ENHANCEMENT OF HEAT TRANSFER USING WIRE COIL INSERTS WITH CHORD RIBS

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ABSTRACT

From last ten years, many efforts have been taken to develop heat transfer enhancement techniques for improving the overall performance of heat exchangers. Energy cost is the main motivation for researchers to work in this area, since improvement in heat exchanger performance saves energy loss, and thereby cost of energy. Several heat transfer enhancement techniques are utilized in order to improve the heat transfer or thermal performance of heat exchangers. Up to now, many attempts have been made to reduce the size and cost of heat exchangers. The performance of heat exchanger depends on large number of variables and thus it makes it very uncertain to predict, which needs enough experience on practical field. Thus the area needs continuous work to be done over. This paper starts with the same idea keeping in mind to contribute in energy saving efforts. The one way to enhance the performance of heat exchanger is to improve tube side heat transfer rate. Generally, heat transfer enhancement techniques can be divided into two groups (passive and active techniques). The active techniques have limitation that they need external power supply for enhancing heat transfer rate. On the other hand the passive techniques have been usually preferred by many researchers since no additional external power is required as extended surfaces, rough surfaces and swirl flow devices. Coiled wire insert is one of the passive heat transfer enhancement techniques, which is extensively used in various heat transfer applications such as, air conditioning and refrigeration systems, heat recovery processes, food and dairy processes, chemical process plants. The passive techniques can be classified as,

(1) Extra inserts to be used inside the tube like, twisted tapes, wire coils etc.

(2) Surface modified rough round tubes, like corrugated and dimpled tubes, special tube geometries as internally finned tubes etc.In petrochemical industrial applications where specifications codes are the requirements, different inserts can be used as they do not change mechanical properties of round tube, but integral roughness modifies the mechanical properties of the tube like stress concentration. The external inserts can be used when it is required to improve performance of an existing heat exchanger.

I. INTRODUCTION

The applications of Wire coil inserts are like oil cooling devices, preheaters or fire tube boilers. They advantages of wire coil inserts in comparison to other heat exchanger performance enhancement techniques can be their low cost, they don't change mechanical strength of original plain tube, their installation and removal is easy and they can be installed in the existing heat exchanger with smooth tube.

Fig. 1 shows a sketch of a wire coil inserted in close contact with the inner tube wall,

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where

p : Helical pitch,

d : Wire-diameter

D : Tube inner diameter.

C_l : Chord rib length

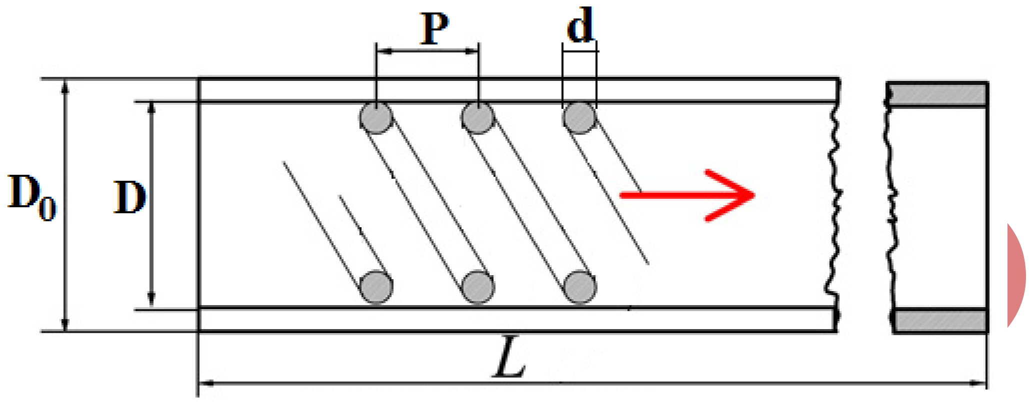

Fig. 1 Wire coil inserted in close contact with the inner tube wall.

