Using Coil-Wire Method to Improve Heat Transfer Characteristics in Pipe Flow: A Mini Review Study

Sarmad A. Ali

Department of Automobile Engineering, College of Engineering-Al Musayab, University of Babylon, Babylon, Iraq
Email: sarmad.ahmed96@uobabylon.edu.iq
https://orcid.org/0009-0001-9231-9523

Abstract

The heat exchanger was invented in thermal contact and at different temperatures for the transfer of enthalpy (thermal energy) between two or more liquids or a liquid and solid surface (one medium to another medium). Basic units called heat exchangers are used to extract and recover heat in the industrial process globally. Various applications and devices use the heat exchanger to exchange heat between two media, including cooling towers, car radiators, condensers, evaporators, etc. An improved technique in the field of heat transfer serves as a research task and is classified as an active, passive, and large-scale composite technique. Active methods need an external power source for the input process and do not need an additional power source or power to improve heat transfer. Passive methods are generally used in both numerical and experimental applications to save energy and cost in enhancing heat transfer and friction losses. The inclusion of wire coils, internal threads, and nanofluid comes under passive methods, which are used to improve the heat exchanger's overall performance and thermal efficiency. The current review investigates the enhancement of the heat transfer rate using wire coils as a means of optimization for two types of laminar and turbulent flow. The current work proposal for future studies of the same field is to use two techniques to improve heat transfer, including a wire coil with a hybrid nanofluid to enhance the thermal conductivity coefficient.

Keywords- Coil-Wire, Pipe Flow, Heat Transfer Enhancement, Passive Method.

I. INTRODUCTION

A special device called an exchanger is used to exchange heat of different degrees between two channels or currents. Devices designed to efficiently transfer heat from one medium to another (this medium is either solid, liquid, or gas) are called heat exchangers, as they are used globally to extract heat and are considered essential devices in the preparation of recovery in various industries. Power plants, chemical plants, air conditioners, etc. The most important applications in which heat exchangers are widely used for heating and cooling processes. The various fields include the aviation industry, electric power generation, petrochemical industries, oil, metallurgy, sugar industries, the electrical sector, pharmaceutical industries, etc. An important character leads out the heat exchanger. The promotion of energy use in industry is a distortion of energy recovery. The design of the heat exchanger is considered a complex strategy because it requires careful analysis of the pressure drop, the economic aspect of the equipment, and the rate of forced heat transfer. The minimum pumping power, a high percentage of heat transfer, and small size are all important and difficult factors for the design of the heat exchanger. Powerful techniques are used to maximize the heat transfer process to improve thermal performance and heat transfer rate. The specific work needed to reduce the heat exchanger's size, enhance the heat exchanger's current capacity, reduce the pumping power, or transfer heat at a lower speed in the heat exchanger are all important main goals to improve the thermophysical properties of the working fluid. For low operating costs, low pressure is the ideal solution. In various industrial or engineering heat exchanger applications, all these benefits have helped Sahar improve heat transfer because it performs a research task in the field of heat transfer science. Various researchers presented an experimental study to improve hydraulic performance, heat transfer properties, and fluid flow by inserting a wire coil with different configurations inside pipes or channels [1-7]. Broadly, the methods of enhancing heat transfer can be classified into two main methods, as follows [8-10]:

- Technique of active.
- Technique of passive.
- Combined technique (active and passive).

1.1. Heat Transfer Active Method

Various means and methods are used to increase the rate of heat transfer in industrial or engineering applications, for example, vibration at the surface, vibration of liquids, mechanical aids, disturbance of various light particles in a flowing current by a magnetic field, etc. All of them are considered active methods of heat transfer because they depend on an external source (energy) [11].

1.2. Heat Transfer Passive Method

The second passive method of heat transfer has no conditions that depend on an external energy source. This technique is characterized by changing the surface texture or making engineering adjustments, for example, various inserts, grooves, additives, and rough surfaces. The main purpose of this technique is to improve the performance and efficiency of the heat exchanger by increasing the surface areas and residence time, i.e., disturbing the actual flow of fluid [11].

