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Thermal Analysis Study in an Annular Diffuser Fitted with Different Hub Geometries

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Abstract- The enhancement of temperature distribution for turbulent flow through an annular diffuser fitted with helical screw-tape hub and twisted square hub were numerically investigated in the present study. The simulations were performed using three twist ratios *y/w* of 1, 1.5, and 2 for the helical screw-tape hub and three twist ratios *y/w* of 1.16, 1.5, and 2.3 for the twisted square hub with Reynolds number $4x10^4$. The annular diffuser geometries and the inlet condition for both hub arrangements were kept constant. The obtained results show that the insertion of the helical screw-tape hub and the twisted square hub will force the temperature to distribute in a helical motion; thereby the turbulence intensity will increase. However the findings showed that the temperature distribution rate was increased with decreasing twist ratio under the same operating conditions. The best temperature distribution was provided by twist ratios *y/w* = 1 and *y/w* = 1.16 for the helical screw-tape hub and the twisted square hub, respectively.

Keywords- *Numerical analysis, temperature distribution, annular diffuser, twists ratio, helical screw-tape hub, twisted square hub, swirl flow*

I. INTRODUCTION

Annular diffusers are divergent flow passages that decelerate a stream of gas or liquid from a high to a low velocity and regain pressure. They play an important role in many fluid machines to convert kinetic energy into pressure energy. They are extensively used in compressors, gas turbines, pumps, fans, wind tunnels, etc. In some applications heat distribution inside these diffusers needs to be promoted, such as combustion process. It can be done by using swirl generators. These generators create turbulent flow and swirling motion that can force the heat transfer in the direction of the flow and in the direction normal to the flow (radial tangential direction) [1]. Swirling motion enhances the thermal performance mainly due to the circulation of the fluid by centrifugal convection because the low density of the warmer fluid is displaced into the cooler fluid. Swirl generators are an effective method used to increase the heat transfer rate and to enhance heat distribution through diffusers and pipes without the need to add any external power. It provides the internal flow with circular and helical motions. Many types of swirl generators have studied to enhance heat distribution such as twisted configuration [2 - 4], helical tape [1, 5], and helical screw-tape [6], etc. Helical tape inserts and twisted arrangements are the most favorable passive techniques because they are inexpensive and can be easily employed to the existing system. Eiamsa et al. [7, 8] studied experimentally different arrangements equipped with twisted tape. The effects of the co-swirl flow and the counter swirl generators through a round tube fitted with helical screw tape and twisted tape were experimentally tested [7]. The result showed that heat transfer with the combined tapes in counter –swirl arrangement was 3.4% and 10% higher than those in co-swirl arrangement and helical tape alone. Furthermore, the twin counter twisted tapes and twin co-twisted tapes as co-swirl flow generators in a test section with four different twist ratios (*y/w* = 2.5, 3.0, 3.5 and 4.0) were studied for Reynolds numbers range between 3700 and 21000 under uniform heat flux conditions [8]. The results showed that the counter-swirl tapes can enhance heat transfer more efficiently than the co-swirl tapes and it was found that heat transfer, and friction factor were increased as the twist ratio (*y/w*) decreased.

Numerical simulations were achieved to get further understand and characterize the swirling flow field [9 - 11]. Escue and Cui [9] obtained numerical study of internal swirling flow. The simulation carried out by two turbulence models, namely, the RNG k–e model and the Reynolds stress model. For validation, results with various swirl numbers were studied and compared with available experimental data. The results revealed that the RNG k–e model is in better agreement with experimental data for low swirl number, while the Reynolds stress model became more suitable as the swirl number was increased. Ehan et al. [10] numerically studied heat distribution and flow behaviors in an annular diffuser with cylindrical hub equipped with helical tape. Different helical tape pitch lengths (20 mm, 30 mm and 40 mm) and different height lengths (20 mm, 22 mm and 24mm) were simulated. The results revealed that using different pitch lengths and height lengths for the helical tape enhanced the temperature distribution. The best temperature distribution was provided by the pitch length (Y = 30 mm) and the height length (H = 22 mm).

