Computational Analysis of a Double Pipe Heat Exchanger with and without Inserts

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Abstract. The article presents the computational study of a double pipe heat exchanger (DPHEX) with and without inserts in both co-current and counter-current configurations with hot air as the fluid in the inner pipe and cold air as the fluid in the annulus. The velocity of hot air was maintained constant at 4.5 m/s and the that of cold air was varied between 2.7 and 6.6 m/s. The hot air was maintained at 90°C in the inlet and that of cold fluid at 32°C in the inlet. Two different inserts were placed in the annulus and their impact on the heat transfer rate, effectiveness and other performance parameters were compared with that of a DPHEX without inserts. The heat transfer rate of DPHEX with continuous insert was found to improve by about 16% than the DPHEX without insert, and about 3 % than the DPHEX with discontinuous insert.

Keywords: double pipe; inserts; heat transfer enhancement; effectiveness; heat transfer rate.

1 Introduction

The DPHEXs find their applications in many chemical, food and air-conditioning sectors. It is a constant endeavour of the scientific community to enhance heat transfer rate in heat exchangers. The general heat transfer enhancement techniques are to use fins or dimples by increasing the heat transfer area or using turbulators or vortex generators to induce turbulence in the flow for better mixing resulting in increased heat transfer rate. Twisted tapes or inserts are one such way of enhancing heat transfer rate.

[1] Sarma et al in their article have highlighted the fact that the rigorous cross mixing of fluid owing to the radially outward directed motion of the particles resulting from the tape twist is the main reason for heat transfer enhancement. The authors have pointed out that the use of twisted tapes generates turbulence to proportions which are higher than that expected in a normal turbulent regime. Further, they have argued that the internal flow, even when Re < 2300, with the use of a twisted tape has to be treated as a pseudo-laminar regime instead of a

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laminar regime. The enhancement of turbulence by the twisted tapes leading to increased heat transfer rates has been stressed by the authors.

[2] Poornodaya et al in their numerical analysis have used twisted tapes with cuts to induce turbulence in the flow and thereby increase the rate of mixing eventually increasing heat transfer rate. The effect of these cut twisted tapes on heat transfer rate and friction factor has been presented along with the optimal values of geometric factors of the twisted tapes and mass flow rates. The authors attributed the increased heat transfer rate to the swirl flow and the recirculation generated by the cut portion of the tapes. The turbulence induced by this geometry has enhanced the heat transfer rate but also with an increase in friction factor.

[3] Rishabh et al in their article have presented a comparison of the performance of DPHEX with a plain twisted tape, triangular perforated twisted tape and without twisted tape computationally. Their study revealed about 1.5 times increase in heat transfer rate for the DPHEX with triangular perforated twisted tape than that with plain twisted tape. However, the authors have also reported about 5.4 times increase in friction factor for the DPHEX with triangular perforated twisted tape than that with plain twisted tape. The flow through the perforations in the twisted tape further increases both heat transfer and pressure drop.

[4] Sivakumar and Rajan have performed experiments of a DPHEX with and without twisted tapes. The authors report about 10% raise in heat transfer rate in DPHEX with twisted tape than that without twisted tape.

[5] Smith et al in their experimental study have used twisted tape inserts of different types by varying the pattern in which the twist ratio is varied. Their study reveals that the heat transfer rate is directly related to the pattern in which the twist ratio is varied in the tape. The periodic increasing and decreasing twist ratios and the intermittently oscillating twist ratio patterns were found to cause more mixing resulting in increased heat transfer rate.

Though twisted tapes induce turbulence and result in increased heat transfer rate, the process of manufacturing the same is tedious and costly. In this article, a coil spring is used as an insert in the annulus in two different configurations. In the first configuration, insert-1, the coil spring is placed in the annulus as a single continuous insert. In the second configuration, insert-2, the coil spring is split into three equal halves and placed at equal intervals from each other in the annulus. The computational results of the DPHEX with insert-1, insert-2 and without inserts are presented in this article.

2 CFD Studies

A CFD study was conducted using Ansys-Fluent for the DPHEX with and without the inserts mentioned above. A transient 3D modelling was used to analyse the system. The solid models of DPHEX with and without inserts were generated using the Geometry Modeller of Ansys and the same is depicted in Figures 1 to 3. The specifications of the outer pipe, inner pipe and inserts are given in Table 1.

