Effect of Coil and Pitch Variation on Thermo-physical Performance of Wire Coil Insert in Tubes

Pardeep Kumar, Manoj Kumar Sain, Praveen Saraswat, Naveen Kumar Sain, Dinesh Kumar Sharma

Department of Mechanical Engineering, Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur, India

Email: **manoj.sain@skit.ac.in, praveen.saraswat@skit.ac.in, naveen.sain@skit.ac.in, dinesh.sharma@skit.ac.in**

Received 29.04.2023 **received in revised form** 02.10.2023, **accepted** 16.10.2023

DOI: 10.47904/IJSKIT.13.2.2023.60-64

Abstract- **Determining the physical characteristics of substances is crucial in the number of sophisticated engineering applications. The physical characteristics of fluids (liquids and gases), such as thermal conductivity, specific heat, density, etc. have a great influence on the design of several engineering applications, such as heat exchangers. One of the goals of this study is to reinforce and enhance certain heat transport concepts, such as convection.**

This research provides a comprehensive experimental analysis of the laminar and transitional behavior of five wire coils with various pitch sizes inside a smooth tube. The heat transfer and pressure drop inside a circular tube fitted with a coiled wired turbulator are reported for a turbulent regime with Reynolds number ranging from 2000 to 10000 and a Prandtl number of 0.7. Results have shown a considerable increase in the pressure drop proportional to the pitch of the spring and thickness of the wire. As compared to regular pipes and coiled pipes with different pitches, the heat transfer characteristics of the conical coil is superior. The conical sets with decreasing pitch appear to have the greatest effectiveness for this improvement. The highest value of the coefficient of friction is noted at Reynolds numbers ranging between 2200 and 3000.

Keyword: **Friction Factor, Pressure Drop, Coil Wire Insert, Heat Transfer.**

1. INTRODUCTION

The design of a heat exchanger is quite decisive for heat exchange between two fluids at different temperatures. The objective of the design is to enhance the heat transfer rate even at low-temperature gradients and to reduce the pressure drop. The applications of heat exchangers are quite versatile and numerous such as in power generation, air-conditioning, automotive sector, etc. Furthermore, heat exchangers allow for the efficient transfer of heat and improve energy efficiency, reduce costs, and thus, minimize environmental impact. Initiatives have been taken to make heat exchangers compact, effective and economical. Heat transfer improvements can generally be classified into two categories. The passive approach consists of swirl flow devices, stretched surfaces, and rough surfaces, in this coiled wire or twisted tape, generally known as "turbulators" are used. In this project, we used round springs with different pitches as turbulators. There are numerous ways to improve the heat transfer and effectiveness of heat exchangers by increasing the heat transfer area and regeneration of the boundary layer using turbulators. These practices are often used to make heat exchangers compact and economical. The flow of air through the tube used to convey heated air and its heat transfer through the tube are of relevance to engineering. The form of energy in transit is heat. The transmission of energy is caused by a variation in temperature because heat happens at the molecular level. Through fluids, heat is carried through convection, through solids by conduction, and through empty space by radiation. The sign for heat is Q.

In this study, coiled wire is inserted into tubes to enhance heat transfer using forced convection techniques. It is mainly useful to create turbulence inside the tube resulting in an enhanced convective heat transfer coefficient. Further, using jet impingement, offset strip fins, and other techniques, the flow boundary layer's thickness can be reduced. In addition to this, several other ways such as swirl flow tool, rough internal surface, or duct rotation can be used to enhance turbulence inside a tube. A closer look at the convective heat transfer mechanism led to the development of the current innovative method for enhancing heat transmission. Several novel techniques to enhance heat transfer have been developed, and this idea offers a fresh understanding of a variety of heat transfer processes and standard methods of enhancement in heat transfer. The aim of the study is to investigate the heat transfer characteristics and pressure drop of a wire-coiled tube with a varying pitch. A lot of research has gone into the creation of tools and the conduct of experiments in order to investigate the conditions which could enhance heat and mass transfer. Two or more of these approaches may be used together to get a larger increase than what one technique alone would provide. Compound enhancement refers to this concurrent use. It should be noted that one of the objectives of research on increased heat transfer is to determine how a preexisting disease affects heat transfer. Examples of this include, the roughness brought on by routine production, the degassing of highly gaseous liquids, surface vibration brought on by rotating machinery, fluid vibration brought on by pump pulsations, and the presence of electric fields in electrical appliances etc.

