[Ray *et al.*, 3(6): June, 2014]
ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 1.852

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

A Review Paper on Heat Transfer Rate Enhancements by Wire Coil Inserts in the Tube

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Abstract

Enhancing heat transfer surface are used in many engineering applications such as heat exchanger, air conditioning, chemical reactor and refrigeration systems etc, hence many techniques have been investigated on enhancement of heat transfer rate and decrease the size and cost of the involving equipment especially in heat exchangers .One of the most important techniques used are passive heat transfer technique. These techniques when adopted in Heat exchanger proved that the overall thermal performance improved significantly. This paper reviews experimental works taken by researchers, on this technique wire coil insert in tubes to enhance the thermal efficiency in heat exchangers and useful to designers implementing passive augmentation techniques in heat exchange. The authors found that variously developed wire coil inserts are popular researched and used to strengthen the heat transfer efficiency for heat exchangers.

Keywords: coil-wire insert, heat transfer enhancement, pressure drop, friction factor.

Introduction

Heat transfer enhancement is typically considered as a means to improve and to intensify the thermal performance of heat transfer system, such as heat exchangers, evaporators, thermal power plants, chemical reactor, air-conditioning equipment and refrigerators, and lately they have been applied widely in industrial application. Recently, large numbers of attempts have been made to develop enhancement techniques to reduce the size and costs of heat exchangers in order to improve the overall performance of heat exchangers. An extensive literature survey of research on all types of enhancement technique is given in Webb and Bergles. Generally, enhancement techniques can be classified in three broad categories:

(a) Active method: Active augmentation, which has been studied extensively, involved some external power input to bring about the desired flow modification for enhancement and has not shown much potential owing to complexity in design. Furthermore, external power is not easy to provide in several applications.

(b) Passive method: This method does not need any external power input and the additional power needed to enhance the heat transfer is taken from the available power in the system.
Tube insert devices including twisted tape, wire coil, extended surface and wire mesh inserts are considered as the most important techniques of this group; in which, twisted tape and wire coil inserts are widely applied than others.

(c) Compound method: a compound method is a hybrid method in which both active and passive methods are used in combination. The compound method involves the complex designs and hence it has limited applications.

Wire coil inserts have been utilized as one of the passive enhancement techniques and are widely utilized in heat transfer equipments. They show several advantages in relation to other enhancement techniques:

1) Easy installation and removal.
2) Simple manufacturing process with low cost.
3) Preservation of original plain tube from mechanical strength.
4) Possibility of installation in an existing smooth tube heat exchanger (retrofit).
5) Fouling mitigation (in refineries, chemical industries and marine applications) [1].

Fig. 1 shows a sketch of a wire coil inserted in close contact with the inner tube wall, where p stands for helical pitch, e for the wire-diameter and d is the tube inner diameter.

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Scientific Journal Impact Factor: 3.449
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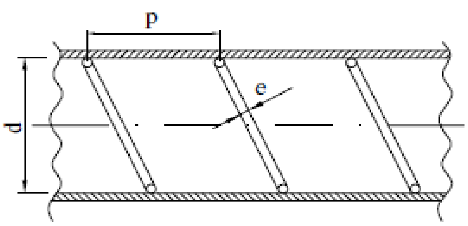
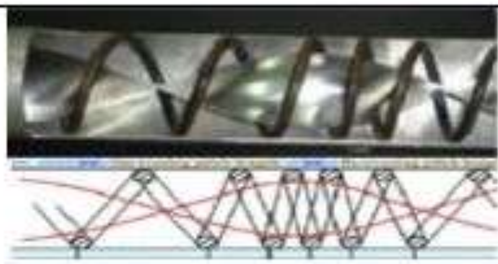
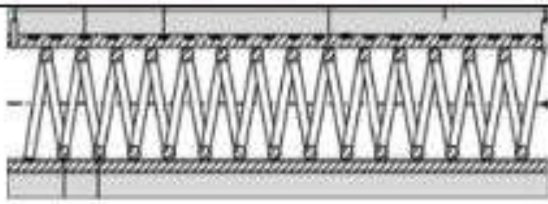


Figure1. Sketch of a helical-wire-coil fitted inside a smooth tube [1].

These parameters can be arranged to define the wire geometry in non-dimensional form. Dimensionless pitch p/d, dimensionless wire-diameter e/d and pitch to wire-diameter ratio p/e.

	• Coiled square wires
	• Non-uniform wire coil combined with twisted tape
	• Coiled wire turbulators
	• Twisted tape and wire coil
	• Triangle cross sectioned coiled wire
	• Wire coil in pipe

Figer 2. Configuration sketches of various wire coils

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literature review

- There are several experimental works done on the thermo hydraulic performance of wire coils enhancement.