Table 1 Specification

Length of outer pipe	1350 mm
OD of outer pipe	39.8 mm

ID of outer pipe	35.5 mm
Length of inner pipe	1540 mm
OD of inner pipe	16 mm
ID of inner pipe	13.7 qmm
Pitch of insert-1 & insert-2	20 mm
Number of revolutions of insert-1	50
Diameters of insert-1 & insert-2	32.8 mm
Free length of insert-1	990 mm
Number of revolutions of insert-2	10
Free length of insert-2	198 mm

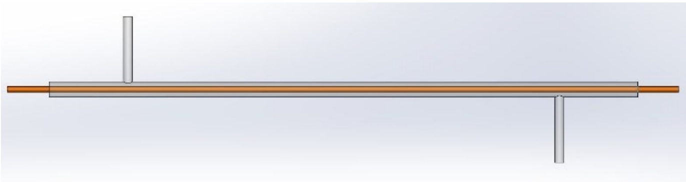

Fig. 1 Solid Model of DPHEX

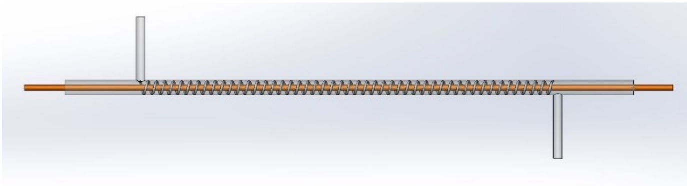

Fig. 2 Solid Model of DPHEX with insert-1

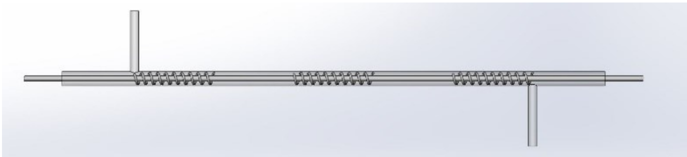

Fig. 3 Solid Model of DPHEX with insert-2

Finer meshing was done with triangular elements for the annulus and polyhedral elements for the inner pipe and inserts.

The Navier-Stokes equations and conservation of energy were used to model the problem. The boundary conditions used in the study is given in Table 2.

Table 2 Boundary Conditions

Boundary Type	**Boundary Conditions**
Inner Pipe Inlet	Velocity Inlet
Inner Pipe Outlet	Pressure Outlet
Annulus Inlet	Velocity Inlet
Annulus Outlet	Pressure Outlet

Inserts	Adiabatic Walls

2.1 Evaluation of Parameters

The velocity of hot and cold air, temperature of hot and cold air at the inlet were taken as the input parameters. Performance parameters such as heat transfer rate, effectiveness, LMTD, overall heat transfer coefficient were evaluated for varied input parameters in both co-current and counter-current configurations.

Heat transfer rate expressed as heat gained by the cold air is estimated using equation (2) wherein $\dot{m}_s$ is the mass flow rate of cold air, c_{ps} is the specific heat, T_{so} is the temperature of cold fluid at the exit and T_{si} is the temperature of cold fluid at the inlet. Mass flow rate is determined using equation (1) wherein \rho is the density of air at the inlet, A is the area of cross section at the inlet and V is the velocity of air at the inlet.

$$\dot{m}_s = \rho AV \tag{1}$$

$$\dot{Q}_s = \dot{m}_s c_{ps}(T_{so} - T_{si}) \tag{2}$$

The effectiveness is calculated using equation (6) which is defined as the ratio of actual heat transfer to the maximum possible heat transfer. T_{ti} and T_{to} stands for the temperature of the hot air at the inlet and exit respectively. The expressions for LMTD in the co-current and counter -current arrangements are given by equations (4) and (5) respectively. The overall heat transfer coefficient is estimated using equation (7) from LMTD and the heat transfer area, A which is expressed in equation (8).

