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# Effect of Spring Turbulators on Heat Transfer Performance in Double Pipe Heat Exchangers: A Parametric Analysis

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## Abstract

*This study presents a parametric analysis of a double-pipe heat exchanger (DPHX) equipped with spring turbulators designed to enhance thermal performance. By increasing the heat transfer coefficient, these turbulators significantly boost heat transfer efficiency. However, this improvement is accompanied by an increased pressure drop, illustrating the balance between thermal enhancement and hydraulic performance.*
*Our investigation focuses on the relationship between the overall heat transfer coefficient, Dean Number, Nusselt number, and the geometric parameters of the spring turbulators. Results show that as Dean Number increases, both the Nusselt number and heat transfer coefficient rise. Larger diameters and pitches of the spring turbulators also contribute to higher heat transfer rates. Conversely, while pressure drop decreases with increasing Dean Number, smaller diameters and larger pitches lead to higher pressure losses. These findings underscore the potential of spring turbulators in optimizing DPHX performance with strategic trade-offs.*

Keywords: heat exchanger, spring turbulators, Nusselt number, Dean number, pressure drop, heat transfer coefficient.

**Nomenclature:**

| | | | |
|---|---|---|---|
| $\beta$ | Dimensionless wire diameter | $K_c$ | Thermal conductivity of cold fluid |
| $\gamma$ | Dimensionless pitch | $K_h$ | Thermal conductivity of hot fluid |
| $\mu_c$ | Absolute viscosity of cold fluid | NTU | Number of transfer units |
| $\mu_h$ | Absolute viscosity of hot fluid | $Nu_a$ | Nusselt number of flow through annulus |
| $Þ_c$ | Density of cold fluid | $Nu_p$ | Nusselt number of the pipe flow |
| $Þ_h$ | Density of hot fluid | $Nu_s$ | Nusselt number from flow through spring turbulators |
| $\xi$ | Effectiveness | P | Pitch of spring turbulators |
| $A_0$ | Heat transfer area | $Pr_c$ | Prandtl number of cold fluid |
| $c_{min}$ | Minimum heat capacity | $Pr_h$ | Prandtl number of hot fluid |
| C | Ratio of heat capacities | Q | Actual heat transfer |
| d | Diameter of spring turbulator | $Q_{max}$ | Maximum heat transfer possible |
| D | Coil diameter of spring turbulator | $r_c$ | Curvature ratio |
| De | Dean Number | $Re_a$ | Reynolds number of flow through annulus |
| $D_{ea}$ | Equivalent diameter of annulus | $Re_p$ | Reynolds number of the pipe flow |
| $D_h$ | Hydraulic diameter | $R_{f,o}$ | Fouling factor |
| $f$ | Friction factor | $\Delta T_{max}$ | Maximum temperature difference |
| $h_a$ | Heat transfer co-efficient of flow through annulus | U | Overall heat transfer co-efficient |
| $h_p$ | Heat transfer co-efficient of the pipe flow | $V_a$ | Velocity of flow through annulus |
| $h_s$ | Heat transfer co-efficient for flow through spring turbulators | $V_p$ | Velocity of flow through pipe |
| $\Delta P$ | Pressure drop | | |

## 1. Introduction

The study of heat transfer enhancement in double pipe heat exchanger is an active area of research. In industries this Double Pipe Heat Exchanger (DPHX) is not widely used due to its low thermal efficiency compared to other types of heat exchangers. But its efficiency can be increased by using turbulators in the inner pipe section. Spring turbulator is a great addition having many advantages like thermal boundary layer reduction, fouling reduction due to turbulent flow, design compactness, flexibility in retrofitting and so on. Parametric analysis plays an important role in this study. Spring's different physical parameters can be varied to observe significant change in DPHX heat transfer efficiency.

Several researches have been carried out regarding DPHX performance enhancement. In 2013, Karakaya et al. explored the use of conical spring turbulators in heat exchangers, evaluating their performance across different angles and Reynolds numbers. [1] Kamboj et al. (2017) focused on optimizing the pitch of divergent-convergent spring turbulators to maximize heat transfer while minimizing power consumption. [2] Pourhedayat et al. (2019) provided comprehensive analysis and empirical correlations for helical tubes equipped with spring-wire turbulators, showing that the geometry of the spring-wire significantly influences the heat transfer coefficient, Nusselt number, and exergy destruction. [3]