Gararcia et al. 2005 [1]: He was experimentally studied in order to characterize their thermohydraulic behavior in laminar, transition and turbulent flow when helical-wire-coils fitted inside a round tube, By using water and water–propylene glycol mixtures at different temperatures, a wide range of flow conditions have been covered. Reynolds numbers from 80 to 90,000 and Prandtl numbers from 2.8 to 150. Six wire coils were tested within a geometrical range of helical pitch $1.17 < p/d < 2.68$ and wire diameter $0.07 < e/d < 0.10$. and he found that In laminar flow wire coils behave mainly as a smooth tube but accelerate transition to critical Reynolds numbers down to 700. Within the transition region, if wire coils are fitted inside a smooth tube heat exchanger, heat transfer rate can be increased up to 200% keeping pumping power constant. In turbulent flow ,wire coils cause a pressure drop increase which depends mainly on pitch to wire- diameter ratio p/e.

Yakut and Sahin. 2004 [2]: they were performing an experiment with the configuration of coiled wire cross section 4mm & length 1240 mm , by using **air** as a working fluid with the Reynolds no. varying from 5000 to 35000 and Pitches are 10,20, 30 mm. they observe that Vortex characteristics of the tabulators should be considered as a selecting criterion with heat transfer and friction characteristics in heat transfer enhancement applications.

P. Promvonge. 2008 [3]: Influences of insertion of wire coils in conjunction with twisted tapes on heat transfer and turbulent flow friction characteristics in a uniform heat-flux, circular tube using air as the test fluid are experimentally investigated. The wire coil used as a turbulator is placed inside the test tube while the twisted tape is inserted into the wire coil to create a continuous impinging swirl flow along the tube wall. The effects of insertion of the two turbulators with different coil pitch and twist ratios on heat transfer and friction loss in the tube are examined for Reynolds number ranging from 3000 to 18,000. The experimental results are compared with those obtained from using wire coil alone, apart from the smooth tube. The results indicate that the presence of wire coils together with twisted tapes leads to a double increase in heat transfer over the use of wire coil alone. The combined twisted tape and wire coil with smaller twist and coil pitch ratios provides higher heat transfer rate than those with larger twist and coil pitch ratios under the same conditions. Also, performance evaluation criteria to assess the real benefits in using both the wire coil and the twisted tape of the enhanced tube are presented.

Promvonge et al. 2011 [4]: Effects of insertion of tandem wire coil elements used as turbulator on heat transfer and turbulent flow friction characteristics in a uniform heat-flux square duct are experimentally investigated in this work. The experiment is conducted for turbulent flow with the Reynolds number from 4000 to 25000. The wire coil element is inserted into the duct with a view to generating a swirl flow that assists to wash up the flow trapped in the duct corners and then increase the heat transfer rate of the test duct. Apart from the full-length coil, using hydraulic diameter of different length coil elements placed in tandem inside the duct with various free-space lengths are introduced to reduce the friction loss. The results obtained from these wire coil element inserts are also compared with those from the smooth duct. The experimental results reveal that the use of wire coil inserts for the full-length coil, different length coil elements with a short free-space length leads to a considerable increase in heat transfer and friction loss over the smooth duct with no insert. The full-length wire coil provides higher heat transfer and friction factor than the tandem wire coil elements under the same operating conditions. Also, performance evaluation criteria to assess the real benefits in using the wire coil insert into the square duct are determined.

Eiamsa-ard et al. 2010 [5]: In this paper, heat transfer, friction factor and thermal performance behaviors in a tube equipped with the combined devices between the twisted tape (TT) and constant/periodically varying wire coil pitch ratio are experimentally investigated. The periodically varying three coil pitch ratios were arranged into two different forms: (1) D-coil (decreasing coil pitch ratio arrangement) and (2) DI-coil (decreasing/increasing coil pitch ratio arrangement) while the twisted tapes were prepared with two different twist ratios. Each device alone is also tested and the results are subjected for comparison with those from the combined devices. The experiments were conducted in a turbulent flow regime with Reynolds numbers ranging from 4600 to 20,000 using air as the test fluid. Compared to each enhancement device, the heat transfer rate is further augmented by the compound devices. Over the range investigated, the highest thermal performance factor of around 1.25 is found by using DI-coil in common with the TT at lower Reynolds number. In addition, the empirical

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 1.852

correlations of the heat transfer (Nu) and pressure drop (f) are also presented.