2. LITERATURE SURVEY

The review of research studies on heat transfer enhancement that have been done by various researchers is included in this section.

Ventsislav [1] conducted an evaluation of the hydraulic and thermal properties of wire coil and twisted tape inserts. The assessment was based on the extended performance evaluation criteria (PEC), using various wire coil inserts that were inserted into tubes. Tube inserts are commonly used in retrofit designs, particularly for shell-tube type heat exchangers as a larger surface area is there for efficient heat transfer. Therefore, tube inserts are frequently employed in such situations. In another study, a concentric twin-pipe heat exchanger was used to evaluate the impact of twisted tape insertion on heat transfer and flow friction characteristics. The twist ratios were varied to enhance the swirl flow inside the tube which could result in an increase in the heat transfer rate. The maximum Nusselt number values for enhancement equipment having values of y as 5.0 and 7.0 were found to be 188% and 159% more as compared to the plain tubes, respectively [2].

Bhardwaj et al. [3] investigated the use of spirally grooved tubes with a twisted tape insert to improve heat transfer and fluid flow characteristics. The grooves were oriented clockwise in relation to the flow direction, and twisted tapes with twist ratios of Y' 3.4, 7.95, and 10.15 were used for the investigation. The study found that thermo-hydraulic properties were inclined to anticlockwise and clockwise twist directions. Comparisons were also made between the properties of smooth tubes and spirally grooved tubes with and without twisted tape while maintaining constant pumping power. The results revealed that the rate of transfer of heat increased significantly in the laminar zone of Reynolds numbers but only slightly in the turbulent zone. However, over a Reynolds number transition region, heat transfer was reduced for both tubes.

Sarada et al. [4] investigated the effect of mesh inserts to improve the turbulent heat transfer rate in a circular tube. There were 16 different kinds of mesh inserts used in this study with screen diameters ranging between 10 to 20 mm and varying porosities between screens. The Reynolds number resulted between 7000 and 14000. It had been reported from the results of this study that mesh inserts doubled the heat transfer rate while pressure drop just got 1.45 times as compared to the plain tube at the same mass flow rate.

Another study by Yadav [5] conducted experiments and observed the effect of twisted-tape (half-length) turbulators on pressure reduction and heat transmission inside twin pipes with a U-bend heat exchanger. The inner tube of the heat exchanger was fitted with half-length twisted tape to create a whirling flow. Half-length twisted tape inserts had a 39% higher heat transfer coefficient than standard heat exchangers. The study also revealed that the heat transfer characteristics of half-length twisted tape were superior to those of plain heat exchangers when measured by equivalent mass flow rate, while heat transfer characteristics of plain smooth tubes were comparatively good than those of twisted tape (half-length), when measured by unit pressure drop. Additionally, plain heat exchangers were found to function thermally 1.3–1.5 times better than half-length twisted tape.

Naphon [6] conducted a study on the impact of coil-wire inserts on pressure drop and heat transfer in horizontally concentric tubes. The effects of coil pitch and other factors on pressure reduction and heat transfer rate characteristics were analyzed. The results indicated that coil-wire inserts significantly enhance heat transfer, especially in the laminar flow region. The study suggests that non-isothermal correlations can be used to predict the heat transfer coefficient and friction factor. The results obtained are consistent with the expected results, demonstrating good agreement between theory and experiment.

The study conducted by Murugesan et al. [7] investigated the heat transfer characteristics and pressure drop of V-cut twisted tape inserts in a circular tube. The research examined different twist ratios and different combinations of depth-to-width ratios to report their effect on friction factor and heat transfer. The study's results reported that the friction factor and average Nusselt number in these tubes were directly proportional to depth ratios and inversely proportional to width ratios, twist ratios (y), and depth ratios (DR). This implies that the heat transfer enhancement and pressure drop increase with increasing depth ratios and decreasing width ratios, twist ratios, and DRs. The experimental results were compared with an empirical correlation to demonstrate a ±10% and ±6% variation in the friction factor and Nusselt number, respectively. This indicates the reliability of the experimental results and the accuracy of the empirical correlation used.