$$\dot{Q}_{max} = C_{min}(T_{ti} - T_{si}) \tag{3}$$

$$LMTD\ (parallel) = \frac{(T_{ti} - T_{si}) - (T_{to} - T_{so})}{ln\left[\frac{T_{ti} - T_{si}}{T_{to} - T_{so}}\right]} \tag{4}$$

$$LMTD\ (counter) = \frac{(T_{ti} - T_{so}) - (T_{to} - T_{si})}{ln\left[\frac{T_{ti} - T_{so}}{T_{to} - T_{si}}\right]} \tag{5}$$

$$\varepsilon = \frac{\dot{Q}_s}{\dot{Q}_{max}} \tag{6}$$

$$U = \frac{\dot{Q}_s}{A * LMTD} \tag{7}$$

$$A = \pi dl \tag{8}$$

3 Results and discussion

It is expected that the DPHEX with insert performs better than that without. The ensuing paragraphs discuss in detail on this. In addition, the question of which among the two inserts yield a superior performance is also answered. This has been done for both the co-current and counter-current configurations.

3.1 Heat Transfer Rate

Figure 4 depicts the variation of heat transfer rate for the co-current and counter-current configurations with and without inserts. It is a clear indication that the DPHEX with insert-1 in the counter-current arrangement fairs better than the DPHEX with insert-2 by almost 3.25% and about 16% higher than the DPHEX without inserts. Further, the DPHEX with insert-1 in the counter-current configuration registers a maximum of about 5.5% increased heat transfer rate than that in the co-current flow configuration. It is obvious from the results that the inserts which are continuous are found to generate a continuous disturbance or turbulence in the annulus which results in increased fluid-mixing and hence an enhancement in heat transfer rate.

3.2 Effectiveness

Figure 5 presents the variation of effectiveness with Reynolds number used in the cold fluid side. A closer observation of Figures 4 and 5 shows a similar trend in the variation of heat transfer rate and effectiveness. The effectiveness is the highest in case of the DPHEX with the continuous inserts. The effectiveness in the DPHEX with insert-1 in the counter-current configuration is about 15% higher than that of DPHEX with insert-2 and about 3.8% higher than that of DPHEX without inserts. The DPHEX with insert-1 in the counter-current arrangement registers a 6% increase in effectiveness than that of the DPHEX with insert-1 in the co-current configuration.