S.Gunes et al. 2010 **[6]:** The paper presents the experimental investigation of heat transfer and pressure drop in a tube with coiled wire inserts placed separately from the tube wall in turbulent flow regime. The experiments were performed with a constant wire thickness of a = 6 mm, three different pitch ratios (P/D = 1, P/D = 2 and P/D = 3) and two different distances between wire and test tube inner wall (s = 1 mm, s = 2 mm) at which the coiled wire inserts were placed separately from the tube wall. Uniform heat flux was applied to the external surface of the tube and Reynolds numbers varied from 4105 to 26400 in the experiments. The experimental results obtained from a smooth tube were compared with those from the studies in literature for validation of experimental setup. The use of coiled wire inserts leads to a considerable increase in heat transfer and pressure drop over the smooth tube. The Nusselt number and friction factor increase with decreasing pitch ratio (P/D) and distance (s) for coiled wire inserts. The highest overall enhancement efficiency of 50% was achieved for the coiled wire with P/D = 1 and s = 1 mm at Reynolds number of 4220. As a result, the experimental results reveal that using these coiled wire inserts are thermodynamically advantageous at all Reynolds numbers

R. Sethumadhavan and M. Raja Rao. 1883 [7] : They are presented an experimental investigations of heat transfer in a 25mm I.D. copper tube, tightly fitted with helical-wire-coil inserts of varying pitch (p), helix angle (x) and wire diameter (e). A similarity law approach was attempted to interpret the friction and heat transfer results and correlate them in terms of roughness. The present results are compared with previously published results and a generalized correlation for the heat transfer roughnees function has been developed, which is applicable for different types of rough surfaces. An optimization study was made on the basis of maximization of the heat transfer rate and also minimization of pumping power and heat exchanger frontal area to identify the most efficient tube within the matrix of data.

M.A. Akhavan-behabadi et al. 2009 [8] : they have performed an experiment with the use of **oil** as a working fluid and configuration are taken as seven coiled wires having pitches 12 to 69 mm. The experimental analysis that has been carried out at low Reynolds numbers ranging from 10 to 1500 and he found that wire coil inserts with lower wire diameters have better performance, especially at low Reynolds numbers. Also, the increase in the coil pitch made a moderate decrease in performance parameter.

Thermal performance analysis

Thermal performance is generally used to evaluate the performance of different inserts such as twisted tape, wire coil, etc., under a particular fluid flow condition. It is a function of the heat transfer coefficient, the friction factor and Reynolds number. For a particular Reynolds number, if an insert device can achieve significant increase of heat transfer coefficient with minimum raise of friction factor, the thermal performance factor of this device is good.

In the present work, air was used as the test fluid. The steady state heat transfer rate is assumed to be equal to the heat loss in the test duct:

$$Q\text{air} = Q\text{conv} \quad (1)$$

In which

$$Q_{\text{air}}=\dot{m}c_{p,\text{air}}(T_o-T_i) \quad (2)$$

The heat supplied by electrical heater plates in the test duct is found to be 3% to 5% higher than the heat absorbed by the fluid for thermal equilibrium test due to convection and radiation heat losses from the test duct to surroundings. Thus, only the heat transfer rate absorbed by the fluid is taken for internal convective heat transfer coefficient calculation. The convection heat transfer from the test duct can be written by

$$Q_{\text{conv}} = hA\,(T_s\text{-}T_b) \quad (3)$$

where

$$T_b= \frac{(\mathbf{To+Ti})}{\mathbf{2}} \quad (4)$$

Ts = average surface temperature

h can be calculated by comparing equation 2 and 3 number, Nu are estimated as follows

$$Nu=hD/k \quad (5)$$

The Reynolds number is given by

$$Re=\rho UD/\mu \quad (6)$$

Pressure drop is given as

$$\nabla P = \rho gh \quad (7)$$

Friction factor f can be written as

$$f = \frac{\Delta P}{(L/D)\rho U^2/2} \quad (8)$$

In which U is mean air velocity in the duct. All thermo-physical properties of air are determined at the overall bulk air temperature from Eq. (4). For a constant pumping power,

$$(\dot{V}\nabla P)_O=(\dot{V}\nabla P)_a \quad (9)$$

Where o and a denote smooth surface and augmented surface respectably.

and the relationship between friction and Reynolds number can be expressed as:

$$(f\,Re^3)_o =(f\,Re^3)_a$$

$$Re_0=Re_a(fa/\,fo)^{1/3} \quad (10)$$

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The thermal enhancement factorη, defined as the ratio of the, h_a of an augmented surface to that of a smooth surface, h_o, at an identical pumping power is suggested by Webb

$$\eta = \left(\frac{h_a}{h_o}\right)_{pp} = \left(\frac{Nu_a}{Nu_o}\right)_{pp} = \left(\frac{Nu_a}{Nu_o}\right)(fa/fo)^{\wedge -1/3} \quad (11)$$