Klaczak (2014) conducted experimental investigations on heat transfer in tubes with spiral and helical turbulators, presenting correlations for calculating the Nusselt number of tubes fitted with these turbulators. [4] Yakut and Sahin (2004) studied the vortex effect of coiled wire turbulators on heat transfer improvement in straight tubes, revealing that increasing the wire pitch reduces vortex shedding frequencies. [5] Promvonge (2011) experimentally studied the thermal performance of circular tubes with twisted tape and wire coil turbulators, demonstrating that their combined use can enhance heat transfer up to double the amount achieved by either method alone. [6]

Raghulnath et al. (2018) investigated the influence of circumferential turbulators on heat transfer performance in shell and tube heat exchangers. They found that inserting a helical turbulator increases turbulence and improves the heat transfer coefficient on the tube side. [7] Salari and Goudarzi (2018) numerically studied heat transfer intensification in tubes using spiral spring turbulators with different cross-sectional shapes, reporting significant enhancements in the Nusselt number, particularly with triangular cross-sections. [8]

The exergy loss and thermal performance caused by conical spring turbulators were experimentally studied by Karakaya and Durmus (2013). They provided empirical correlations expressing how Reynolds numbers affect the heat transfer coefficient, pressure drop, and exergy efficiency in pipes with and without conical spring turbulators. [9] Chompookham et al. (2010) studied the effect of serrated helical wire coil inserts on heat transfer and fluid flow in tubular heat exchangers, reporting that decreasing wire pitch increases the heat transfer coefficient. [10]

More recently, Promvonge (2014) explored the thermal performance of circular tubes fitted with coiled square wires, finding that square wire turbulators significantly enhance thermal performance compared to circular wire inserts. [11] Yang et al. (2015) used the Taguchi method to numerically investigate the performance of spiral corrugated tubes, identifying geometric parameters that optimize heat transfer. [12] Zhou et al. (2019) examined the combined use of spring turbulators and air bubble injection in straight pipes, achieving up to 40% enhancement in the Nusselt number. [13]

Panahi and Zamzamian (2020) investigated the thermal performance improvement of shell and coiled heat exchangers with helical tubes equipped with helical wire turbulators, showing that these turbulators enhance heat transfer and pressure drop. [14] Hashemian et al. (2021) studied the hydraulic, thermal, and exergetic performance of two-phase flow in helically coiled tubes fitted with helical wire turbulators, finding that smooth helically coiled tubes exhibited higher exergetic performance. [15] Mashoofi et al. (2022) conducted experimental research on tube-in-tube helical heat exchangers with spring wire turbulators, demonstrating significant improvements in thermal performance. [16]

Zhai et al. (2023) explored the thermo-hydraulic performance of nanofluid flow in spirally coiled tubes with varying screw pitch and rotation angles, identifying critical Reynolds numbers where performance peaks. [17] Fayez Aldawi (2022) experimentally investigated the use of spring wire turbulators in spirally coiled tubes in solar ponds, achieving up to 170% growth in the Nusselt number. [18] Khosravi-Bizhaem and Abbassi (2021) studied the effect of curvature ratio on entropy generation in curved, coiled tubes using nanofluid flow, finding that increasing nanofluid volume fraction enhances the tube's performance index. [19]

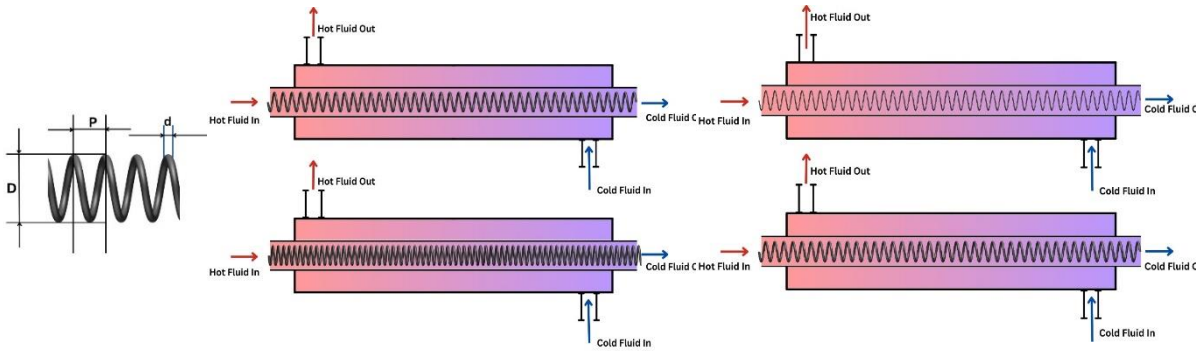
While these studies have provided valuable insights into various turbulator designs, there remains a gap in the comprehensive parametric analysis of spring turbulators in DPHXs. Our research aims to fill this gap by conducting a detailed parametric study on the effects of spring turbulator geometry on heat transfer characteristics in DPHXs. Our motivation for this research stems from the need to optimize heat exchanger performance across various industries. Our study investigates the effects of spring turbulators on the overall heat transfer coefficient of a DPHX, with particular emphasis on the relationship between Dean Number, Nusselt number, and various