Numerical simulations have been carried out to investigate the temperature distribution in an annular diffuser fitted with two different hub geometries using heat source [11]. The results have been made according to twisted rectangular hub with two different pitch lengths Y of 43 mm and 32 mm and pimpled hub with two different radiuses R of 3.5 mm and 4.5 mm. The results showed that pitch length *Y* of 32 mm has the best effect and the distribution of temperature will be better enhanced by using pimpled hub.

The internal flow fitted with dual twisted configuration elements had been numerically investigated by Erdemir et al. [12]. They studied the fluid flow characteristics of internal flow in turbulent flow by examining the effect of different diameter ratio (*d/D*) on the heat transfer behavior. The result showed that the creation of helical and swirling motion increased the heat transfer.

Over the past few years, the use of nanofluids techniques showed uncommonly improvement the flow thermal properties such as thermal conductivity, stability, convection heat transfer coefficient and reduced the consume power and the costs. Recently, helical tapes and twisted arrangements were used in nanofluids flow to improve thermal properties [13 - 15]. The effect of perforated helical twisted-tapes on the thermal performance characteristics were experimentally investigated [13]. It was conducted with different diameter ratios and different perforation pitch ratios. The experimental results showed that the use of perforated helical twisted-tapes led to the reduction of friction loss and heat transfer. However the friction loss and thermal performance factor were increased as diameter ratio decreased and pitch ratio increased. Other studies were conducted using triple twisted tape and screw helical tape inserts [14, 15]. Both arrangements obtained that thermal performance will be enhanced.

In the present work, an annular diffuser fitted with helical screw-tape hub and an annular diffuser fitted with twisted square hub is simulated. The aim is to study the influence of different hub configurations on temperature distribution inside the annular diffuser using air as the working fluid. In this study the effect of different twist ratios of the helical screw-tape hub and the twisted hub on temperature distribution are simulated and analyzed by means of CFD software. All of the simulations are achieved at the same inlet conditions.

II. Methodology

A. Annular Diffuser with Helical Screw-Tape Hub Geometry:

The annular diffuser fitted with helical screw-tape insert geometry is shown in Fig.1. CAD drawing for different twisted ratios is shown in Fig. 2. Three different twisted ratios *y/w* of 1, 1.5 and 2 are simulated.

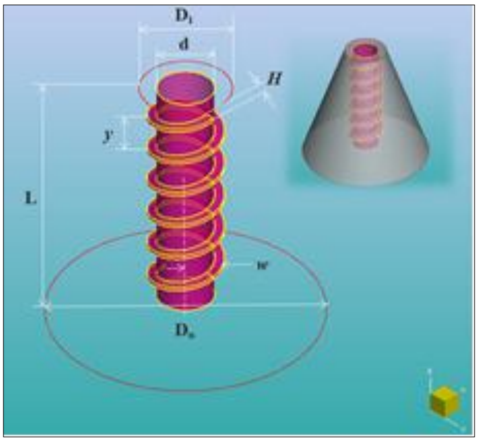


Figure 1. Annular diffuser geometry with helical screw-tape hub

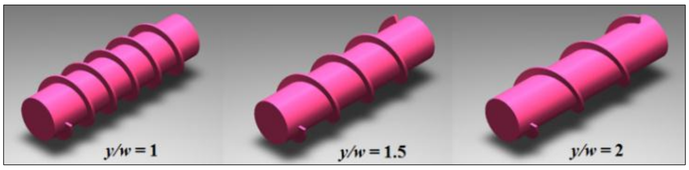


Figure 2. CAD drawing for helical screw-tape hub with different twist ratios

B. Annular Diffuser with Twisted Square Hub Geometry:

The annular diffuser fitted with twisted square hub insert geometry is shown in Fig.3. CAD drawing for different twisted ratios is shown in Fig. 4. Three different twisted ratios y/w of 1.16, 1.5 and 2.3 are simulated. The geometries of the tested diffusers are shown in table 1.