These parameters can be arranged to define the wire geometry in non-dimensional form:

Dimensionless pitch p/D,

Dimensionless wire-diameter d/D and

Dimensionless pitch to wire-diameter ratio p/d

Dimensionless Chord Length C_l/D

The tube side flow pattern is modified by the presence of a helically coiled wire with chord ribs as follows:
If the wire coil acts as a swirl flow generator, a helical flow at the periphery is produced. The chord ribs disturb the central core flow, this disturbed central flow gets superimposed upon the helical swirl flow at periphery and large package of centrifugal forces are produced. In most of liquids, where density decreases with temperature, centrifugal forces produce a movement of the heated fluid from the boundary layer towards the tube axis, which produces a heat transfer augmentation. If the wire coil acts as a turbulence promoter, flow turbulence level is increased by a separation and reattachment mechanism. Besides, whenever wire coils are in contact with the tube wall, they act as roughness elements and disturb the existing laminar sublayer.

Depending on flow conditions and wire coil geometry, the heat transfer rate will increase through one or both of the mechanisms mentioned earlier. However, it is expected that wire coils will act as artificial roughness at high Reynolds numbers.
The wire coil is quite simple to manufacture, to insert and remove from the tube which, therefore, justifies its usage in heat transfer enhancement. Coiled wire, twisted tape or other swirl flow devices inserted into a flow provide swirling flow and periodic redevelopment of the boundary layer, increase the effective heat transfer area

and the turbulence intensity. The swirl induced tangential flow velocity component causes improved fluid mixing between the tube core and the wall region nearby, thus enhancing the heat transfer by rapid fluid mixing. On the other hand, the swirl induced heat transfer enhancement brings along inevitable shear stress and pressure loss in coiled wire or twisted tape inserted tube.

II. LITERATURE SURVEY

Alberto Garcı´a, Pedro G. Vicente, Antonio Viedma [1] in their paper experimentally studied heat transfer enhancement with wire coil inserts in laminar-transition-turbulent regimes at different Prandtl numbers. In their study they used helical-wire-coils fitted inside a round tube in objective to characterize their thermo hydraulic behavior in laminar, transition and turbulent flow. They used water and water–propylene glycol mixtures at different temperatures, and obtained wide range of flow conditions to be covered.

They varied Reynolds numbers from 80 to 90,000 and Prandtl numbers from 2.8 to 150. Six wire coils were tested under their study within a geometrical range of helical pitch $1.17 < p/d < 2.68$ and wire diameter $0.07 < e/d < 0.10$. They have developed experimental correlations relating fanning friction factor and Nusselt number as functions of flow and dimensionless geometric parameters. Their result shows that pressure drop increases up to nine times. Isothermal pressure drop experiments were carried out by employing water and water–propylene glycol mixtures.

They obtained Fanning friction factors for Reynolds number range from 100 to 90,000. Smooth tube friction factor results have been compared to the analytical solution in the laminar region and to the widely known Blasius equation in the turbulent region. They found measurements deviation (<3%) was in accordance with the uncertainty analysis, and assured a proper instrumentation adjustment.

The heat transfer increases up to four times compared to the empty smooth tube for turbulent flow conditions. Heat transfer tests under uniform heat flux condition were carried out in a smooth empty tube and in the same tube with 6 wire coil inserts. The range of flow conditions for Re = 80–90,000 and Pr = 2.8–150 was covered. It was found that at low Reynolds numbers, wire coils behave as a smooth tube but accelerate transition to critical Reynolds numbers down to 700.

Their discussion speaks, 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. Wire coil inserts offer their best performance within the transition region where they show a considerable advantage over other enhancement techniques.

Alberto Garcı´a, Juan P. Solano, Pedro G. Vicente, Antonio Viedma [2] worked over enhancement of laminar and transitional flow heat transfer in tubes by means of wire coil inserts. The study under

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experimental conditions for three wire coils of different pitch inserted in a smooth tube in laminar and transition regimes were done by them. Their team carried Isothermal pressure drop tests and heat transfer experiments under uniform heat flux. For fully laminar region the friction factor increases within the range of 5% and 40%. It was found to them that continuous transition from laminar flow to turbulent flow, keeping the pressure drop to be same as that of smooth tube pressures drop. They kept pressure drop instabilities and fluctuations to be null.