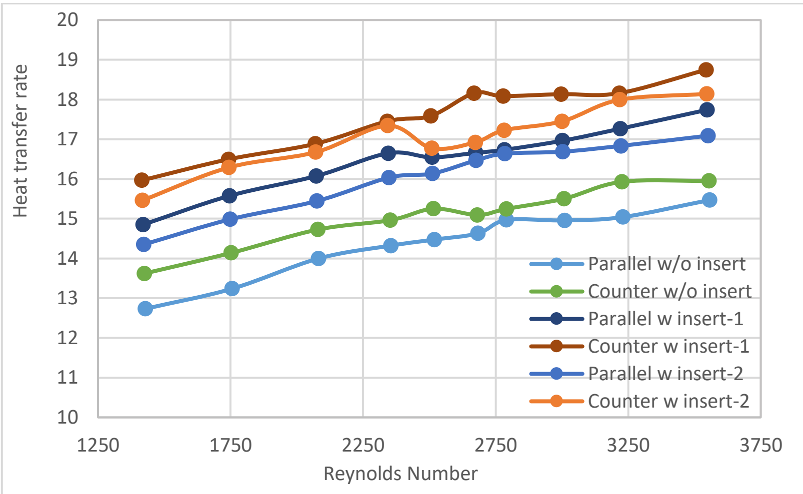

Fig. 4 Variation of Heat Transfer Rate

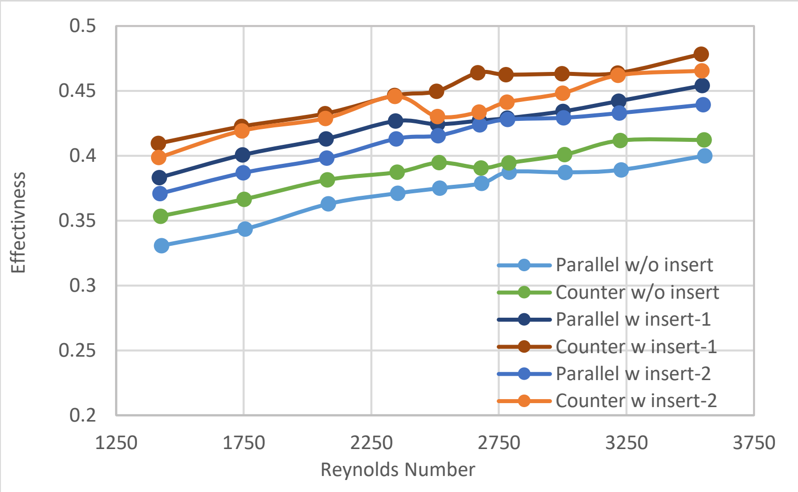

Fig. 5 Variation of Effectiveness

3.3 Logarithmic Mean Temperature Difference

The variation in LMTD for different Reynolds number is depicted in Figure 6. It is obvious that a higher LMTD would result in higher heat transfer rate. However, it can be seen from Figure 6, that the LMTD is found to be lower for the counter-current DPHEX configuration with insert-1 and lowest for the co-current configuration with insert-1. It is therefore essential to observe the variation of overall heat transfer coefficient. The lower values of LMTD could be compensated by a much higher increase in the overall heat transfer coefficient. Figure 6 records about 13% increase in the value of LMTD for the DPHEX without inserts when compared with that of DPHEX with insert-1 and about 7% increase when compared with that of DPHEX with insert-2.

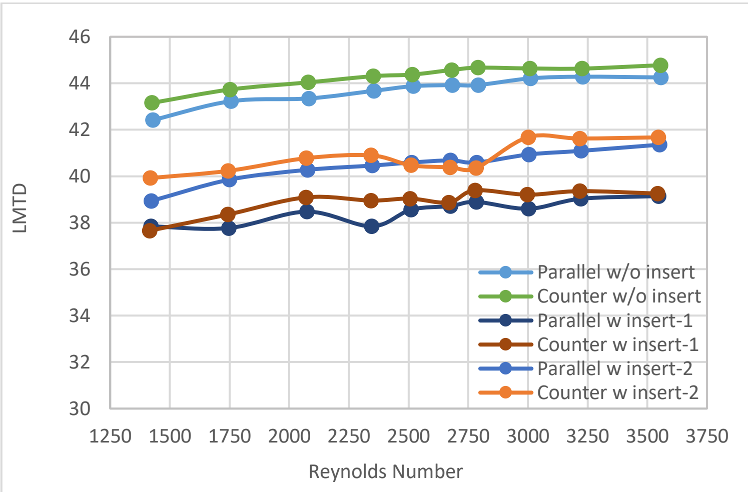

Fig. 6 Variation of LMTD

3.4 Overall Heat Transfer Coefficient

The variation of overall heat transfer coefficient for different Reynolds number is depicted in Figure 7. As pointed out in the previous section, it can be seen that the overall heat transfer coefficient is found to be maximum for the DPHEX with insert-1 when compared with the rest. Though the LMTD for DPHEX with insert-1 is 13% lesser than that of DPHEX without insert, the former registers a 29% increase in overall heat transfer coefficient than the later. The reduction in LMTD is superseded by the increase in overall heat transfer coefficient, proving it to be the effective configuration in enhancing heat transfer rate. Further, the DPHEX with insert-1 in the counter-current arrangement is found to record a 9.2% higher overall heat transfer coefficient than the DPHEX with insert-2 in the counter-current arrangement.