The study by Theonponga et al. [8] on the enhancement of heat transmission in heat exchanger tubes using perforated twisted tapes (PTTs) with parallel wings is a valuable contribution to the field of heat transfer. The research aims to investigate the effectiveness of PTTs with different wing depth ratios and hole diameter ratios in improving heat transmission. The study's results showed that the use of PTTs improved heat transmission by 208%, compared to plain tubes, while typical twisted tapes improved heat transmission by 190%. This indicates that PTTs with parallel wings are more effective in enhancing heat transmission than typical twisted tapes. The study also developed empirical correlations between thermal performance, heat transfer, and friction factor for tubes with PTTs. The use of PTT dye injection enabled the observation of the axial/swirling flow patterns, which provides a better understanding of the flow behavior and heat transfer characteristics inside the tubes with PTTs. The study's methodology, experimental setup, and analysis are well-structured and reliable, making it a valuable reference for future research in this field.

Wolverine Tube Industry has released a data book for engineers that outlines various techniques for calculating heat transfer rate and pressure drop in turbulent flows within different types of tubes, including corrugated tubes, fine tubes, and tubes with twisted tape inserts. It also allows to estimate the impact of inlet configuration on heat transfer rate and pressure drop even in the transition region between laminar and turbulent flow inside plain tubes. In addition, the book includes an overview of forecasting techniques for turbulent flow heat transfer in plane tubes to assist readers. The data book is a valuable resource for engineers seeking to improve their understanding of heat transfer and pressure drop in different types of tubes [9].

Hamid et al. [10] conducted experiments encompassing a wide range of Reynolds numbers, spanning from 2300 to 12,000. Their primary objective was to assess the heat transfer efficiency and friction characteristics of TiO_2-SiO_2 nanofluids when utilizing wire coil inserts. To generate the TiO_2-SiO_2 nanofluids, a meticulous two-step method was employed, varying the volume concentrations from 0.5% to 3.0%. Additionally, the wire coil inserts were configured with diverse pitch-to-diameter (P/D) ratios, ranging from 0.83 to 4.17.

This study reported by Keklikcioglu and Ozceyhan [11] delved into the impact of employing convergent, convergent-divergent, and divergent conical wire coils within a flow region containing a mixture of ethylene glycol and water. For the experiments, three distinct volumetric ratios of ethylene glycol and water, specifically (0:100), (20:80), and (40:60), were considered. Convergent, convergent-divergent, and divergent conical wire coils with two different pitch ratios, 2 and 3, were employed in the setup. The experimental conditions involved turbulent flow, with Reynolds numbers ranging from 4627 to 25,099, and a constant heat flux. The utilization of conical wire coils was found to significantly increase both the heat transfer rate and fluid friction. Conversely, the introduction of ethylene glycol into pure water resulted in a decrease in the heat transfer rate, with only a slight increase in the friction factor.

In another study by Khorasani et al. [12], it was highlighted that altering the pitch and wire diameter had a substantial impact on the thermal performance of the helical heat exchanger. Increasing the spring pitch and wire diameter of the spiral tube led to an increase in the Nusselt (Nu) number by as much as 73% and 70%, respectively.

This study evaluates the heat transfer rate, pressure drop, and impact of surface roughness on turbulence intensity in wire-coiled tubes of different diameters and pitches.

3. EXPERIMENTAL SET-UP

An open-loop experimental setup is configured to conduct the experiments for the desired investigation, as shown in Figure 1. The setup comprised of a 7.5 kW blower, a 2500 mm calming tube, and a coiled wire insert inside a tube of 47.5 mm diameter. This copper test tube has a length of 305 mm, and a wall thickness of 1.5 mm as reported in Table 1. The coiled wire insert is made of a small steel wire with square and circular cross sections of 2- and 3-mm thickness. The tube contained two arrays of coiled wires (15- and 20-mm spring pitches) with various cross sections, which were introduced into the tube from a wall-attached position. To ensure a homogenous heat flux boundary condition, the tube was heated by continuously encircling a flexible electrical wire. The electrical output power was controlled by a variable dimmer stat to maintain a constant heat flux along the entire length of the test section, with the current kept below 3 A. Measures were taken to prevent system leaks and convective heat loss to the environment. A multi-channel temperature measuring equipment and type K thermocouples were used to monitor the interior and external temperatures of bulk air at various locations.