TABLE I. Diffuser Geometries

Parameters	***Dimension [mm]***
Inlet diameter, D_i	48
Outlet diameter, D_o	145
Length, *L*	140
Hub diameter, *d*	30
Hub width, *W*	30
Hub height, *W*	30

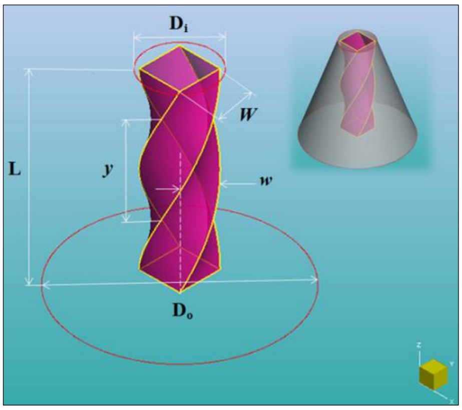


Figure 3. Annular diffuser geometry with twisted square hub

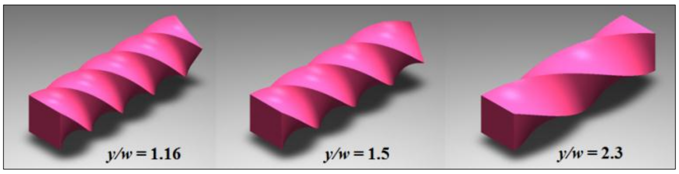


Figure 4. CAD drawing for helical tape hub with different twist ratios

III. Computational Modeling

In the present work numerical study was conducted with a helical screw-tape hub and twisted square hub inserts in an annular diffuser. The commercial software NUMECA FINE™ /Open *v*3.1 was chosen as the CFD tool for this work. The standard ***k-ε*** model was applied as a turbulence model and the numerical analyses were performed in three dimensional domains. The turbulence kinetic energy *k* and its rate of dissipation *ε* calculations followed literature reference. Standard *k–ε* turbulence model was allowed to predict the heat transfer and fluid flow characteristics. This turbulence model has been successfully applied to flows with engineering applications including internal flows [12]. The turbulence kinetic energy *k* and its rate of dissipation ε was obtained from the following transport equations [16],

$$k = \frac{3}{2}(VI)^2 \tag{1}$$

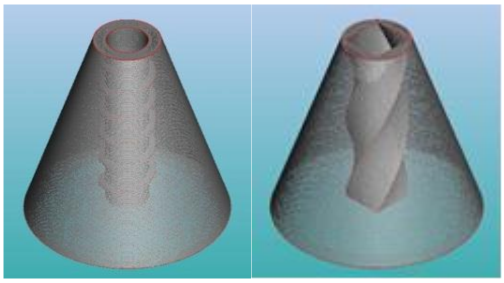
$$I = 0.16\,(Re)^{-\frac{1}{8}} \tag{2}$$

$$\varepsilon = C_\mu^{\frac{3}{4}}\, k^{\frac{3}{2}} \tag{3}$$

$$l = 0.07\,L \tag{4}$$

Where, *V* is the inlet velocity magnitude, *I* is the initial turbulence intensity, Re is Reynolds number, *k-ε* is a model parameter whose value is typically given as 0.09, *l* is the turbulence length scale and *L* is a characteristic length. For this study, *L* is considered as the hydraulic diameter. Typical values of boundary conditions are given in table 2.

Fig. 5(a,b) shows mesh generation of an annular diffuser fitted with helical tape hub for 1835286 cells and an annular diffuser fitted with twisted square hub for 1145020 cells.



