Numerical Comparison of Temperature Distribution in an Annular Diffuser Equipped with Helical Tape Hub and Twisted Rectangular Hub

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Abstract: - Numerical simulations of the temperature distribution in an annular diffuser equipped with helical tape hub and a twisted rectangular hub are carried out in this work. Different twisted ratio for the annular diffuser with both helical tape hub ($Y/W = 1, 1.5, 2$) and rectangular twisted hub ($Y/W = 1.16, 1.5, 2.3$) are simulated and compared. The geometry of the annular diffuser and the inlet condition for both hub configurations are kept constant. The result obtains that using both helical tape hub and twisted rectangular hub will force the temperature to distribute in a helical direction; however the use of helical tape hub will enhance the temperature distribution better.

Key-Words: - Numerical simulation, temperature distribution, helical tape, rectangular hub, annular diffuser, twisted ratio, swirl flow.

1 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 application heat distribution inside these diffusers need to be promoted, such as combustion process. It can be done by using swirl generators. These generators create swirling motion that can force the heat transfer in the direction of flow and in the direction normal to the flow (radial tangential direction)\textsuperscript{[1]}. Swirl generators provide the internal flow with circular and helical motions. It is 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. Many types of swirl generators have studied to promote heat distribution such as twisted configuration\textsuperscript{[2 and 3]}, helical tape\textsuperscript{[1 and 4]}, and helical screw-tape\textsuperscript{[5]}, etc. Eiamsa et al.\textsuperscript{[6, and 7]} studied experimentally different configurations equipped with twisted tape. The effect of the co-swirl flow and the counter swirl generators through a round tube fitted with helical screw tape and twisted tape has been experimentally tested\textsuperscript{[6]}. 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. Other researchers studied 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 $4.0$) for Reynolds numbers range between $3700$ and $21,000$ under uniform heat flux conditions\textsuperscript{[7]}. The results showed that the counter-swirl tapes can enhance heat transfer more efficiently than the co-swirl tapes and it is found that heat transfer, and friction factor increased as the twist ratio ($y/w$) decreased.

Numerical simulations were obtained to get further understand and characterize the swirling flow field\textsuperscript{[8 and 9]}. Escue and Cui\textsuperscript{[8]} 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 obtained 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.\textsuperscript{[9]} numerically studied heat distribution and flow behaviors in an annular diffuser with cylindrical hub equipped with helical tape. Different helical tape pitch and different helical tape heights were simulated. The results showed that using different pitches and different heights for the helical tape promoted the temperature distribution. The internal flow fitted with dual twisted configuration elements had been numerically investigated by Erdemir et al.\textsuperscript{[10]} to study the fluid flow characteristics of internal flow in turbulent flow regime. They
examine the effect of different diameter ratio (d/D) on the heat transfer behavior. The result indicated that the creation of helical and swirling motion increased the heat transfer. Helical tape inserts and twisted configuration are the most favorable passive techniques because they are inexpensive and can be easily employed to the existing system.

In this work, an annular diffuser with helical tape hub and an annular diffuser with twisted rectangular hub are simulated. The aim is to study the influence of heat distribution inside the annular diffuser equipped with two different hub configurations. In this study the effect of different twisted ratio of both the helical tape 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 with Reynolds number around 2.502 × 10^4 based on the inlet diameter of the diffuser.

2 Methodology

2.1 Annular diffuser geometry:
2.1.1 Annular diffuser with helical tape hub geometry:
The annular diffuser with helical tape insert geometry is shown in Fig. 1-a. CAD drawing for different twisted ratio is shown in Fig. 2-a. Three different twisted ratio (Y/W = 1, 1.5, and 2) are simulated. The dimensions of the tested diffusers are shown in Table 1.

2.1.2 Annular diffuser with twisted rectangular hub geometry:
The annular diffuser with twisted rectangular hub geometry is shown in Fig. 1-b. CAD drawing is shown in Fig. 2-b. Three twisted ratio (Y/W = 1.16, 1.5, and 2.3) are simulated. Table 2 shows the dimensions of the tested diffuser.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Dimension [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet diameter, D_i</td>
<td>48</td>
</tr>
<tr>
<td>Outlet diameter, D_o</td>
<td>145</td>
</tr>
<tr>
<td>Length, L</td>
<td>140</td>
</tr>
<tr>
<td>Hub width, d</td>
<td>30</td>
</tr>
<tr>
<td>Hub height, W</td>
<td>30</td>
</tr>
</tbody>
</table>

Fig. 1, annular diffuser geometry, a: with helical tape hub, b: with twisted rectangular hub.

Table 1, diffuser dimensions with helical tape hub.

<table>
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<td>140</td>
</tr>
<tr>
<td>Hub diameter, d</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 2, diffuser dimensions with twisted rectangular hub

Fig. 2, annular diffuser CAD drawing for, a: helical tape hub with different twisted ratio, b: twisted rectangular hub with different twisted ratio.