Their performed heat transfer experiments were within the limits for Re = 10 to 2500, Pr = 200 to 700 and Ra = 3 x 106 to 108. The result discussed by them shows, at Reynolds numbers below 200, wire coils do not enhance heat transfer with respect to a smooth tube. For Reynolds numbers between 200 and 1000, wire coils considerably increase heat transfer. At Reynolds numbers above Re = 1000 to 1300, transition from laminar to turbulent flow takes place. At Reynolds number around 1000, wire inserts increased the heat transfer coefficient up to eight times as compared to the smooth tube. They also performed a comparison of performance between wire coils and twisted tape inserts which shown that wire inserts perform better than twisted tapes in the low Reynolds number range: Re = 700 to 2500.

D. Muñoz-Esparza, E. Sanmiguel-Rojas [8] performed numerical simulations over the laminar flow in pipes with wire coil inserts. Helical wire coils fitted inside a round pipe is a simple and well-known heat transfer enhancement technique in order to improve the overall performance of heat exchangers. Three-dimensional numerical simulations of the incompressible laminar flow that develops into smooth round pipes of diameter, d, with wire coil inserts of helical pitch, p, and diameter, e, have been accomplished by them with the finite volume method. In particular, they described the behavior of the Fanning friction factor, f, as a function of the Reynolds number. For a wire coil of 40 pitches in length with dimensionless pitch p/d = 2.5 and dimensionless wire diameter e/d = 0.074, both pitch-periodic and full domain numerical results have been validated with experiments. They found an excellent agreement with both numerical models and experimental results for Re < 500, showing the friction factor a quasi-linear dependence on Re when is plotted in log–log axes. For 500 < Re < 600 both experimental and full domain numerical results of the values for the friction factor leave the quasi-linear trend observed for Re < 500. Their full domain numerical calculations reveal the onset of a linear instability into the range 500 < Re < 550 that becomes the flow unsteady and breaks the periodic axial pattern of the flow. The friction factor becomes constant in the range, 600 < Re < 850, and only the full numerical model shows a good agreement with the experimental results, but periodic numerical simulations fail. For 850 < Re, even the full domain laminar model fails due to the onset of turbulent outbreaks. Finally, the effect of the pitch on the friction factor has been addressed by performing a parametrical study with a pitch-periodic computational domain for wire coils within the dimensionless pitch range, 1.50 ≤ p/d ≤ 4.50, and dimensionless wire diameter, e/d = 0.074, showing that the increase of the non-dimensional pitch, p/d, decreases the friction factor.

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Lieke Wang and Bengt Sunden [9] worked on different types of wire coil inserts and presented performance comparison amongst them. Their paper discusses the selection of different tube inserts, and makes comprehensive comparison on the thermal and hydraulic performance for the two most common tube inserts: twisted tape insert and wire coil insert. The comparison was conducted in both laminar and turbulent regions. Their results say, tube insert technology is more effective in the laminar region than the turbulent region. In the laminar region, the heat transfer enhancement ratio and the overall enhancement ratio can be up to 30 and 16, respectively. But in the turbulent region, they can be only up to 3.5 and 2.0, respectively. This is probably the reason that in practice tube insert technology is often used in the laminar region, not in the turbulent region, where other enhancement technologies are common, such as ribs, low fins, etc.

They states that, if the pressure drop is of no concern, twisted tape inserts are preferred in both laminar and turbulent regions. This is because twisted tape inserts provide higher heat transfer enhancement ratio than wire coil inserts. However, in the situation where pressure drop is a crucial constraint, wire coil inserts may become more effective due to less pressure drop penalty.

They discus, that heat exchanger performance is well connected to the fluid property. Through their comparison, it can be concluded that the tube insert technology is more effective for those fluids with high viscosity i.e. high Prandtl number flow, particularly in the laminar region. In fact, many high viscous liquids operate in laminar region and have relatively low heat transfer coefficient.

They end up with a very important conclusion, that in the selection of tube insert, the shape of the insert is important. For wire coil insert with helix angle of 75 has higher heat transfer enhancement ratio than a twisted tape insert with helix angle of 45 in laminar region. This makes the selection complicated, and one cannot simply conclude what insert is preferable. Their calculations show that the performance trend of different inserts does not depend on the insert thickness, variation in insert thickness affects the individual performance of insert type.