(a) (b)

Figure 5. Mesh generation for an annular diffuser fitted with (a) helical screw-tape hub, (b) twisted square hub

TABLE II. Typical Values of Boundary Conditions

Parameters/Properties	***Value***
Inlet pressure , *Pi*	289000 [Pa]
Inlet Temperature, *Ti*	870.266 [K]
Kinematic Viscosity, ν	3.4077×10^{-5} [m^2/s]
Inlet air velocity, *Vi*	49.12 [m/s]

A. Grid Independence Study

Two studies were carried out to evaluate the effects of grid sizes on the accuracy of the numerical solutions results. First study was performed with five different meshes with total number of cells 852677, 1325728, 1624027, 2010342 and 3028988 for the helical screw-tape hub and second study was completed with five grid volumes 795511, 1290012, 1553556, 2484110 and 3409284 for the twisted square hub. The results of the static temperature at the outlet were compared for all the simulations. The grid system (1624027) with difference percentage 0.35% was adequately dense for the simulations of the annular diffuser fitted with helical screw-tape hub. While, the results indicate that the number of cells of (1553556) cells, which was recorded 0.12% different percentage was adequately dense for the simulations of the annular diffuser fitted with twisted square hub as shown in figure 6.

B. Heat Source arrangements

To analyze the temperature distribution, a spherical heat source of 10 kW with a radius of 0.005 m was put in the diffuser at 22 mm from the longitudinal axis, 23 mm downstream of the inlet section as shown in figure 7. The heat source was fitted with the beginning of the tested swirl generator models that include helical screw-tape with and without center-rod. The unsymmetrical location was purposely chosen in order to better observe the swirling motion.

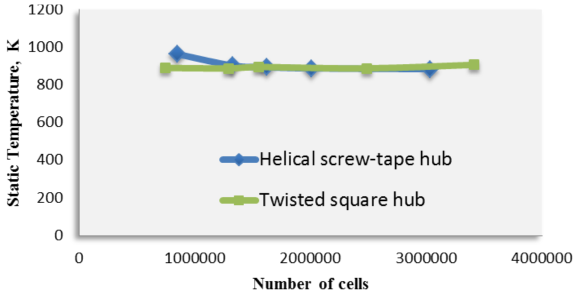


Figure 6. Grid independence study

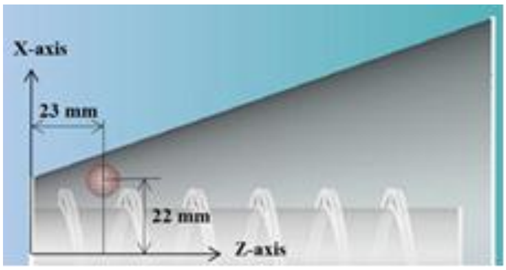


Figure 7. Heat source position

IV. RESULTS AND DISCUSSION

Temperature distribution is numerically investigated for an annular diffuser fitted with helical screw-tape hub and twisted square hub to study temperature behavior in both hub arrangements

A. *Cutting Planes*

Simulation results will be discussed for three different cutting planes in the radial direction of the flow for both hub arrangement at 30 mm (section 1-1), 70 mm (section 2-2), and 110 mm (section 3-3) as displayed in figure 8.

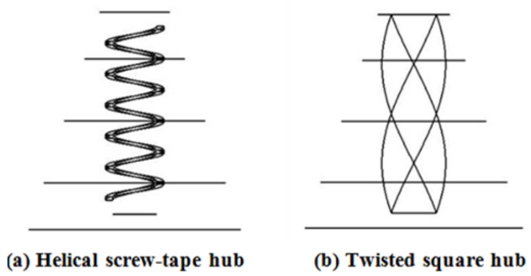


Figure 8. Cutting sections

B. *Effect of Helical Screw-Tape Hub with Different Twist Ratios*

Temperature distribution in a helical screw-tape hub was visualized in Figs 9-11(a). The temperature range is presented from 450 K (dark blue) to 3500 K (red).

