure 1. b) for the insertion into the finned tube.

![Figure 1. (a) Schematic diagram of experimental setup.](image-url)
**Figure 1.** (b) Copper wire coil with pitch of 2 mm(d), 6 mm(3d), 12 mm(6d).

DATA REDUCTION

\[ Q_{h} = m_{h} c_{p, h}(T_{hi} - T_{ho}) \]  
\[ Q_{c} = m_{c} c_{p, c}(T_{co} - T_{ci}) \]  
\[ Q_{ave} = \frac{Q_{hotfluid} + Q_{coldfluid}}{2} \]  
\[ LMTD = \frac{(T_{hi} - T_{ho}) - (T_{ho} - T_{ci})}{\ln \left( \frac{T_{hi} - T_{ho}}{T_{ho} - T_{ci}} \right)} \]  
\[ \rho_{eff} = \rho_{b} \left(1 - \varphi_{np} \right) + \rho_{np} \varphi_{np} \]  
\[ k_{eff} = \frac{k_{b}(k_{np} + 2k_{b} - 2\varphi_{np}(k_{b} - k_{np}))}{k_{np} + 2k_{b} + \varphi_{np}(k_{b} - k_{np})} \] (Maxwell model)  
\[ c_{p,eff} = \frac{(1-\varphi_{np})\rho_{b} c_{p,b} + \varphi_{np} \rho_{np} c_{p,np}}{\rho_{eff}} \] (Thermal equilibrium model)  
\[ \mu_{eff} = (1 + 2.5\varphi_{np})\mu_{b} \] (Einstein model)  

Reynolds number, \( R_{e,Dh} = \frac{\rho v D_{h}}{\mu} \)  

Prandtl number, \( Pr = \frac{\mu c_{p}}{\kappa} \)  

Stanton number, \( St = \frac{Nu}{R_{e} \times Pr} \)  

\[ f = \frac{\Delta P_{ex}}{\left( \frac{D_{h}}{2} \right)^{2} \rho v^{2}} \]  

\[ TPR = \frac{(UA)_{finned}(f)}{(UA)_{plain}(p)} = \frac{1 + \beta_{f}}{St_{p}\left[ f_{r_{p}} \right]^{-1/2} P_{r}^{-1/2} \left[ \frac{A_{g}}{A_{p}} \right]^{1/2}} + \beta_{f} \]  

RESULTS AND DISCUSSIONS

Fig. 2 shows variation of heat transfer rate with flow rate of 0.4 vol. % Fe_{3}O_{4}-water nanofluid. It is observed that, for the given type of coil insert, heat transfer rate increases with flow rate. Wire coil insert of 2 mm pitch
yields higher value of heat transfer rate compared to the insert of 6 mm & 12 mm pitch. The comparison of friction factors for the flow of 0.4 vol. % Fe₃O₄-water nanofluid through the finned tube with and without presence of wire coil inserts is shown Fig. 3. It is observed that the friction factors are higher for the wire coil inserts compared to the case of without inserts at all volume flow rates. The maximum pressure drop takes place for the wire coil insert of 2 mm pitch and friction factor is 81% higher compared to the friction factor of finned tube without insert. Thermal performance ratio is increased up to certain volume flow rate and then decreased for the studied cases of wire coil inserts as shown in Fig. 4.

**Figure 2.** Variation of heat transfer rate with flow rate of 0.4 vol. % Fe₃O₄-water nanofluid

**Figure 3.** Comparison of friction factors for the flow of 0.4 vol. % Fe₃O₄-water nanofluid
CONCLUSIONS

Maximum increase in heat transfer rate with wire coil inserts to that of without inserts in eight finned tube heat exchangers is 15.67 %, 10.18 % and 4.55 % for 2 mm, 6 mm and 12 mm pitch of wire coil respectively for the flow of 0.4 vol.% Fe₃O₄-water nanofluid at 6 LPM. The maximum pressure drop takes place for wire coil insert of 2 mm pitch in eight-fin tube and friction factor is 81 % higher compared to the eight-fin tube without insert for the flow of 0.4 vol.% Fe₃O₄-water nanofluid. The maximum pressure drops and higher friction factor with coil insert of 2 mm pitch is due to increased obstruction to the flow and higher area of surface contact of flowing fluid.

REFERENCES