Table 1 Technical specifications of the experimental setup

S. No.	Specifications	Unit	Value
1	Length of test pipe	mm	304.8
2	Diameter of test pipe	mm	31.75
3	Digital Ammeter	A	0-20
4	Digital Voltmeter	V	0-750
5	Temperature indicator	°C	0-600

6	Blower	kW	7.5
7	Heater	kW	0.7

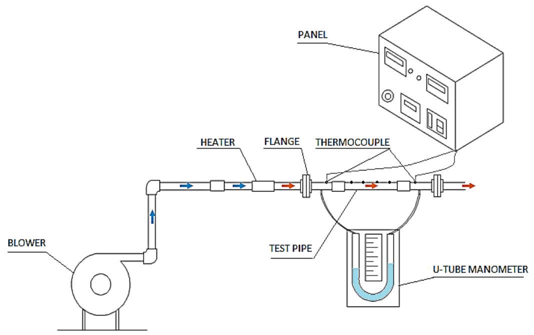

Figure 1: Experimental setup

As shown in Figure 1, Five thermocouples are placed around the tube to measure circumferential temperature variation, and another five are on the local wall of the tube. The airflow rate has been measured with the help of an anemometer whereas a U-tube manometer filled with water is used to note pressure variations at different Reynolds numbers. The U-tube manometers were also used to measure the pressure drop in the heat transfer test tubes. The volumetric airflow rates from the blower could be adjusted by changing the motor speed. An electrical heater, wrapped around the test portion and with adjustable settings, was used to warm the bulk air during the experiments. Thermocouples were calibrated to within 0.2°C using a thermostat before use to measure the entrance and exit temperatures of the bulk air from the tube. The Nusselt number has been calculated with the help of an average of temperature readings at different positions along the outside of the test pipe. Similarly, the bulk air's temperature, volumetric flow rate, and pressure drop are recorded for each test under steady-state conditions, while maintaining the inlet temperature of air at 25 °C.

4. RESULT AND DISCUSSIONS

The apparatus setup described earlier was used to pass 25 °C bulk air from a 7.5 kW blower through the orifice meter and into the heat transfer test section. The anemometer was used to measure the rate of airflow. The small pressure decrease experienced at low Reynolds numbers was accurately measured using U-tube manometers and water with a specific gravity of 0.826. The pressure decreases in the test tube used for measuring heat transfer was observed using U-tube manometers. The volumetric air flow rates from the blower could be adjusted by changing the motor speed through the inverter before the test tube's entrance. An electrical heater with adjustable settings was used to warm the bulk air during the experiments. The input and exit temperatures of the bulk air from the tube were measured using multi-channel Chromel constantan thermocouples that had been calibrated to within 0.2°C by a thermostat. Table 2 shows the desired outputs from the experimental investigation.

Table 2: Desired output from the experimental investigation

	H_{mano}	Velocity (m/s)	T_{in} (°C)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_{out} (°C)
Plain Pipe	6	1.5	56	48	43	42	50
		2	58	51	46	44	52
		3	55	51	49	42	54
		4	55	50	48	42	51
		5	52	51	50	45	51
Coil Pitch 12”	6	1.5	57	46	45	40	52
		2	59	52	48	43	53
		3	55	51	48	45	55
		4	56	51	47	41	52
		5	51	49	45	43	49
Coil Pitch 9”	7	1.5	61	47	45	44	55
		2	55	46	41	40	49
		3	54	48	45	40	53
		4	54	50	49	40	53
		5	52	50	48	42	51
Coil Pitch 6”	8	1.5	50	41	35	34	49
		2	59	49	47	40	56
		3	57	50	46	41	55
		4	52	47	45	40	51
		5	53	51	45	41	51

Table 3 Results for pipe with conical spring set-1

v m/s	h_{exp} W/m^2-K	$h_{theo.}$ W/m^2-K	Re	Pr	Nu	η %	f
1.5	46.55	9.99	2712	0.70	11.6	97.9	0.07
2	60.34	12.46	3682	0.70	14.2	98.6	0.06
3	90.96	17.31	5423	0.70	19.4	98.2	0.03
4	120.1	1.78	7257	0.70	24.5	98.7	0.01
5	148.7	26.06	9196	0.70	29.6	98.1	0.01

Table 3 reports the Reynolds, Prandtl, average Nusselt, efficiency enhancement, and friction factor values for conical spring set 1 at various velocities.