For the three cutting sections shown in Fig. 9(a) for twist ratio (y/w = 1), it observes that the temperature in section 1-1, at the heat source location is at maximum (around 3300 K). In section 2-2 the insert of the helical screw-tape force the temperature to be distributed in a helical and circulation motion, thereby the distribution area becomes bigger in section 3-3.

For the twist ratio (y/w = 1.5) represents in Fig. 10(a), the temperature starts to distribute in the radial direction and in the direction of the flow from section 1-1 until section 3-3. Results show that distribution area starts to increase through the planes in the radial and flow direction.

In Fig. 11(a), this shows twist ratio (y/w = 2). It can be seen that the phenomenon appears to be similar. The temperature starts to distribute from section 1-1 until section 3-3. Results obtain that the existence of helical screw-tape force the temperature to move in the radial direction and in the direction of the flow as well.

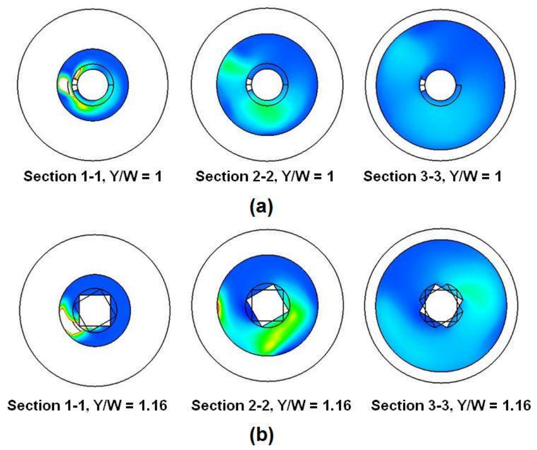


Figure 9. Three sections for an annular diffuser fitted with (a) helical screw-tape hub twist ratio (y/w = 1), (b) twisted square hub twist ratio (y/w = 1.16)

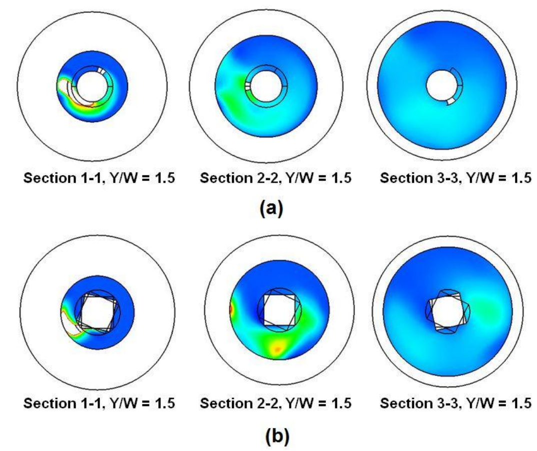


Figure 10. Three sections for an annular diffuser fitted with (a) helical screw-tape hub twist ratio (y/w = 1.5), (b) twisted square hub twist ratio (y/w = 1.5)

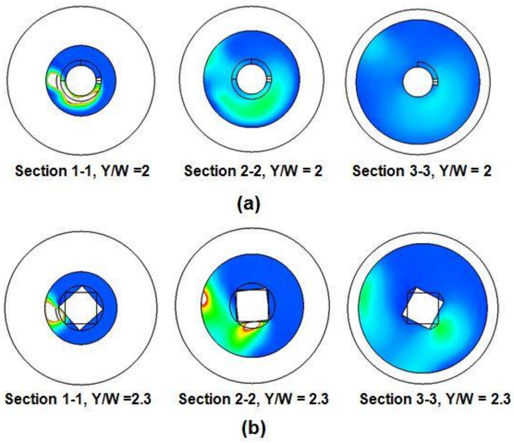


Figure 11. Three sections for an annular diffuser fitted with (a) helical screw-tape hub twist ratio (*y/w* = 2), (b) twisted square hub twist ratio (*y/w* = 2.3)

The variation of temperature distribution with the dimensionless length *X/L* is shown in Figs 12-14 for the helical screw-tape hub. It can be seen that twist ratio *y/w* of 1 is provided the best temperature distribution for the three sections. Fig. 13 indicates section (2-2) which represents the temperature behavior in this part after 70 mm from the annular diffuser inlet. It shows that the static temperature distribution with twist ratios (*y/w* = 1) and (*y/w* = 1.5) are almost have a similar effects. However, the twist ratio of 1.5 provide higher temperature rate.