1.3. The most important definitions

Thermal performance factor is one of the most important terms for improving various heat transfer processes. Various common inserts are used in pipes or channels, such as wire coils, twisted tape, protrusions, etc. The thermal performance factor is used to evaluate performance. The thermal performance factor is expressed as a function of the heat transfer coefficient with the friction factor. A good, efficient, and thermal performance engineering device or application is described in the case of a significant increase in the heat transfer coefficient offset by a minimum increase in the friction factor. The following mathematical equation expresses the thermal performance factor [12]:

$$\eta = \frac{Nu / Nu_o}{(f / f_o)^{1/3}} \qquad (1)$$

The pumping force is measured by the friction factor using the following equation [12]:

$$f = \frac{\Delta p}{(\rho u^2 / 2)(L / D_h)} \qquad (2)$$

The Prandtl number defines the ratio of momentum diffusion to heat diffusion. The distance between two points of the same axial plane of flow, whether pipes or channels, is called the pitch. The torsion ratio is defined as the ratio between the inner tube's pitch and diameter [12].

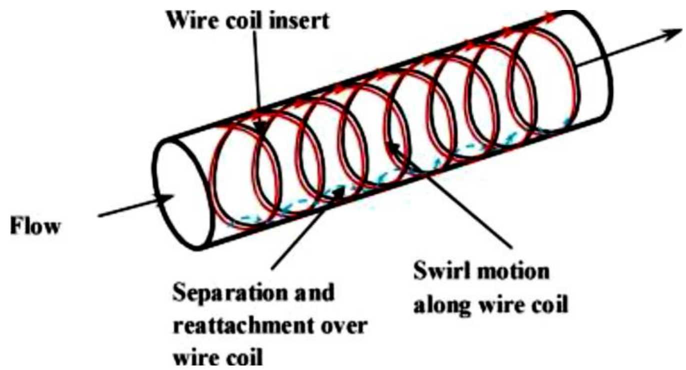
$$\Pr = \frac{\upsilon}{\alpha} \qquad (3)$$

II. Insert of Wire Coil

Various engineering and industrial applications include air conditioning, cooling devices, cooling and heating systems, etc. Figure (1) shows that wire coils are inserted to enhance heat transfer, which is one of the passive methods adopted in these devices [13].

The following points show the main benefits of improving heat transfer in heat exchangers by inserting wire coils compared to other techniques used [14]:

1. Simple manufacturing process and lower cost.
2. Easy to remove and install.
3. The original tube does not affect the mechanical strength.



Figure, 1 Insert the wire coil inside the pipe along the axis of the fluid flow [13].

2.1. Insert of Wire Coil in Laminar Flow

Table (1) reviews the important analysis of wire coils used for laminar flow type. Inaba Hideo [15] experimentally studied the inclusion of wire coils, which increases the heat transfer rate inside the tube with turbulent flow. Several experimental relationships were presented, including the Prandtl number, the Nusselt number, and the Nusselt number as a function of the Prandtl number. They also found the length of the wire coils proportional to the pressure drop. Lieke Wang and Bengt Sunden [16] experimentally proved in the turbulent flow zone that the wire coil insert improves heat transfer compared to the twisted tape insert gives a low thermal efficiency of the pipe. Hideo Inaba et al. [17] studied the heat transfer of flowing water into a tube by inserting a wire coil with additives, reducing the intake flow. They also found that with a decrease in the flow resistance in the pipe, the coefficient of forced heat transfer gradually decreases.

TABLE I. An overview of the research on wire coil inserts in laminar flow.