III. EXPERIMENTAL SETUP

The experimental facility required is a simple forced convection setup with tube fitted with blower for forced convection environment and heating coil around its surface to produce heat flux. There are two main classes of experimental setups available to study effect of turbulators on heat transfer and pressure drop, one working under water as working fluid and other air as working fluid. The setup constructed for study of water as working fluid face a major problem to store water, it need storage tanks which in turn increases its weight. This paper is to study effect of wire coil on heat transfer enhancement under air as working fluid and thus setup with water as

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working fluid is not focused. The open loop experimental facility used in the experiments is schematically shown in Fig. 2.

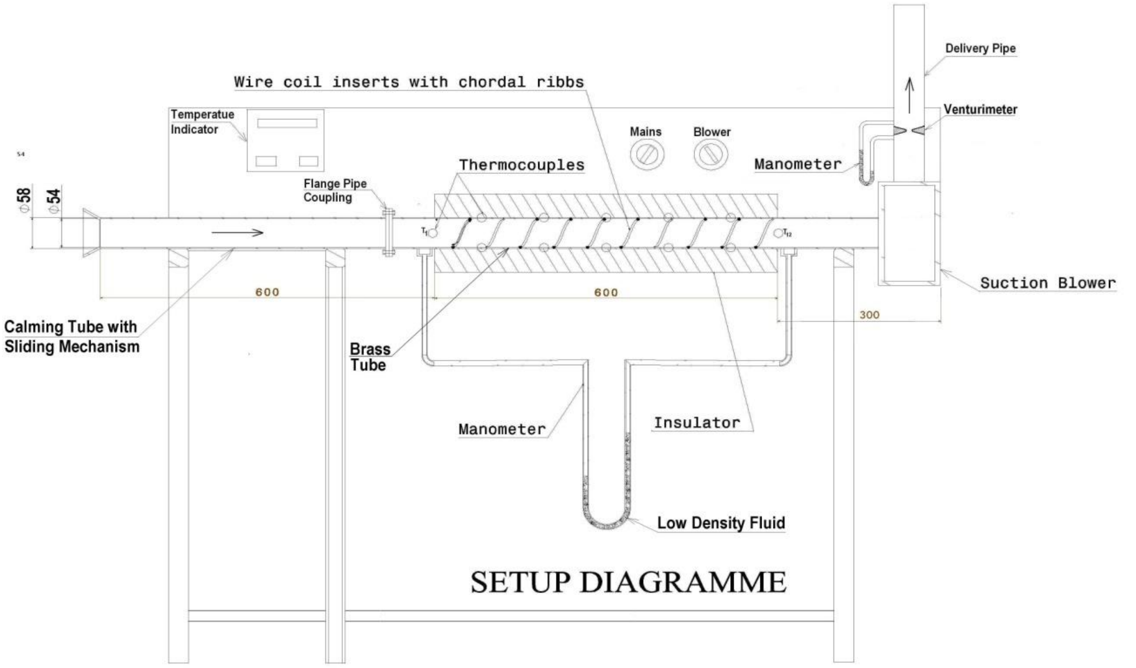

Fig.2 : Experimental Setup

The experimental setup consists of following main components:

Blower, Venturimeter, Test section, Insulation, Thermocouples, Coupling, Calming tube, Pressure transmitter, Data logger, Heater etc.

3.1.1 **Blower:** The facility includes a blower to provide air velocity, coupled with inverter to vary air velocity. A 0.5 HP capacity blower is used. The suction side of the blower is used to avoid eddies. A nozzle is used to enter the air in the tube uniformly.

3.1.2 **Venturimeter & Pressure Transmitter:** It is used to measure the mass flow rate of air, and thereby velocity of air. Generally Venturimeter is fitted across the delivery side of the blower to avoid the effect of its back pressure on test section. The Venturimeter should be calibrated as per calibration process available in literature. The volumetric air flow rates from the blower were adjusted by varying motor speed through an inverter.

The pressure drop across the test tube is measured by using a differential pressure transmitter.

3.1.3 **Test Section:** The test section is length of tube in which wire coil inserts are to be placed and is heated from outside. The test tube length selected is 600 mm with a coiled wire insert. The material used for test tube is SS304 seamless steel test tube and has 54 mm inner diameter (D), 58 mm outer diameter (Do), and 2 mm thickness (t).