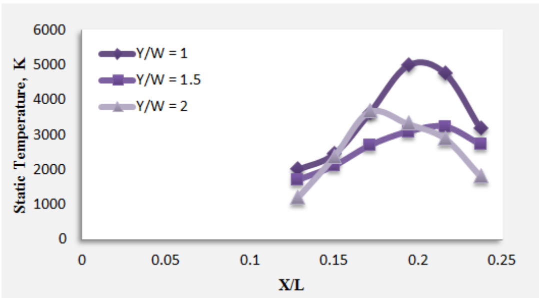


Figure 12. Variation of temperature distribution in section (1-1) for an annular diffuser fitted with helical screw-tape hub

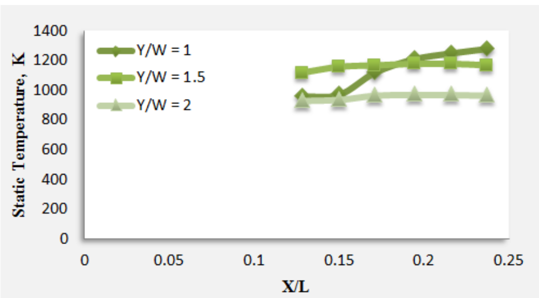


Figure 13. Variation of temperature distribution in section (2-2) for an annular diffuser fitted with helical screw-tape hub

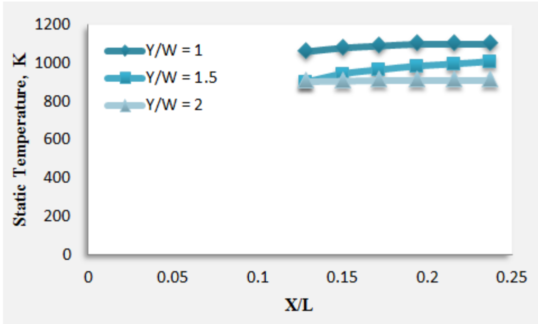


Figure 14. Variation of temperature distribution in section (3-3) for an annular diffuser fitted with helical screw-tape hub

C. Effect of Twisted Square Hub with Different Twist Ratios:

Figs 9-11(b) represent the temperature distribution in an annular diffuser fitted with twisted square hub. The temperature range is presented from 450 K (dark blue) to 3500 K (red). Fig. 9-b represents the effect of twisted square hub with twist ratio (*y/w* = 1.16) on the temperature distribution in an annular diffuser. In section 1-1 the temperature is almost 3400 K near the heat source. It starts to distribute because of the twisted configuration effects which help the temperature to distribute in the radial and axial direction. In section 2-2 the circular motion forced the temperature to be distributed in the radial direction and in section 3-3, the distribution area becomes bigger. For Fig.10 (b) and Fig.11 (b), it can be seen that twist arrangement cause the behavior of the flow and the distribution of temperature to be almost similar to the previous results.

