Imperial Journal of Interdisciplinary Research (IJIR)
Vol-2, Issue-11, 2016
ISSN: 2454-1362, http://www.onlinejournal.in
Proceedings of RAASA'16" Chemnokrat-16"

Experimental Investigation on Heat Transfer Augmentation in Helical Coil Heat Exchanger Using Wire Coil/ Spring Inserts

Abhishek J K Thomas, Nikhil S Thomas, Bindeesh R C, Unaira P and K.B. Radhakrishnan*,
Dept. of Chemical engineering, TKM College of Engineering, Kollam
*drkbrnair20@gmail.com

Abstract: *Experiments have been carried out to evaluate the performance of heat transfer in helical coiled tube heat exchanger with wire coil inserts. Coiled wire of different pitches and same diameter were fabricated and used as tube inserts in copper helical coiled heat exchanger. The effect of pitch of the coil wire insert on the heat transfer were studied experimentally for different Reynolds numbers of the fluid inside the coiled tube ranging from 7000 to 28000. The experiments were performed with three different pitches. All the coils were having same cross sectional area. Further the heat transfer in helical coiled heat exchanger were simulated by varying the coil pitches and at different fluid using ANSYS FLUENT package 14.0 & 15.0. The experimental results showed that the use of wire coil inserts leads to a significant enhancement in heat transfer rate.*

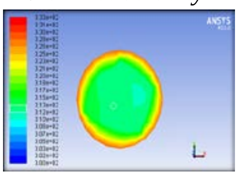
Key words: *Heat Transfer augmentation, Wire coil inserts, Helical coil*

INTRODUCTION

The conversion, utilization, and recovery of energy in industrial, commercial, and domestic application usually involve a heat transfer process. Improved heat exchange, over and above that in the usual or standard practice, can significantly improve the thermal efficiency in such applications as well as the economics of their design and operation. The need to increase the thermal performance of heat based equipment (for instance, heat exchangers), thereby effecting energy, material, and cost savings as well as a consequential mitigation of environmental degradation has led to the development and use of many heat transfer enhancement techniques. These methods are referred to as augmentation or intensification techniques. The conventional heat exchangers can be generally improved by means of various augmentation techniques. In general, the enhancement techniques can be divided into two main groups: active and passive techniques. The active techniques require external forces, e.g. electric field, acoustic, and surface vibration. The passive techniques require special surface geometries such as roughness surface, treated surface and extended surface or fluid additives. Coil wire insert consider one of passive techniques used to enhance heat transfer in helical coil heat exchanger. For decades, many of the wire coil devices employed for augmentation of laminar or turbulent flow heat transfer have been reported and discussed [1]. Analysis of coiled-tube heat exchangers to improve the heat transfer rate with spirally corrugated wall was investigated by Zachar [2]. Different geometrical parameters of helical corrugation on the outer surface of helically coiled-tube heat exchangers are examined to improve the inside heat transfer rate. A comparison of the thermal and hydraulic performances between twisted tape inserts and coiled wire inserts was introduced by Wang and Sunden [3] for both laminar and turbulent flow regions. They found that the coiled wire performs effectively in enhancing heat transfer in a turbulent flow region, whereas the twisted tape yields a poorer overall efficiency. Jafari Nasr et al [4] proposed an empirical correlation for heat transfer augmentation in a straight tube with coil inserts with Nusselt number in terms of Reynolds number, coil pitch, hydraulic diameter and diameter of the coil tube. The equation is applicable when 4200 < Re < 49000 and in the geometric range of helical pitch 0.156 < p/dh < 0.354 and wire diameter 0.027< e/dh < 0.094. The present study deals with the heat transfer augmentation in a helical coiled heat exchanger with spring inserts. The experimental results obtained in the present study were fitted in the correlation provided by Jafari Nasr et al [4] by bringing correction factor for the coil effect. A model was developed using ANSYSIS Fluent in coiled tubes with spring type of inserts and the effect of additional oscillations was attributed in the model by selecting the κ-ε model. The analysis of coil tube with and without wire coil inserts of constant pitch at various flow rates in ANSYS Fluent 14.0 & 15.0 were performed. Simulations were carried out by varying the velocity of the fluid and the effect of exit temperature of the coil fluid with and without tube inserts were analyzed. Appreciable enhancement in the outlet temperature of the fluid under the condition of no inserts and with inserts was observed. The analysis gave promising enhancement in heat transfer for coil tubes with spring inserts compared to that of the coil tubes without any inserts. The outlet temperature contours of the fluid are given below.