Name of author	Type of Fluid	Wire coil shape	Kind of Study	Remarks
Inaba Hideo [15]	Water	Coil of wire	Experimental in pipe flow with circular cross-section	Low-pressure loss and high rate of heat transfer and establish empirical correlation
Lieke Wang and Bengt Sunden [16]	Water	Coil of wire	Experimental in the pipe heat exchanger with circular cross-section	Enhance the heat transfer rate of the turbulent flow area by inserting wire coils
Hideo Inaba et al. [17]	Water	Coil of wire	Experimental in 3D pipe flow	Reduced resistance to fluid flow causes a decrease in the coefficient of forced heat transfer.

2.2. Insert of Wire Coli in Turbulent Flow

The crucial analysis of using wire coils for laminar flow type is presented in Table (2). T. S. Ravigururajan and A. E. Bergles. [18] presented an experimental study of applying the correlation in general to the friction factor and the coefficient of heat transfer by forced convection, covering the Prantl number and the type of roughness related to the B. S. Petukhov [19] relationship. H. R. Rahai and T. W. Wong. [20] deduced a decrease in the average maximum velocity of the fluid and an increase in mixing as well as an increase in the turbulent kinetic energy by increasing the large pitch spacing of the wire coils inside the tube. Eldon W. Sams [21] Experimentally analyzed the increase in the heat transfer rate in a three-dimensional pipe with single-phase turbulent flow by inserting wire coils to obstruct the flow and generate vortices. Mehmet E. Arici [22] experimentally studied the inclusion of wire coils to enhance heat transfer and turbulent fluid flow. They summarized the reduction of heat transfer for fixing the wire coil to the tube wall in increasing the number of fixed Reynolds in the pitch of the wire coil. In another case, they noticed that the increase in the pitch of the sound led to an increase in heat transfer i.e., displaced wire coils. A. García et al. [23] investigated the thermo-hydraulic behaviour of various types of techniques for improving heat transfer based on artificial roughness, including corrugated pipes, dimpled pipes, and wire coils. Among a wide range of geometric shapes discussed by the authors in the previous literature, three samples were selected for comparison between them. Experimental data were used for heat transfer and pressure drop in laminar, transitional, and turbulent systems. K. Abdul Hamid et al. [24] presented an experimental investigation to enhance the heat transfer rate using composite techniques by adding nanomaterials (TiO_2 and SiO_2) at volumetric concentrations (0.5 -3%) with the inclusion of a single-phase incompressible turbulent flow coil wire in the Reynolds number range (2300-12000). The wire coil inserts are designed at various pitch ratios over diameter (P/D) in the range of (0.83–4.17). The experimental results showed the heat transfer performance improved by (254.4 %) compared to the empty tube. Taha Tuna Göksu and Fuat Yılmaz [25] presented a numerical study using the Ansys Fluent program to improve heat transfer with a single-phase turbulent flow for the Reynolds number range (4387 and 18415) in a channel with a square cross-section by inserting a wire coil in two different cases, the first circular and the other triangular to show the effect of the geometric shape on the thermohydraulic properties. The results indicated that the number of Nusselt marks improved significantly when using a wire coil compared to an empty channel. Arvind A. Kapse et al. [26] experimentally evaluated the thermal performance of a circular copper tube in a heat exchanger using the passive method by inserting a wire coil with turbulent water flow for the Reynolds number (8000-32000) experimental mathematical equations of the Nusselt number and the friction factor were verified with the numerical side. The range of 0.846 to 0.921 is seen in the average performance ratios considering the equal pumping power criterion, which is also presented. Sarmad A. Ali and Suhad A. Rasheed [27] focused on doing numerical simulations of three channels with equal hydraulic diameters of 0.15 m (square, rectangle, and triangle) and filled glass balls with a diameter of 0.012 m as a porous material via forced convection heat transfer. Although the upper surface of the test portion is thermally insulated, the bottom surface experiences a uniform heat flux along the fluid flow of (5 kW /m^2). The study simulation and fluid flow analysis inside three channels were conducted using the turbulent k-ε model. The work aims to improve the thermal characteristics of a liquid (water) and examine its impact on temperature distribution, velocity, and pressure.

TABLE II. Investigations on wire coil inserts in turbulent flow summarized.