Figs. 15-17 show the variation of static temperature distribution with the dimensionless radial distance *X/L* for the above mentioned cutting sections with different twist ratios *y/w* of 1.16, 1.5 and 2.3 in an annular diffuser fitted with twisted square hub. It can be seen from these Figs. that twist ratio *y/w* of 1.16 provided good temperature distribution compare with the other tested twist ratios. Section (1-1) in Fig. 15 indicates temperature behavior in this part which placed in 30 mm from the inlet of the annular diffuser with twisted square hub. It shows that the temperature distribution with twist ratios (*y/w* = 1.5) and (*y/w* = 2.3) are almost have the same effect in this section. The second section (2-2) in Fig. 16 shows the distribution relations and the results reveal that the twist ratios (*y/w* = 1.5) and (*y/w* = 2.3) are so close, which means that these two twist ratios roughly influence the temperature distribution in the same way.

Fig. 17 represents section (3-3). The results follow the previous sections. Finally, it can be indicated that twist ratios (*y/w* = 1.5) and (*y/w* = 2.3) for all cutting sections have the same effect.

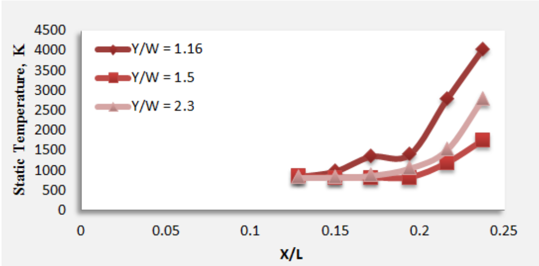


Figure 15. Variation of temperature distribution in section (1-1) for an annular diffuser fitted with twisted square hub

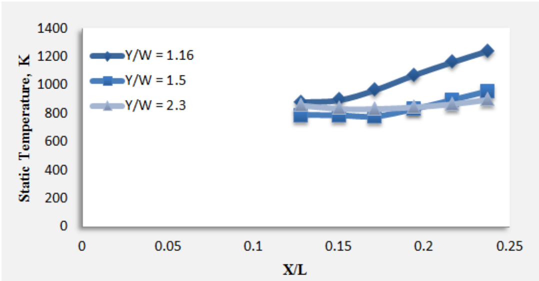


Figure 16. Variation of temperature distribution in section (2-2) for an annular diffuser fitted with twisted square hub

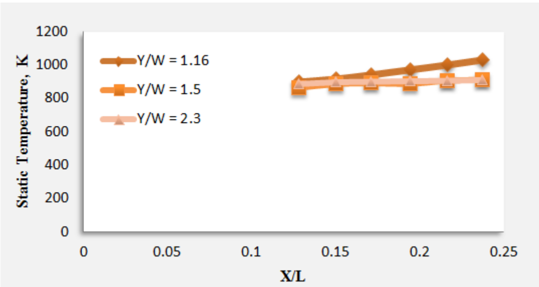


Figure 17. Variation of temperature distribution in section (3-3) for an annular diffuser fitted with twisted square hub

D. Effect Comparison of Introducing Helical Screw-Tape Hub and Twisted Square Hub in an Annular Diffuser

The comparison of using annular diffuser with helical screw-tape hub and annular diffuser with twisted square hub for three different twist ratios indicates clearly that the inserts of both arrangements will affect the temperature distribution in positive way and the temperature will distribute in several directions. Figs 18-20 display the variation of the temperature distribution with the dimensionless radial length *X/L* in an outlet plane for the helical screw-tape hub and the twisted square hub in the annular diffuser.

It can be seen from Fig. 18 that both the helical screw-tape hub inserts and the twisted square hub inserts have a good influence on the temperature distribution. However the insertion of the helical screw-tape provided the best temperature distribution compared with the twisted square hub with almost the same twist ratio at the same section.

Fig. 19 shows a comparison of the proposed hub arrangements with the twist ratio (y/w = 1.5) at the outlet plane. The simulation results indicate that hub arrangements have the same effect in this section with a little different, but still the helical screw-tape hub has the better effect. Twist ratios (y/w = 2) and (y/w = 2.3) are plotted and compared in Fig. 20. It can be seen the influence of helical screw-tape inserts is much better.