OUTLET TEMPERATURE CONTOURS

Fluid inlet velocity = 0.4 ms^{-1}



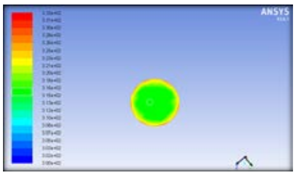
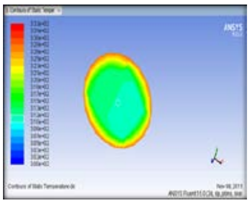


Fig. 1. Without coil insert Fig. 2. With wire coil insert

Fluid inlet velocity = 0.6 ms^{-1}



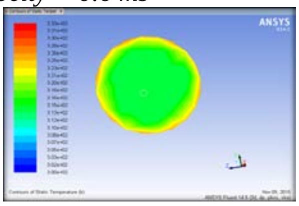
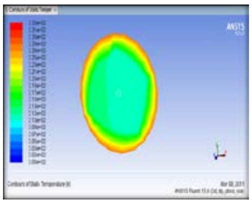


Fig. 3. Without coil insert. Fig 4. With coil insert

Inlet velocity = 0.8 ms^{-1}



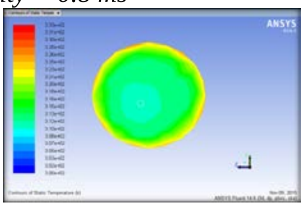
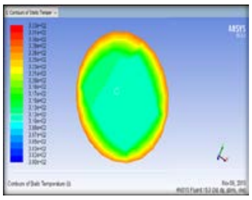


Fig 5: Without wire coil insert Fig. 6. With wire coil insert

Inlet velocity = 1 ms^{-1}



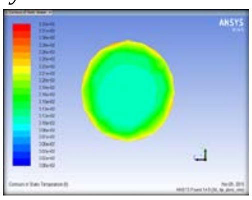


Fig. 7: Without coil insert Fig. 8: With wire coil insert

The temperature profiles for the coils with and without wire inserts are obtained and analyzed. Constant wall temperature of 333K was maintained in the coil tube walls and the inlet water temperature to be 300K. The fluid used for experiments is water and the helical coiled heat exchanger is constructed with copper.

From the temperature contours plots, it has been observed that the bulk mean temperature of the fluid outlet without wire inserts is 311K for an inlet velocity of 0.4m/s. Further it has been observed that in a small region the outlet water temperature is 309 K which is found to be increasing with increase in fluid velocity.

At the above flow rates, the average fluid temperature at the outlet has reached 316K with wire coil insert, and this remained at the same value in the entire cross section of the flow region. Almost the same kind of behavior is observed for the inlet fluid velocity was 0.6m/s.

EXPERIMENTAL SET UP

A test rig has been constructed in the laboratory for studying the effect of pitch of the coil wire inserts in a helical coiled heat exchanger on heat transfer at varying flow rates of the fluid in the coil.