3.2 Wire Coil Geometries

The coiled wire used in experiments is fabricated from Spring Steel with spring manufacturing method and are of three different wire diameters, 1, 2 and 3 mm. The chord Ribs are brazed along chord of circle traced by the plan of coil, as shown in fig. 3. There are three different lengths of chord ribs are considered in the experimental study. This configuration is shown in fig. 4

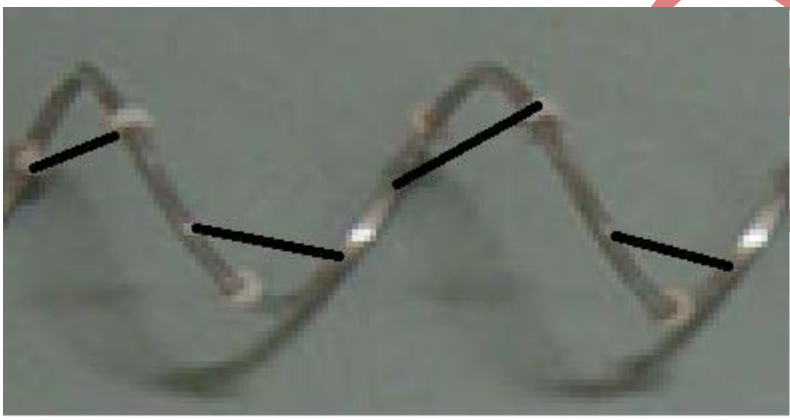

Fig.3 : The coiled wire inserts with Chord Rib.

The coiled wire insert with chord rib and the details of wire coil are given in Fig. 4 and 5 respectively. The Teflon rings are manufactured according to the wire thickness in order to fix the coiled wire separated from the tube wall. These rings are densely attached onto the inserts, thus the contact of inserts with tube inner wall is prevented. The coiled wire inserts with Teflon rings used in the experimental study are shown in Fig. 3.

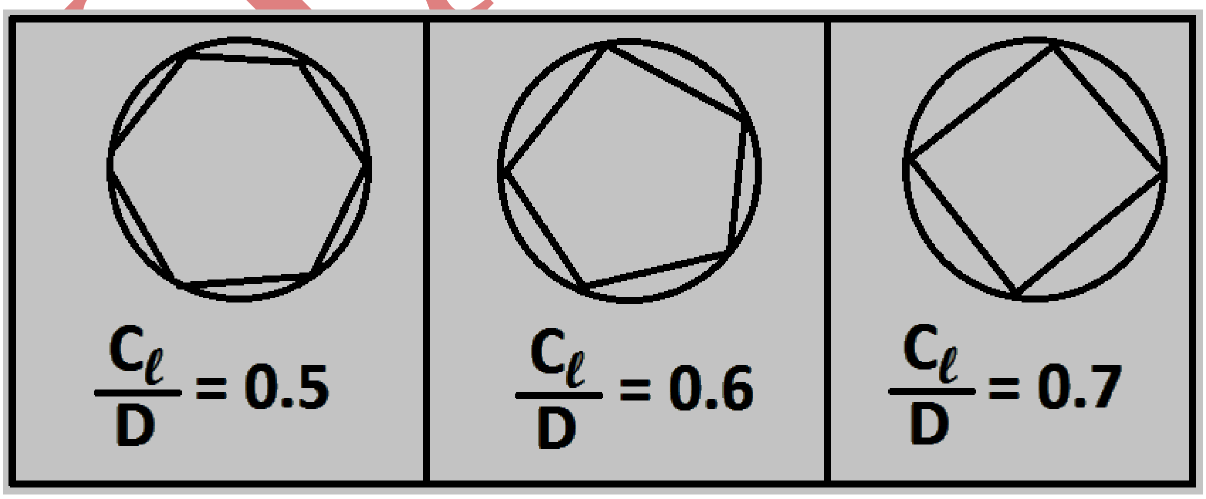

Fig.4 : Three Configurations of Chord Length .