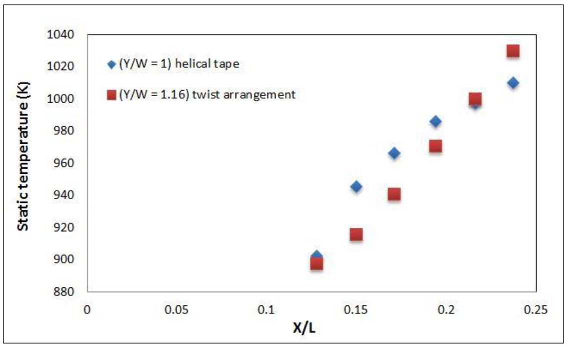


Figure 18. Outlet temperature distribution for twist ratios (y/w = 1) and (y/w = 1.16)

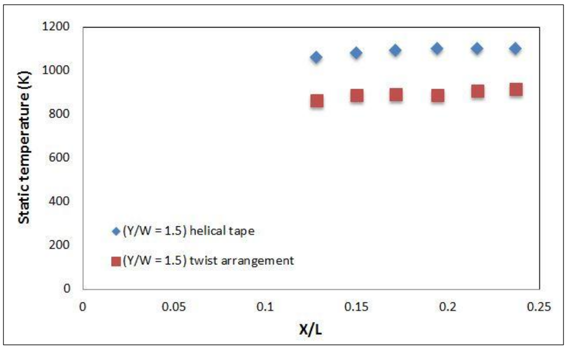


Figure 19. Outlet temperature distribution for twist ratio (y/w = 1.5)

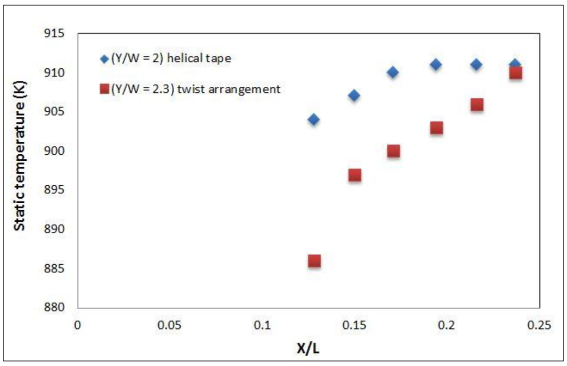


Figure 20. Outlet temperature distribution for twist ratios (y/w = 2) and (y/w = 2.3)

V. CONCLUSION

A numerical study of temperature distribution in an annular diffuser fitted with a helical screw-tape and a twisted square hub was carried out for three twist ratios. It was achieved by the use of Computational Fluid Dynamics (CFD).

The simulation results show the dependence of the temperature distribution on both the helical screw-tape and the twist arrangement. The numerical study confirms that the temperature will follow helical and circular motion due to the present of helical screw-tape inserts and the twist arrangement inserts. Based on the numerical simulation results, the following conclusions can be made:

1. In the annular diffuser fitted with helical screw-tape hub and for the three twist ratios *y/w* of 1, 1.5, and 2, temperature distribution in twist ratio (*y/w* = 1) for the three sections is found to be higher than other two twist ratios.

2. In the annular diffuser fitted with twisted square hub for the three twist ratios *y/w* of 1.16, 1.5 and 2.3, temperature distribution in twist ratio (*y/w* = 1.16) seem to be higher than the other tested twist ratios.

3. The comparison of temperature distribution in the outlet plane for the helical screw-tape twist ratios *y/w* of 1, 1.5, and 2 and the twisted square hub twist ratios *y/w* of 1.16, 1.5, and 2.3 shows clearly that helical screw-tape inserts gives better enhancement.

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Author is working as a lecturer at Electronic Technologies Department, Institute of Technology Baghdad, Middle Technical University/ Baghdad, Iraq. Her research interests include but not limited to, CFD analysis, thermo fluid including; swirl flow, temperature distribution, introducing different technics in diffusers, Nanofluids technologies.