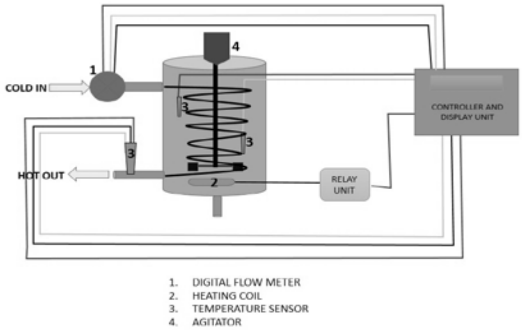
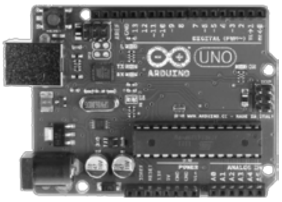


Figure 9. Test rig

The schematic representation is shown in the figure 9 above. A vessel made of SS 304 of capacity 20L was used for bath of immersing the helical coil having a tube inside diameter of 13 mm and outer diameter 15 mm. The diameter of the helix is 33 cm and is made of copper with a coil pitch of 4 cm and having 5 turns. The helical coil was cut into two halves and flared to join together so as to make the insertion of the wire coil inserts easier. This helped in the timely detachment and attachment of coil.

Sufficient quantity of water was taken in the vessel so that the helical coil assembly can be fully immersed in the water bath. The entire vessel was properly insulated with Styrofoam insulation and the temperature of the bath was maintained constant using rely type control. An agitator was provided to achieve uniform mixing of the fluid thus ensuring constant temperature of the fluid in the vessel. Two heaters of 1000 and 1500W were provided to the vessel for heating the water and the temperature of the bath was maintained at 60 ^{0}C during the experiment. The helical coil tube of outside 15 mm diameter and wall thickness 1.5 mm consisting of 5 turns was suspended from the top using an adjustable nut bolt mechanism. Sufficient spacing between the coil and heater was maintained. The coil Inlet and outlet were inserted through the top lid of the vessel and the coil was mounted upright by providing adequate support.

On board controller and sensors were used to measure the temperature of the bath, at the coil inlet and outlet. A Graphic User Interface (GUI) developed using Qt creator [5] recorded the temperatures. Arduino sketch [6] was used to implement the various sensor programs to the controller.



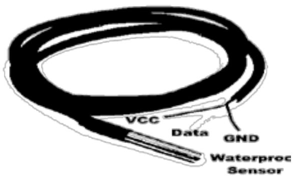


Fig 12: Arduino Controller [6] & Recorder#
Temperature Sensor DS18B20#

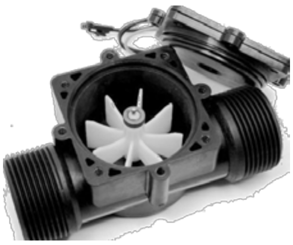


Fig 13: Flow Meter YF-S201#
Relay Unit #

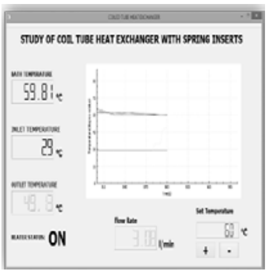


Fig 10: Helical Coil Tube Fig 11. Coil Tube user interface

Experiment

The equipment is operated with the bath temperature maintained at 60^0c. The heater is installed at the bottom of the vessel. The vessel is filled with sufficient amount of water so that the coil will be completely immersed. The micro controller is connected to the computer so that the current status of the test rig will be known. The three thermocouples provided at the respective locations will record the fluid inlet, outlet and bath temperatures. The measured variables are recorded and displayed in the GUI (Graphic User Interface) in the system.

Required flow rate is achieved by allowing fluid to pass through the inlet tube. The flow rate will be measured by the electronic turbine flow meter. The outlet temperature and the inlet temperature are noted on reaching the steady state condition. The experiment is repeated for different flow rates with and without spring inserts in the helical coil. The experiment was repeated with spring inserts of different pitches.