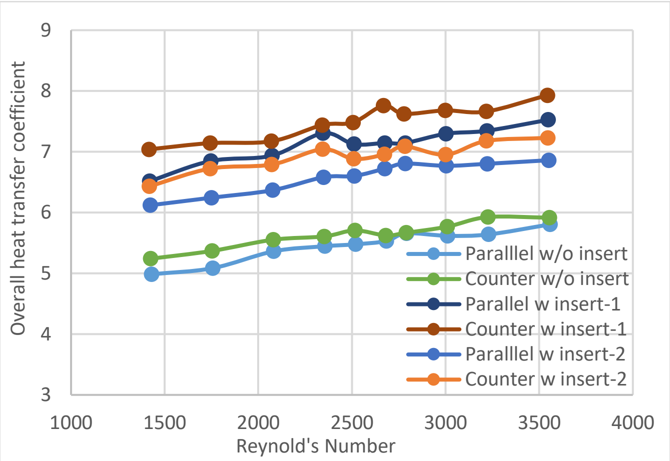

Fig. 7 Variation of Overall Heat Transfer Coefficient

3.5 Velocity Contours

The velocity contours from the computational analysis are portrayed in Figures 8 and 9. The Figure 8 shows the flow taking place past the insert-1 with the turbulence being created which would result in better mixing of the fluid in the annulus between the pipes. Better mixing can be attributed to the fact wherein the velocity range could be observed between 1.4 m/s and 2.1 m/s (in sky blue colour) throughout the length of insert-1. However, in Figure 9, the same sort of mixing can be seen only in regions where the velocity ranges between 1.5 m/s and 2.4 m/s (in sky blue colour), only in the regions wherein the inserts are placed. Further, lower velocities ranging from 0.7 to1.5 m/s could be seen in regions wherein no inserts are available in the annulus. This is a clear indication of the fact that the continuous insert in the annulus generates more turbulence, which in turn, results in better mixing and eventually an enhanced heat transfer rate.

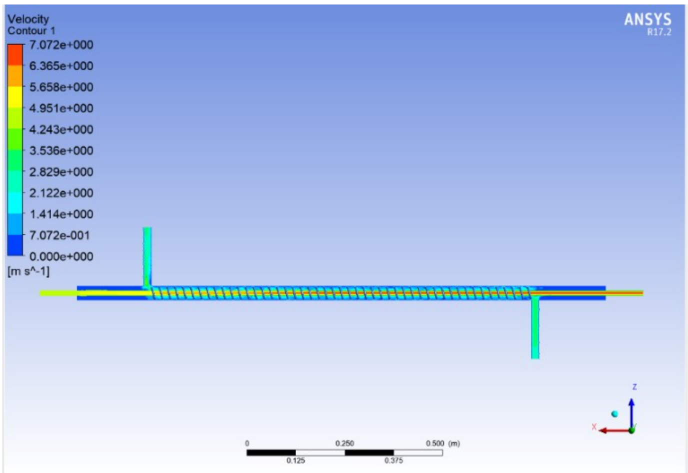

Fig. 8 Velocity Contour in DPHEX with insert-1

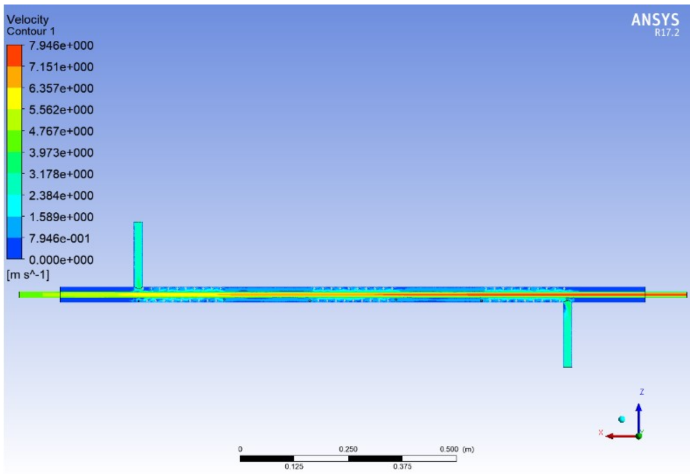

Fig. 9 Velocity Contour in DPHEX with insert-2

4 Conclusion

The study clearly reveals that the DPHEX with insert-1 is found to yield a higher heat transfer rate owing to the continuous disruptions which it caused to the flow in the annulus. Obviously, the DPHEX without inserts resulted in lesser heat transfer rate as it was deprived of heat transfer enhancements. The use of a coil spring as insert could avoid complex manufacturing processes as in case of other inserts with perforations. Further, the turbulence generated in lower Reynolds number increases mixing of fluid resulting in enhanced heat transfer rate.

Furthermore, this study can be extended to coil springs of different diameters and pitches.

5 References

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