2.2 Computational simulation:
Numerical study of the temperature distribution inside an annular diffuser equipped with both helical tape hub and twisted rectangular hub is 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 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 flows with engineering applications including internal flows [10]. The turbulence kinetic energy k, and its rate of dissipation ε, is obtained from the following transport equations [11]:

\[ k = 0.002 \left( \frac{u}{D} \right)^2 \]
\[ \varepsilon = \left( \frac{k}{\nu} \right)^{1.5} / 0.3 D \]

Where, u is the inlet velocity and D is the inlet diameter.

Typical values of boundary conditions are given in Table 3. Fig. 3-a shows mesh generation of an annular diffuser with helical tape hub for 1835286 cells. Fig. 3-b shows an annular diffuser with twisted rectangular hub for 1145020 cells.
Table 3, typical values of boundary conditions.

<table>
<thead>
<tr>
<th>Parameters/Properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet pressure, $P_i$</td>
<td>289000 [Pa]</td>
</tr>
<tr>
<td>Outlet Pressure, $P_o$</td>
<td>270000 [Pa]</td>
</tr>
<tr>
<td>Inlet Temperature, $T_i$</td>
<td>870.266 [K]</td>
</tr>
<tr>
<td>Kinematic Viscosity, $\nu$</td>
<td>$9.42 \times 10^{-5}$ [m²/s]</td>
</tr>
<tr>
<td>Reynolds Number, Re</td>
<td>$2.502 \times 10^4$</td>
</tr>
<tr>
<td>Inlet velocity of air, $V_i$</td>
<td>49.12 [m/s]</td>
</tr>
<tr>
<td>Turbulence kinetic energy, $k$</td>
<td>$3.48 \times 10^2$ [m²/s²]</td>
</tr>
<tr>
<td>Turbulence dissipation rate, $\varepsilon$</td>
<td>152.37 [m²/s³]</td>
</tr>
</tbody>
</table>

2.3 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 25 mm from the longitudinal axis, 22 mm downstream of the inlet section. It is with the beginning of the helical tape and the twisted configuration. The unsymmetrical location is purposely chosen in order to better observe the swirling motion.

3 RESULTS AND DISCUSSION
Temperature distribution is numerically obtained for an annular diffuser equipped with helical tape hub and twisted rectangular hub in order to compare the behavior of the temperature in both configurations.

3.1 Cutting sections:
Results will be discussed for three cutting sections for both configuration along the radial direction of the annular diffuser with helical tape hub and twisted rectangular hub at 30 mm (section 1-1), 70 mm (section 2-2), 110 mm (section 3-3), from the inlet section.

3.2 Effect of helical tape hub with different twisted ratio:
For the three cutting sections shown in Fig. 4-a, for twisted ratio ($Y/W = 1$) the temperature range is presented from 480 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 3300 K). In section 2-2 the insert of the helical tape force the temperature to be distributed in a helical motion and distribution area becomes bigger in section 3-3. Twisted ratio ($Y/W = 1.5$) represented in Fig. 5-a, the temperature starts to distribute in the radial direction and in the direction of flow from section 1-1 until section 3-3. In Fig. 6-a, which shows twisted ratio ($Y/W = 2$), it can be seen that the phenomenon appears to be similar.

3.3 Effect of twisted rectangular hub with different twisted ratio:
Fig. 4-b represents the effect of twisted rectangular hub with twisted ratio ($Y/W = 1.16$) on the temperature distribution in an annular diffuser. There are three cutting sections. The temperature range is given 480 K (dark blue) to 3500 K (red). In section 1-1 the temperature is almost 3500 K near the heat source. It starts to distribute because of the twisted configuration effects. In section 2-2 the circular motion forced the temperature to be distributed in the radial direction and in section 3-3, the distributed area becomes bigger. From Fig. 5-b and Fig. 6-b it can be noticed that the behavior of the flow and the behavior of temperature distribution seems to be almost similar.

3.3 Compare the effect of an annular diffuser with both helical tape hub and twisted rectangular hub:
In Fig. 4, for both configurations it can be obtained that for almost the same twisted ratio the temperature starts to follow helical and swirl motion. Fig. 5 shows that the distribution area in the helical tape hub in three sections is wider than that in twisted rectangular hub. Both configurations in Fig. 6 represent that the temperature distributes in the radial direction and in the flow direction.

4 Conclusion
A study of the heat distribution in an annular diffuser equipped with helical tape and twisted rectangular hub is carried out in order to investigate the influence of the helical tape and the twisted configuration on the heat distribution. This was achieved by the use of Computational Fluid Dynamics (CFD).

The simulation results showed the dependence of the heat distribution on both the helical tape and the twisted arrangement. The numerical study confirms that the temperature will follow helical and circular motion due to the present of helical tape insert and due to the twisted hub. For different twisted ratio, the results achieved that using helical tape hub will get better distribution.
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References:


