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Temperature Distribution Simulation of Divergent Fluid Flow with Helical Arrangement

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***Abstract*—**Numerical study is performed to investigate the temperature distribution in an annular diffuser fitted with helical tape hub. Different pitches (Y = 20 mm, and Y = 30 mm) for the helical tape are studied with different heights (H = 20 mm, 22 mm, and 24 mm) to be compared. The geometry of the annular diffuser and the inlet condition for both hub arrangements are kept constant. The result obtains that using helical tape insert with different pitches and different heights will force the temperature to distribute in a helical direction; however the use of helical tape hub with height (H = 22 mm) for both pitches enhance the temperature distribution in a good manner.

***Keywords*—**Helical tape, divergent fluid flow, temperature distribution, swirl flow, CFD.

I. Introduction

TEMPERATURE distribution in divergent fluid flow like diffusers and annular diffusers have been applied in many areas such as gas turbines, compressors, pumps, wind tunnels, etc. They are used to decelerate the flow 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. In heating engineering applications that adopt temperature distribution such as combustion process, it is essential to use swirl generators that provide a rotational flow around an axis parallel to the flow direction. It creates swirling motion that can force the heat transfer in the direction of the flow and in the direction normal to the flow [1]. Helical tapes are one important group of swirl generator which mostly applied for heat transfer improvement. It is an efficient 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. Yang et al. [2] found that with the insertion of a swirl number equal to zero (without swirling flow) in a convergent passage there was no significant effect on the heat transfer. But after the swirling flow was generated, the heat transfer increased with increasing the swirl number. This increasing of the heat transfer was mostly due to the circular and helical motion and the swirl velocity of the flow.

Heat transfer enhancement techniques have been extensively developed to improve the thermal performance of heating/cooling systems. Swirl flow is the one of the enhancement techniques widely applied to the mentioned systems in many technical applications. Promvonge et al. [3] experimentally investigated turbulent convective heat transfer characteristics using a helical-ribbed tube fitted with twin twisted tapes. The experimental results obtained that the compound enhancement devices of the helical-ribbed tube and the twin twisted tapes showed a considerable improvement of heat transfer rate and thermal performance relative to the smooth tube and the helical-ribbed tube acting alone, depending on twist ratios.

Helical screw-tape arrangement was widely used to improve and to enhance the heat distribution in the flow [4], [5]. Both researchers studied this arrangement experimentally and numerically. Sivashanmugam et al. [4] experimentally tested the effect of the co-swirl flow and the counter swirl generators through a round tube fitted with helical screw tape and twisted tape. 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. Zhang et al. [5] numerically simulated the helical screw-tape to improve the temperature uniformity and to reduce the flow resistance in the core flow of tube. Different widths had been investigated for different inlet volume flow rates by numerical simulation. The simulation results showed that the average overall heat transfer coefficients in circular plain tubes were enhanced with helical screw-tape of different widths.

Computational simulations were obtained to get further understand and characterize the swirling flow field [6]–[9]. Wirachman et al. [6] and Ehan et al. [7] numerically studied the effect of helical tape on temperature distribution and flow behaviors in both conical diffuser and in an annular diffuser with cylindrical hub. Different helical tape pitch and different helical tape heights were simulated. The results showed that using helical tape with different pitches and different heights in both conical diffuser and annular diffuser promoted the temperature distribution. From simulation results Ehan et al. [8] obtained that using an annular diffuser fitted with helical tape hub and an annular diffuser fitted with twisted rectangular hub will force the temperature to distribute in a rotational direction; however, the used of helical tape hub enhanced the temperature distribution better. Heat distribution and flow behaviors were studied in an annular diffuser with cylindrical hub fitted with pimples [9]. Pimples with different radius and pitches have been used. The results showed that pimples provide the flow with turbulence and enhanced the temperature distribution. However the study indicated that using different pimple diameters had a better influence than using different pitches.

Many researchers used different arrangement to produce swirl flow. Eiamsa-ard et al.[10] applied twin counter twisted

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tapes and twin co-twisted tape 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) for Reynolds numbers range between 3700 and 21,000 under uniform heat flux conditions. The results showed that the counter-swirl tapes can enhance heat transfer more efficiently than the coswirl tapes and it is found that heat transfer, and friction factor increased as the twist ratio (y/w) decreased. Today Eiamsa-ard [11] uses new configurations for swirl creation. The effects of the regularly-spaced twisted tape (RS-TT) on the heat transfer and fluid performance have been reported along with those of a typical length twisted tape. The typical length twisted tapes with two different twist ratios, the regularly-spaced twisted tape (RS-TT) with two different twist ratios and three free space ratios were used for comparative study. The numerical simulation gave extra understanding for the physical behavior of the fluid flow, fluid temperature and local Nusselt number characteristics of a tube fitted with (RS-TT) in the turbulent flow regime. The experimental results showed that heat transfer rate and friction increased with decreasing twist ratio and space ratio.

The present work aim is to study two pitches with different heights in an annular diffuser fitted with helical tape. The different heights are used for comparative reasons. First study is pitch (Y = 20 mm) with different heights (H = 20 mm, 22 mm, and 24 mm), and second study is pitch (Y = 30 mm) with different heights (H = 20mm, 22mm, and 24 mm). All the simulations are carried out at the same inlet conditions with Reynolds number around 6.918×10^4 based on the inlet diameter of the diffuser as a hydraulic diameter.

II. Methodology

A. Annular Diffuser with Helical Tape Geometry

The annular diffuser and the helical tape insert geometry are shown in Fig. 1. Simulations are conducted with two states: first, helical tape pitch (Y = 20 mm) with different heights (H = 20 mm, 22 mm, and 24 mm), and second study is pitch (Y = 30 mm) with different heights (H = 20mm, 22mm, and 24 mm). Fig. 2 shows CAD drawing for helical tape with pitches (Y = 20 mm, and Y = 30 mm) with different heights. Table I shows the dimensions of the tested diffusers.

B. Computational Simulation

Numerical simulations of temperature distribution inside an annular diffuser fitted with helical tape hub for two pitches with different heights are carried out in the present work. The commercial software Numeca Fine/Open v.3.1 is chosen as the Computational Fluid Dynamics (CFD) tool for this work.

The numerical analyses were performed in three dimensional domains applying standard k-ε model as a turbulence model. Standard k–ε turbulence model is allowed to predict the heat transfer and fluid flow characteristics. This turbulence model has been successfully applied to flow with engineering applications including internal flow [12]. The turbulence kinetic energy k, and its rate of dissipation ε, is obtained from the following transport equations [13]:

$$k = 0.002\,(u)^2$$

$$\varepsilon = (k)^{1.5} / 0.3\,D$$

where, u is the inlet velocity and D is the inlet, diameter. Typical values of boundary conditions are given in Table II. Fig. 3 shows mesh generation of an annular diffuser with helical tape hub for more than 1800000 cells.

C. Heat Source

For this study, a spherical heat source of 10 kW with the radius of 0.005 m is put in the diffuser at 22 mm from the longitudinal axis, 21 mm downstream of the inlet section. It is with the beginning of the helical tape. The unsymmetrical location is purposely chosen in order to better observe the swirling motion.

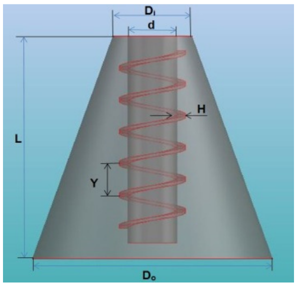

Fig. 1 Annular diffuser geometry with helical tape hub

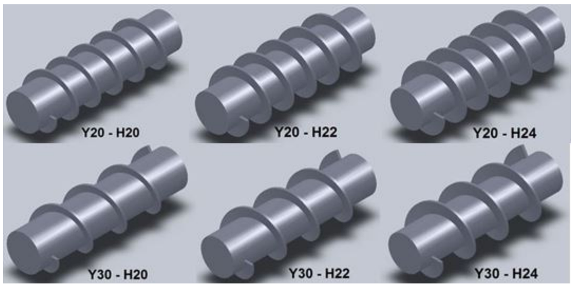

Fig. 2 CAD drawing for two pitches with different helical tape heights

TABLE I
ANNULAR DIFFUSER DIMENSIONS

Symbol	Parameters	dimensions
D_i	Inlet diameter	48 mm
D_o	Outlet diameter	145 mm
L	Length	140 mm
d	Hub diameter	30 mm

TABLE II
BOUNDARY CONDITIONS

Symbol	Parameters	Values
P_i	Inlet pressure	289000 pa
V_i	Inlet velocity	49.12 m/s
T_{in}	Inlet temperature	870.266 K
ν	Kinematic Viscosity	9.421×10^{-5} m^2/s
Re	Reynolds Number	6.918×10^4

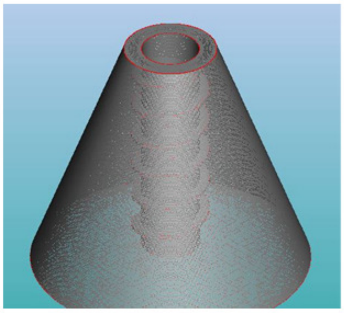

Fig. 3 Mesh generation of an annular diffuser with helical tape hub

D. Cutting Sections

Fig. 4 shows three cutting sections along the radial direction of the annular diffuser at 30 mm (section 1-1), 70 mm (section 2-2), and 110 mm (section 3-3).

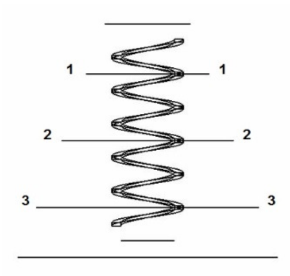

Fig. 4 Three cutting sections in the radial direction of the annular diffuser

III. Results and Discussion

Temperature distribution is numerically obtained for an annular diffuser fitted with helical tape for two pitches (*Y*) with different heights (*H*).

A. The Influence of Pitch (Y = 20 mm) with Different Heights

Results are respectively shown in Figs. 5 and 6. It is discussed for three cutting sections (section 1-1, section 2-2, and section 3-3). Fig. 5 represents the effect of pitch (*Y* = 20 mm) with different heights (*H* = 20 mm, 22 mm, and 24 mm) on the temperature distribution. Starting from (*Y* = 20mm, and *H* = 20mm) temperature range is presented from 450 K (dark blue) to 3500 K (red). It observes that the temperature in section 1-1, at the heat source location is at maximum (around 3400 K). In section 2-2 the insert of the helical tape forces the temperature to be distributed in a helical and a circulation motion. Therefore the distribution area becomes wider in section 3-3. For (*Y* = 20mm, and *H* = 22mm) the behavior of the distribution is the same, however the colored area which represent the distribution is wider. In (*Y* = 20mm, and *H* = 24mm) it follows the same procedure.

Fig. 6 shows the comparison between the three different heights for the same pitch (*Y* = 20 mm). From the results they show clearly that the three results relations are so close. However the heights (*H* = 22 mm) give better effect.

B. The Influence of Pitch (Y = 30 mm) with Different Heights

Three different heights are showed in Fig. 7 with pitch (*Y* = 30 mm). For the three cutting sections shown in this figure the temperature range is presented from 450 K (dark blue) to 3500 K (red). In section 1-1 the temperature is almost 3500 K near the heat source. The helical tapes with different heights will cause the flow to move in a helical motion. Therefore this will force the temperature in these arrangements to be distributed in a helical way in the radial direction of the flow and in the direction of the flow as well.