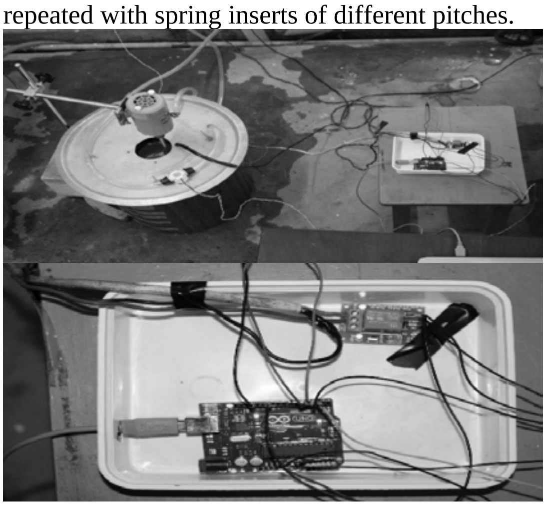


Fig 14: Test Rig Assembly

Results and Discussion

Empirical correlations for heat transfer in helical coils with helical wire inserts have not been reported in literature. Hence the analysis of the experimental data was done by using the correlation for inside heat transfer coefficient with inserts in straight tubes after incorporating a correction factor. *Jafari Nasr et al.,* [4] proposed the following empirical correlation for heat transfer coefficient in straight tubes with helical inserts.

$$Nu = 1.287\ \mathrm{Re}^{0.415}\ \mathrm{Pr}^{0.6876} \left(\frac{P}{d_h}\right)^{-0.2565} \left(\frac{e}{d_h}\right)^{0.2865} \qquad (1)$$

Pr = Prandtl number; *P* = Pitch of the coil insert, m
d_h= Hydraulic diameter, m

$$d_h = \frac{D^2 - e^2}{D} \qquad (2)$$

e = Diameter of wire coil insert, m

A Correction factor for the coil effect was incorporated in the same way as that was done for the flow in helical coil without inserts and hence the above correlation was modified as below in eqn. 3.

$$Nu = 1.287\ \mathrm{Re}^{0.415}\ \mathrm{Pr}^{0.6876} \left(\frac{P}{d_h}\right)^{-0.2565} \left(\frac{e}{d_h}\right)^{0.2865} \left(1 + \frac{3.5D}{D_c}\right) \quad (3)$$

Here Dc is the diameter of the helix.
The experimental data were fitted in the above equation and the inside heat transfer coefficient was determined at varying flow rates and coil pitches. Experiments were conducted with three different

pitches (3mm, 4mm and 5 mm) and without inserts at Reynolds numbers approximately between 7000 and 28000. The following Dittus Boelter equation is used for determining the inside heat transfer coefficient without coil inserts. The inside heat transfer coefficient obtained from the present study was also compared with that predicted by Jafari Nasr et al., [4] correlation. The values obtained in the present study are not in agreement with that of Jafari Nasr et al., as the present study was conducted on a helical coil with coiled wire inserts which is likely to give higher increase in heat transfer coefficient compared to that in a straight tube with coiled wire inserts.

$$Nu = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4} \quad (4)$$

The variation of inside heat transfer coefficient with Reynolds number without insert and with insert having a pitch of 3mm is shown in figure 15. It is observed that significant enhancement in heat transfer coefficient has been observed by inserting the coil wire insert in the helical coil.

Fig 16 shows the effect of coil pitch on the inside heat transfer coefficient. It is observed that the insert coil having a pitch of 3 mm gives the maximum enhancement in heat transfer rate compared to the insert coils of 4 mm and 5 mm.

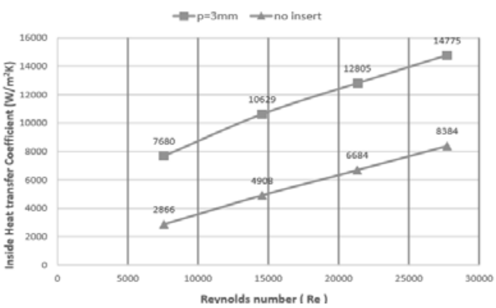


Fig 15: Effect of inside heat transfer coefficient with and without coil insert

The overall heat transfer coefficient has been obtained from the energy balance between the sensible heat change of the fluid in the coil and the rate equation. The variation of the overall heat transfer coefficient with Reynolds number without inserts and the that using coil inserts of different pitches is represented in fig 17. It is evident that the coil inserts of lower pitch gives higher enhancement in heat transfer rate. The oscillations of the coil inserts causes secondary flows which in turn contributes to the heat transfer enhancement.