Conclusion

I. Wire coiled tube increases the pressure drop comparing to an empty tube. The pressure drop depends on the wire geometry and is always act a significant.
II. Wire coil inserts perform better in transition and turbulent region flow. Within the transition region, if wire coils are fitted inside a smooth tube heat exchanger, heat transfer rate can be increased up to 200% keeping pumping power constant.
III. In laminar flow wire coil insert is not very effective and results show that wire coils behave like as a smooth tube but accelerate transition to critical Reynolds numbers down to 700.
IV. In turbulent flow ,wire coils cause a high pressure drop increase which depends mainly on pitch to wire diameter ratio p/e.
V. If the pressure drop is not concerned, wire coil inserts are preferred in both laminar and turbulent regions.
VI. In the selection of the wire coil inserts, the shape of the insert is important.
VII. Wire coil gives better overall performance if the pressure drop penalty is considered.
VIII. The other several passive techniques to enhance the heat transfer in a flow, such as ribs, wire coil are generally more efficient in the turbulent flow than in the laminar flow excepted twisted tape it gives better result in laminar flow.

If wire coils are compared with a smooth tube at constant pumping power, an increase in heat transfer is obtained, especially at low Reynolds number. The coiled circular wire should be applied instead of the smooth one to obtain higher heat transfer and performance, leading to more compact heat exchanger. We observed that the heat transfer in case of the conical coil is highest as compare to the plain pipe and the pipe containing the coil of different pitches. The enhancement efficiency increases with the decreasing pitches and found highest in the conical sets.

Nomenclature

A	heat transfer surface area of test duct, m^2
$C_{p\,air}$	specific heat capacity of air, J/kg^{-1}·K^{-1}
D	hydraulic diameter of square duct, m
f	friction factor
h	average heat transfer coefficient, W·m^{-2}·K^{-1}
K	thermal conductivity of air, W·m^{-1}·K^{-1}
Nu	nusselt number ($Nu = hD/k$)
∇P	pressure drop, Pa
Pr	prandtl number
Q	heat transfer, W
Re	reynolds number
S	free-space between coil elements, m
T	steady state temperature, K
U	mean velocity, m·s^{-1}
$\dot{V}$	volumetric flow rate, m^3·s^{-1}
η	thermal enhancement factor
μ	dynamic viscosity, pa-s^{-1}
ρ	density of air, kg·m^{-3}
L	length of the test tube

Subscripts

a	augmented
conv	convection
i	inlet
o	out
pp	pumping power

References

1. *Alberto Garcı´a , Pedro G. Vicente , Antonio Viedma. Experimental study of heat transfer enhancement with wire coil inserts in laminar-transition-turbulent regimes at different Prandtl numbers, International Journal of Heat and Mass Transfer, 2005,48. pp. 4640–51.*
2. *K. Yakut ,B Sahin . The effects of vortex characteristics on performance of coiled wire turbulators used for heat transfer augmentation. Applied Thermal Engineering 2004;24:2427–38.*
3. *P. Promvonge . Thermal augmentation in circular tube with twisted tape and wire coil turbulators. Energy Conversion and Management 2008;49:2949–55.*
4. *S. Eiamsa-ard, Narin Koolnapadol And P.Promvonge. heat transfer behavior in a square duct with tandem wire coil element insert fluid dynamics and transport phenomena chinese journal of chemical engineering, 2012;20(5): 863-69*
5. *S. Eiamsa-ard ,P. Nivesrangsan , S.Chokphoemphun , P.Promvonge . Influence of combined non-uniform wire coil and twisted tape inserts on thermal performance characteristics. International*

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 1.852

Communications in Heat and Mass Transfer 2010;37:850–56.

6. *S. Gunes ,V. Ozceyhan ,O Buyukalaca . Heat transfer enhancement in a tube with equilateral triangle cross sectioned coiled wire inserts. Experimental Thermal and Fluid Science 2010;34:684–91.*
7. *R. Sethumadhavan And M. Raja Rao. Turbulent Flow Heat Transfer And Fluid Friction In Helical-Wire-Coil-Inserted Tubes. International Journal Of Heat And Mass Transfer Vol. 26. No. 12. Pp. 1833-45. 1983*
8. *MA Akhavan-Behabadi, R. Kumar , MR Salimpour, R Azimi Pressure drop and heat transfer augmentation due to coiled wire inserts during laminar flow of oil inside a horizontal tube. International Journal of Thermal Sciences 2010;49:373–79.*
9. *M.R. Jafari Nasr *, A. Habibi Khalaj, S.H. Mozaffari. Modeling of heat transfer enhancement by wire coil inserts using artificial neural network analysis, Applied Thermal Engineering 30 (2010) 143–51*
10. *Paisarn Naphon, "Effect of coil-wire insert on heat transfer enhancement and pressure drop of the horizontal concentric tubes", International Communications in Heat and Mass Transfer, 2006, 33. pp. 753–63.*
11. *S. Liu , M.Sakr , A comprehensive review on passive heat transfer enhancements in pipe exchangers Renewable and Sustainable Energy Reviews 19 (2013) 64–81*