geometric parameters of the spring turbulator. We have demonstrated that increasing the Dean Number leads to a corresponding increase in the Nusselt number and consequently, the heat transfer coefficient. For a given Dean Number, larger diameters and pitches of the spring turbulator result in higher Nusselt numbers and heat transfer coefficients. Conversely, the pressure drop decreases with increasing Dean Number but shows higher values for greater pitch of the spring turbulator. By understanding the relationships between Dean Number, spring turbulator geometry, and heat transfer characteristics, we can provide valuable insights for designing more efficient heat exchangers. This research has wide-ranging applications, including industrial cooling and heating systems, HVAC systems and thermal management in the automotive and aerospace industries. The potential for improved energy efficiency and reduced operational costs makes this research particularly relevant in the context of increasing global energy demands and environmental concerns.

## 2. Methodology

For the parametric analysis, spring diameters of 0.2 mm, 0.4 mm, 0.6 mm, 0.8 mm, and 1 mm were considered while maintaining a constant pitch of 8 mm, and varying pitch values of 2 mm, 4 mm, 6 mm, and 8 mm were analyzed with the spring diameter held constant at 1 mm. Figure 1 helps to understand the differences observed in the DPHX due to the change in the turbulator geometry. The software package MATLAB was employed for the parametric analysis, utilizing the equations discussed in 2.1. The variation of the Nusselt number and pressure drop was analyzed with respect to the change in Dean number.

The Dean number (De) is considered a variable in this analysis because it plays a critical role in characterizing flow behavior in curved geometries. By accounting for the combined influences of Reynolds number and tube curvature, the Dean number helps to capture the intensity of secondary flows generated by the curvature. These secondary flows create enhanced turbulence, which in turn improves convective heat transfer by disrupting the thermal boundary layer.




(a) (b) (c)

**Fig. 1.** Visualisation of (a) Geometric parameters of the spring turbulator, (b) DPHX with variable pitch of spring turbulator, (c) DPHX with variable diameter of spring turbulator

### 2.1. Governing Equations:

The heat transfer coefficient for the pipe side without spring turbulators in the DPHX was determined using established correlations for turbulent pipe flow, ensuring accurate representation of thermal behavior in the absence of turbulators through the following expression:

$$h_p = \frac{Nu_p \times K_h}{D_h} \quad (1)$$

Where, the Nusselt number and Reynolds number for the pipe side of the DPHX are calculated using the following correlations:

$$Nu_p = 0.64 \times Re_p^{\,0.56} \times Pr_h^{\,0.3}, \quad Re_p = \frac{\rho_h \times v_p \times D_h}{\mu_h} \quad (2,3)$$

Nusselt number is obtained from the correlation for Turbulent Flow, since Reynolds number of the pipe flow was more than 2300 for this model.
For the pipe side with spring turbulators of the DPHX, heat transfer co-efficient of the pipe flow is determined by the same formula. Correlation of the Nusselt Number varies due to the spring turbulators.

$$h_s = \frac{Nu_s \times K_h}{D_h} \quad (4)$$

Here, the Nusselt number for flow through the spring turbulators is given using:

$$Nu_s = 3.81 \times De^{0.67} \times \gamma^{0.195} \times \beta^{0.447} \quad (5)$$

Nusselt Number is obtained from the correlation by using Dean Number, Dimensionless Pitch and Dimensionless wire diameter. Curvature ratio, $r_c$ is obtained from the ratio of the Coil Diameter and the wire diameter.

$$r_c = \frac{D}{d} \quad (6)$$

Dimensionless pitch, γ and dimensionless wire diameter, β are obtained by the correlation with spring pitch, wire diameter and curvature ratio.

$$\gamma = \frac{p}{2 \times 3.14 \times r_c}, \quad \beta = \frac{d}{2 \times 3.14 \times r_c} \quad (7,8)$$