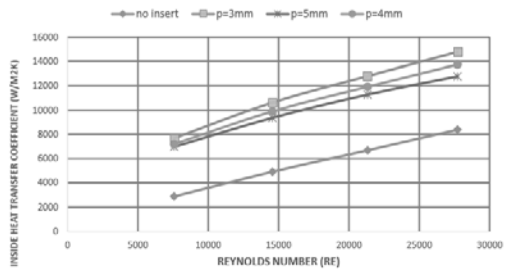


Fig 16: Effect of Coil insert pitch on inside heat transfer coefficient

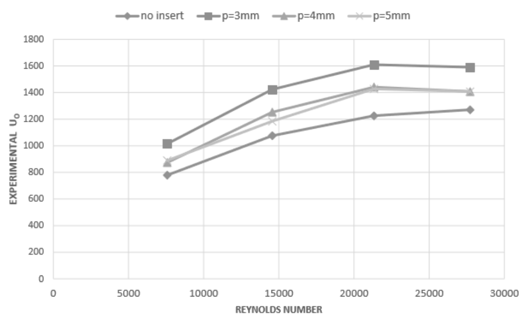


Fig: 17: Effect of coil insert itch on Overall heat transfer coefficient

CONCLUSION

The inside heat transfer coefficients at different flow rates for helical coil tube heat exchanger with spring/coil inserts have been studied. Experiments were conducted in the helical coiled heat exchanger for varying fluid Reynolds numbers and using different spring/coil coil inserts having different pitches. Coil inserts with three different pitches were used in the experiments. It was found that spring inserts provide greater turbulence and secondary flows within the tubes which enhances the heat transfer. Among the different spring inserts used in the study, inserts with 3mm pitch showed better enhancement than inserts with higher pitches. It has been observed that as the pitch increases the heat transfer augmentation decreases. An average increase of 120% in the coil side inside heat transfer coefficient was observed for coil tubes with 3mm pitch spring inserts when compared to when no inserts were used under similar experimental conditions. The variation of pressure drop on account of inserting the passive devices has not been evaluated in this study.

NOMENCLATURE

Cp	:	Specific heat capacity of fluid
d_h	:	Hydraulic diameter
D	:	Diameter of helical coil tube
Dc	:	Diameter of the helical coil (helix)
e	:	Diameter of coil
Nu	:	Nusselt number
P	:	Pitch of the coil insert
Pr	:	Prandtl number
Re	:	Reynold's number, Re = $\frac{\rho U D}{\mu}$
U	:	Velocity of fluid
k	:	Thermal conductivity of fluid
μ	:	Viscosity of fluid
ρ	:	Density of fluid

REFERENCES

[1] Qasim Saleh Mahdi, Al-Mustansiriyah, Sahar Abdul Fattah and Osama Mahdi Jasim, Experimental and Numerical Investigation to Enhance the Performance of Helical Coiled Tube Heat Exchanger by Using Turbulators, Journal of Engineering and Development, Vol. 18, No.6, ISSN 1813- 7822, November 2014.

[2] Zachar A., Analysis of coiled-tube heat exchangers to improve heat transfer rate with spirally corrugated wall, International Journal of Heat and Mass Transfer, Vol. 53, pp. 3928–3939,2010.

[3] Wang L, Sunden B, Performance comparison of some tube inserts, International Communication Heat and Mass Transfer 29, 45–56, 2002

[4] Modeling of heat transfer enhancement by wire coil inserts using artificial neural network analysis M.R. Jafari Nasr, A. Habibi Khalaj, S.H. Mozaffari, Applied Thermal Engineering, 30, 143-151, 2010.

[5] www.qt.io/Qt creator 3.5.1 (open source).

[6] www.arduino.cc, Arduino sketch 1.6.7.