Name of author	Type of Fluid	Wire coil shape	Kind of Study	Remarks
T. S. Ravigururajan and A. E. Bergles. [18]	Water	Inserting coils of wire	Experimental in single-phase for pipe	Development and derivation of experimental relationships of the Nusselt number and friction factor.
H. R. Rahai and T. W. Wong. [19]	Air	Inserting coils of wire	Experimental in the turbulent jet from round tubes	Decrease in the average maximum velocity of the fluid due to an increase in the large mixing spacing, kinetic energy, and half the width of the coil.
Eldon W. Sams [21]	Air	Inserting coils of wire	Experimental turbulent flow in pipe	The developed correlation of the heat transfer rate and the friction factor as well as by the wire coils generates vortices for the fluid flow inside the tube.
Mehmet E. Arici [22]	Water	Inserting coils of wire	Turbulent flow experiment in a pipe	The heat transfer rate represented by the number of Nusselt increases by increasing the pitch of the wire coils of the three-dimensional pipe.
García et al. [23]	water	Inserting coils of wire, dimple surface, and corrugated pipe	Numerical analysis to heat transfer enhancement using three methods wire coils, dimple, and corrugated	The pressure drop characteristics are more influenced by the form of the artificial roughness than by the enhancement of heat transfer.

				Similarly, this form has a major role in determining how quickly the shift to turbulence occurs and whether it happens smoothly or abruptly.
K. Abdul Hamid et al. [24]	water	Inclusion of nanomaterial with a wire coil as a composite technology	Experimental investigation to improve turbulent flow in the tube	• Applications involving heat transmission can benefit greatly from TiO_2-SiO_2 nanofluids with wire coils. • Heat transfer performance improved by (254.4 %) compared to the empty tube.
Taha Tuna Göksu and Fuat Yılmaz [25]	water	Circular and triangular wire coil	Numerical realization of the use of different types of wire coil to improve the flow and heat transfer properties	• The performance coefficient of the numerical study is 30% greater than that of a plain tube, indicating its efficacy and prominence in improving heat transportation.
Arvind A. Kapse et al. [26]	water	Inserting coils of wire	Experimental analysis of heat transfer and pressure drop by inserting a wire coil into a circular tube	• The rate of the Nusselt number is gradually increased by increasing the Reynolds number and with the inclusion of a wire coil. • Compared with the empty tube, the heat transfer improvement is higher when using the wire coil.

III. CONCLUSIONS

The current study reviews the priority and importance given to the use of the passive method of heat transfer by inserting wire coils. It was concluded that it is possible to use every passive method to enhance heat transfer. In addition, the thermal performance of the wire coils depends on the number of Prandtl laminar flows. Also, it performs the best improvement of the heat transfer rate by turbulent flow compared to any other inclusion. Moreover, the spiral shape of the coiled wires significantly helps by creating a vortex type to obstruct the flow, thereby increasing the heat transfer rates. However, the pressure resistance requirements are high and cause an increase in friction resistance. Two strategies are proposed for future research in this field to promote heat transmission. One involves using a wire coil with a hybrid nanofluid to increase the thermal conductivity coefficient. In general, the study concludes that in engineering industrial applications, the inclusion of a wire coil is suitable for increasing heat transfer and improving the properties of laminar or turbulent flow.

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NOMENCLATURE

D_h	Hydraulic diameter of pipe (m)
f	Friction factor with inserted wire coil in the pipe
f_o	Friction factor without inserted wire coil in the pipe
k	Turbulent kinetic energy (J/kg)
L	Length of pipe (m)
Nu	Nusselt number with inserted wire coil in the pipe
Nu_o	Nusselt number without inserted wire coil in the pipe
p	Pressure (N/m^2)
u	Fluid velocity (m/s)
α	diffusion in heat (m^2/s)
ε	Turbulent dissipation rate (J/kg. s)
ρ	Fluid density (kg/m^3)
υ	diffusion in momentum (m^2/s)

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