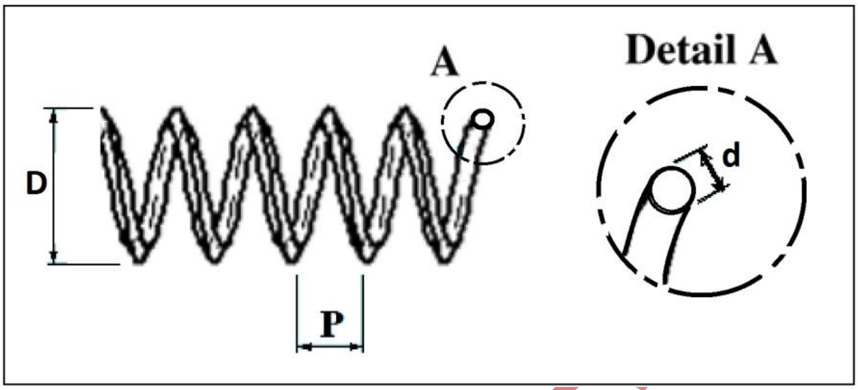

Fig.5 : The details of coiled wire.

IV. HEAT TRANSFER ANALYSIS

The heat flux applied to the test tube cause an increase in the outer surface temperature of the test tube in axial direction. Therefore, the heat loss is calculated for each part of the test tube in which the thermocouples exist. The total heat loss is taken as the sum of these 7 parts. The heat loss is the heat transfers from the outer tube wall to the surroundings and calculated as follows:

$$Q_{loss} = \frac{T_s - T_{OSI}}{R_{ins}}$$

$$R_{ins} = \frac{ln\frac{r_o}{r_i}}{2\pi L K_{ins}}$$

R_{ins} is the conduction resistance offered by insulating material in the path of heat transfer.

The steady state heat transfer rate and heat flux applied to the test tube are can be written as;

$$Q_{conv} = \Delta VI - Q_{loss}$$

The heat provided by the electrical cable in the test tube is about 3–4% higher than the heat absorbed by the air for the thermal equilibrium test because of the convection and radiation heat losses (Q_{loss}) from the test section to the surroundings. Therefore, only the heat transfer rate absorbed by the air is taken into consideration for the convective heat transfer coefficient calculation. Again convection heat transfer can also be calculated as follows,

$$Q_{conv} = \dot{m}_{air} C_{p\,air} (T_o - T_i)$$

Now the heat transfer rate per unit area i.e. Heat Flux can be found out as,

$$q = \frac{Q_{conv}}{\pi DL}$$

Where (πDL) is the inside surface area area of test section.

To find local one dimensional heat transfer coefficient in x-direction we use,

$$h_x = \frac{q}{[T_{s(x)} - T_{\infty(x)}]}$$

Here, $T_{s(x)}$ and $T_{\infty(x)}$ represent the local inner wall temperature of the heated test tube and local bulk temperature of the fluid, respectively. All of the thermo-physical properties of air are determined at the overall bulk mean temperature.

From local heat transfer coefficient local Nusselt number is calculated with the expression,

$$Nu_x = \frac{h_x D}{K_{air}}$$

To determine nature of flow we need Reynolds number and can be obtained from equation as,

$$Re = \frac{V_{air} D}{\gamma}$$

Here Velocity of the air is obtained with the help of mass flow rate from Venturimeter data.

Then Friction Factor (f) can be calculated as,

$$f = \frac{\Delta P}{\frac{1}{2}\rho V_{air}{}^2 \frac{L}{D}}$$

Using Constant Pumping Evaluation Criterion,

$$(\dot{v}\Delta P)_s = (\dot{v}\Delta P)_c$$

The relationship between friction factor and Reynolds number

$$(f\,Re^3)_s = (fRe^3)_c$$

Thus $$Re_s = Re_c \left(\frac{f_c}{f_s}\right)^{\frac{1}{3}}$$

The overall enhancement efficiency (η) is expressed as the ratio of the, h_c of an enhanced tube with coiled wire insert to that of a smooth tube, h_s at a constant pumping power,

$$\eta = \left.\frac{h_c}{h_s}\right|_{pp} = \left.\frac{Nu_c}{Nu_s}\right|_{pp} = \left(\frac{Nu_c}{Nu_s} x \frac{f_s}{f_c}\right)^{\frac{1}{3}}$$

The overall enhancement efficiency is used to account the effect of enhancement in heat transfer rate and the increase in pressure drop due to use of wire coil inserts simultaneously.

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