Fig. 8 shows the effect relations between three different heights for pitch (*Y* = 30 mm). It is observed the same results showed in Fig. 5 and the height (*H* = 22 mm) present better effect.

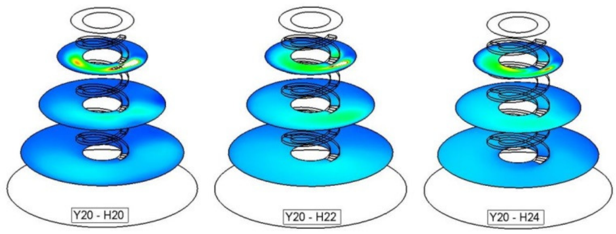

Fig.5 Different heights for the pitch (*Y* = 20 mm) in an annular diffuser

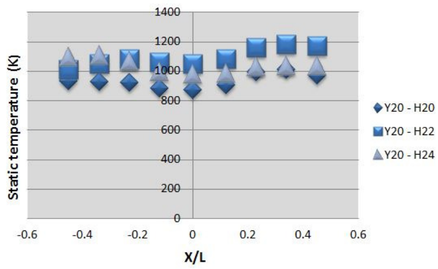

Fig. 6 Comparison between different heights for pitch (*Y* = 20mm)

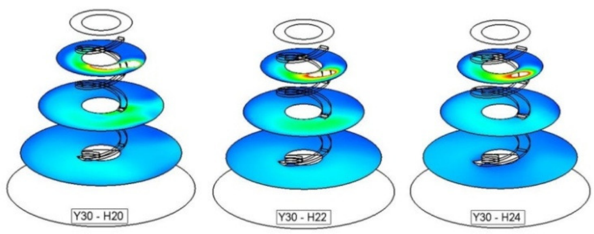

Fig.7 Different heights for the pitch (*Y* = 30 mm) in an annular diffuser

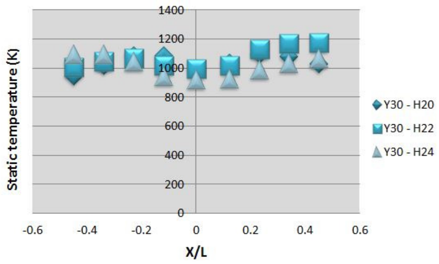

Fig. 8 Comparison between different heights for pitch (Y = 30mm)

C. Comparison of Different Heights for Different Pitches

A comparison between two pitches (Y = 20 mm, and Y = 30 mm) for the same heights (H = 22 mm) has been achieved and shown in Fig. 9. The results show that both carves give almost the same results but pitch (Y = 20 mm) with heights (H = 22 mm) gives a little bit better effect.

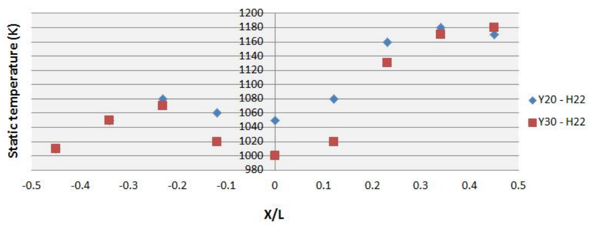

Fig. 9 Comparison between different pitches for height (H = 22 mm)

IV. Conclusion

In the present study conclusion has been made according to simulation results for two concepts; first simulation results of temperature distribution in an annular diffuser fitted with helical tape hub for two different pitches with different heights. Second comparisons between the best height effect for both pitches with height (H = 22 mm). Therefore the following conclusions can be made from the numerical simulation study:

1) The results show clearly the dependence of the temperature distribution on the existence of the helical tape. Since the temperature will follow helical and circular motion due to the present of helical tape insert.
2) Different heights for the same pitch will enhance the distribution and the results indicate that height (H = 22 mm) has a good effect for both pitches (Y = 20 mm, and Y= 30 mm)
3) It can be seen that height (H = 22 mm) for pitch (Y = 20 mm) almost give a better effect.

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