The Dean number is the key parameter influencing the Nusselt number, with its correlation presented below:

$$De = Re_p \times \sqrt{\frac{D_h}{2 \times r_c}} \quad (9)$$

In the annulus region, cold fluid is assumed to flow, and no external performance-enhancing measures have been implemented. For the annulus side, heat transfer co-efficient is given by:

$$h_a = \frac{Nu_a \times K_c}{D_{ea}} \quad (10)$$

Similarly, the Nusselt number and Reynolds number for the annular region is calculated using:

$$Nu_a = 0.023 \times Re_a^{0.8} \times Pr_c^{0.4}, \quad Re_a = \frac{\rho_c \times v_a \times D_{ea}}{\mu_c} \quad (11,12)$$

Correlation of Nusselt number is obtained considering the turbulent flow. Overall heat transfer co-efficient, U is determined considering with spring turbulators. Fouling factor is denoted by $R_{f,o}$.

$$\frac{1}{U} = \frac{1}{h_a} + \frac{1}{h_s} + 2R_{f,o} \quad (13)$$

The effectiveness-NTU (Number of Transfer Units) method was employed to model the heat transfer process in the DPHX. The heat transfer rate $Q$ is given by:

$$Q = \xi \times Q_{max} \quad (14)$$

Where:

$$Q_{max} = c_{min} \times \Delta T_{max} \quad (15)$$

$$\xi = \frac{1 - e^{-NTU(1-c)}}{1 - ce^{-NTU(1-c)}}, \quad NTU = \frac{U \times A_o}{c_{min}} \quad (16,17)$$

The friction factor for the spring turbulators was calculated using the correlation:

$$f = 1.6 \times De^{-0.96} \times \gamma^{0.897} \times \beta^{-1.7} \quad (18)$$

The pressure drop $\Delta P$ across the heat exchanger is given by:

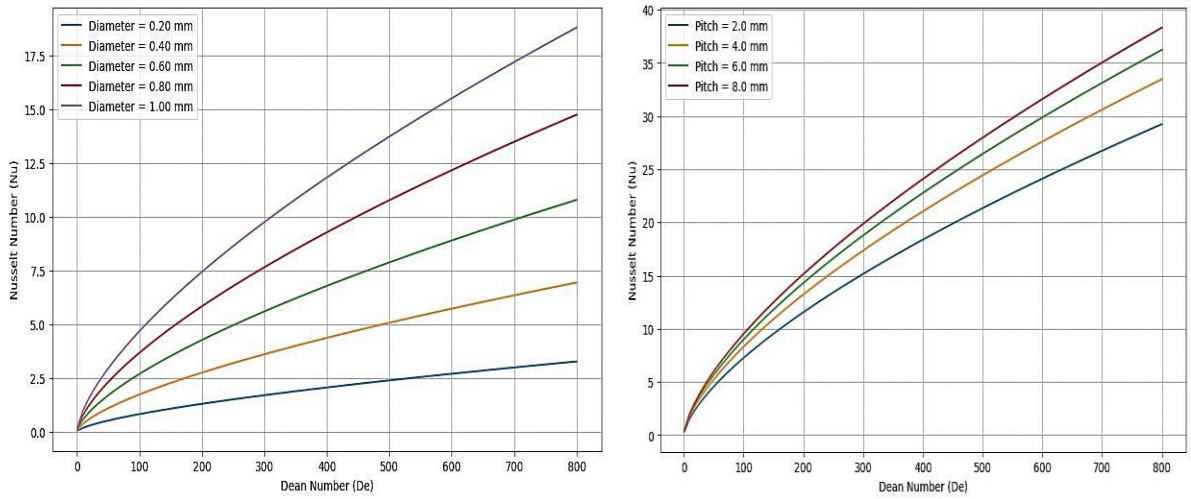
$$\Delta P = f \times \frac{L}{D_h} \times \frac{\rho v^2}{2} \quad (19)$$

## 3. Results and Discussion

### 3.1 Heat Transfer (Nusselt Number) Analysis:

The heat transfer coefficient for DPHX increases after using the spring turbulator. Using those correlations for different conditions of temperature, the heat transfer coefficient is always higher for the DPHX with spring turbulator than the general DPHX. Sharaf et al (2024) showed that the heat transfer coefficient increased significantly when spring turbulators were employed, compared to a standard DPHX without such

inserts(spring turbulators). [20] Fig.2 (a) presents the variation of Nusselt number with Dean number for different wire diameter at constant value of spring pitch. Fig.2 (b) shows the variation of Nusselt Number with Dean Number for different pitch of the spring at constant wire diameter.
From the comparison in Fig.2(a), the Nusselt is increasing with the increasing spring pitch and diameter. The maximum Nusselt number is obtained when the wire's diameter is 1mm and minimum Nusselt number is obtained at 0.2 diameter. The wire of larger diameter makes the turbulator harder, making a strong barrier for the water to flow, increasing the contact time for heat transfer and the pressure drop. Larger diameter increases the resistance to the flow of water and creates more turbulence. As turbulence is beneficial to the heat transfer, it increases the heat transfer coefficient as well as Nusselt number. In other words, the smaller diameter of the wire, lower the resistance against the water flow which effects the lower heat transfer coefficient and Nusselt number of the HX.