Table 4 Results for pipe with conical spring set -2

v m/s	h_{exp} W/m^2-K	$h_{theo.}$ W/m^2-K	Re	Pr	Nu	η %	f
1.5	46.23	9.96	2689	0.70	11.5	94.9	0.07
2	60.04	12.52	3624	0.70	14.0	95.5	0.05
3	88.66	17.29	5456	0.70	19.5	95.2	0.02
4	120.6	21.73	7319	0.70	24.6	95.3	0.01
5	149.9	25.94	9193	0.70	29.6	94.6	0.01

Table 4 reports the various Reynolds, Prandtl, average Nusselt, efficiency enhancement, and friction factor values for conical spring set 2 at various velocities.

5. CONCLUSION

This experiment investigated the effects of using coiled square wire turbulators on heat transfer and airflow friction in a circular tube, with a Reynolds number range of 2000-10,000 and a Prandtl number of 0.7. Results showed that the use of coiled circular wire turbulators resulted in significant improvements in heat transfer and a large pressure variation that was mainly influenced by wire thickness and spring pitches. However, the Nusselt number enhancement tends to decrease rapidly as Reynolds number increases. Comparing the wire coils to a smooth tube with constant pumping power, especially at low Reynolds numbers, the rate of heat transfer is higher. Despite substantial differences in wire coil analyses, their performance was similar. By using coiled circular wire instead of smooth wire, the heat exchanger can be made smaller due to the increased heat transfer rate and performance.

Future research on wire coil inserts in tubes can be focused on optimization techniques, experimental validation, and advanced materials. Understanding fluid dynamics, transient behavior, and environmental impact is crucial. Practical applications, education, and standardization efforts will help optimize performance and sustainability in various industries.

REFERENCES

[1] V. Zimparov, "Energy conservation through heat transfer enhancement Techniques", international journal of energy research, vol 26, no.-3, pp.675-696, June 2001.

[2] W. Noothong, S. Eiamsa-ard and P. Promvonge. "Effect of Twisted-tape Inserts on Heat Transfer in a Tube", Proceeding of the second joint International Conference on "Sustainable Energy and Environment, pp.1-5, 2006.

[3] P. Bharadwaj, A.D. Khondge, A.W. Date, "Heat transfer and pressure drop in a spirally grooved tube with twisted tape insert", proceeding of the international journal of Heat and mass transfer 52, pp.1938-1944 2009.

[4] N. Sarada S., K. K. Radha and A. V. S. Raju, "Investigation in a circular tube to enhance turbulent heat transfer using mesh inserts", Int. J. Heat mass transfer vol. 4, no. 5, pp.53- 60, July 2009.

[5] A. Yadav, Effect of Half Length Twisted-Tape Turbulators on Heat Transfer and "Pressure Drop Characteristics inside a Double Pipe U-Bend Heat Exchanger", Jordan journal of mechanical and industrial engg. Vol. 3, No. 1, pp. 17-22, March. 2009.

[6] P. Naphon, T. Suchana "Heat transfer enhancement and pressure drop of the horizontal concentric tube with twisted wires brush inserts", International Communications in Heat and Mass Transfer 38, pp.236–241, 2011.

[7] P. Murugesan, K. Mayilsamy, S. Suresh, P.S.S. Srinivasan, "Heat transfer and pressure drop characteristics in a circular tube fitted with and without V-cut twisted tape insert", International Communications in Heat and Mass Transfer 38, pp. 329–334, 2011.

[8] C. Thianponga, P. Eiamsa-arda, P. Promvongea, S. Eiamsaardb, "Effect of perforated twisted-tapes with parallel wings on heat transfer enhancement in a heat exchanger tube", Energy Procedia,14, pp.1117 – 1123,2012.

[9] A. E. Zohir, M. A. Habib & M. A. Nemitallah, "Heat transfer characteristics in a Double-Pipe Heat Exchanger Equipped with coiled circular wires", PP 1-17, 2015.

[10] K. A. Hamid, W. H. Azmi, R. Mamat, & V. K. Sharma, "Heat transfer performance of TiO2–SiO2 nanofluids in a tube with wire coil inserts". Applied Thermal Engineering, 152, pp275-286, 2019.

[11] O. Keklikcioglu, & V. Ozceyhan, "Heat transfer augmentation in a tube with conical wire coils using a mixture of ethylene glycol/water as a fluid". International Journal of Thermal Sciences, 171, 107204,2022.

[12] S. Khorasani, S. Jafarmadar, S. Pourhedayat, M.A. A. Abdollahi, & A. Heydarpour, "Experimental investigations on the effect of geometrical properties of helical wire turbulators on thermal performance of a helically coiled tube". Applied thermal engineering, 147, 983-990, 2019.