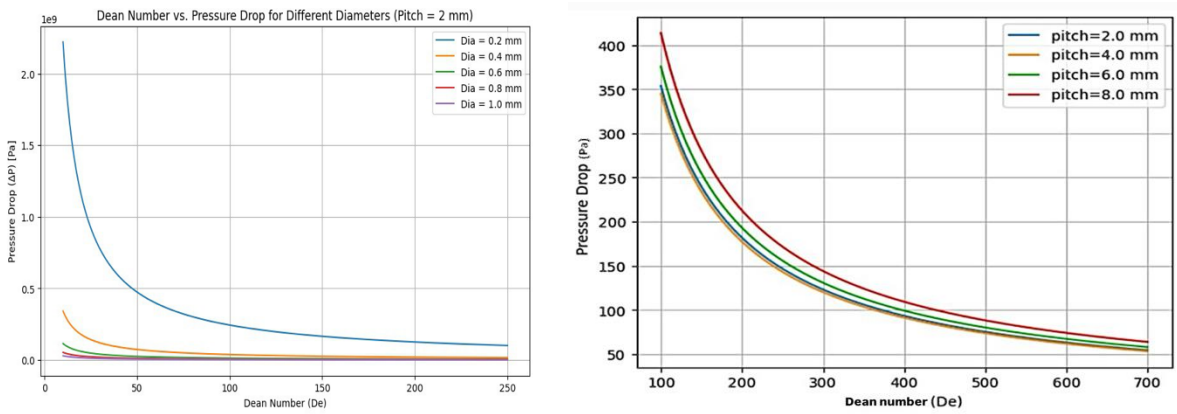

(a) (b)

**Fig.2.** Variation of Nusselt number with Dean number for (a) different spring diameters and (b) pitch

Fig.2(b) shows that the geometrical characteristics of the spring turbulator has a major impact on the Nusselt number of the HX. The pitch of the spring turbulator affects the intensity and distribution of turbulence within the fluid flow. A larger pitch generally increases turbulence enhancing the convective heat transfer between the fluid and the pipe wall. The higher Nusselt number is obtained for a higher pitch value of 8mm.Therefore, selecting the appropriate spring pitch is crucial for optimizing the heat exchanger's performance, balancing enhanced heat transfer with efficient operation.

### 3.2 Pressure Drop Analysis:

Fig.3 shows the behavior of pressure drop with Dean number. The pitch of the spring has a significant impact on the pressure drop. For smaller pitch pressure drop becomes higher due to increased flow resistance and friction. Smaller pitch springs increase friction and pressure drop, while larger pitch springs reduce friction and pressure drop by offering less resistance to flow. Balancing these effects is essential for optimizing both heat transfer performance and operational efficiency in heat exchangers. The overall heat transfer rate in the heat exchanger depends on both the heat transfer coefficient and the surface area available for heat exchanger. Larger pitches and larger diameters enhance heat transfer coefficients and Nusselt numbers, increasing pressure drops observed for smaller diameters and larger pitches as seen in Fig.3(a) and Fig.3(b). Overall heat transfer coefficient can be improved with larger diameters but can be limited by increased pressure drop.




(a) (b)

**Fig.3.** Variation of pressure drop with Dean number for different spring diameters and pitch

## 4. Conclusion

This study has provided a comprehensive parametric analysis of the thermal and hydraulic performance of a Double Pipe Heat Exchanger (DPHX) equipped with spring turbulators. Our findings indicate that the use of spring turbulators significantly enhances the overall heat transfer coefficient, driven by increases in both the Nusselt number and Dean Number. Larger spring diameters and pitches contribute to heat transfer improvement, confirming the effectiveness of geometric optimization in enhancing thermal performance.

However, this enhancement comes with a clear trade-off: the increase in pressure drop, particularly in cases where smaller diameters and larger pitches are employed. This underscores the need for careful design consideration to balance heat transfer efficiency and hydraulic losses.

Overall, our analysis affirms that while spring turbulators offer a promising approach to boosting DPHX performance, optimal performance can only be achieved by carefully managing the interaction between thermal enhancement and flow resistance. Future studies may explore this balance in experimental setups to validate and refine these findings.

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