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Performance analysis of annulus diffusing area with divergent dimpled tube

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Abstract

Flow properties and performances are analyzed in an annulus-diffusing channel with divergent dimpled tube DDT. 3-D Computational Fluid Dynamics CFD has been achieved to study the flow characteristics. The standard k-e turbulence model is employed in the numerical simulations. The main goal of the study is to present details of flow field characteristics and velocity distribution enhancement of the flow in an annulus-diffusing channel fitted with DDT. The effects of three different area ratios ARs (2, 2.5 and 3) on the flow performance have been discussed. The velocity structure in terms of radial velocities and pressure structures is studied by using commercial software ANSYS. Area ratios (ARs) and Reynolds number (Re) 62393 are achieved as governing parameters. The results show that the velocity and pressure performance is strongly affected by the insertions of dimples. The velocity values decrease and the pressure drop increases with an increasing area ratio through the diffusing channel. Therefore, increasing area ratio AR increases model performance.

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Keywords: CFD; Diffusing channel; Dimpled tube; Velocity profile; Pressure drop

1. Introduction

Areas of annulus diffusing are widely used in various industrial processes. Dimples insertion are played an important role to control and improve flow performance. Thermal processes always need to homogenize the flow mixture. They need a swirl flow devices, which is one method of passive techniques. These techniques do not need any additional external power.

These methods include different types of inserts such as twisted tape, helical-screw tape, pimples, dimples, etc. Dimples were widely investigated by many researchers for the past decades. The low cost and ease of applying them to the existing system make it a very favorable insert technique for generating swirl flow.

The enhancement of the velocity profile in the turbulent flow based on the dimples method is one of the most effective processes to improve the flow characteristics by disturbing the boundary layer around the dimples areas, generating tangential velocity components, and increasing fluid turbulence.

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Nomenclature	
Di	Diffusing channel inlet diameter, mm
Do	Diffusing channel outlet diameter, mm
L	Diffusing channel length, mm
dti	Divergent tube inlet diameter, mm
dto	Divergent tube outlet diameter, mm
Lt	Divergent tube length, mm
dm	Semi dimple diameter, mm
Р	Inlet pressure, bar
V	Inlet velocity, m s^{-1}
ρ	Density, kg m ⁻³
Re	Reynolds Number
Greek Symbols	
Κ	Turbulent kinetic energy, m^2/s^2
ε	Turbulence dissipation, m ² /s ³
l	Turbulence length scale, mm
Ι	Initial turbulence intensity
$C\mu$	k - ε model parameter
λ	Thermal conductivity
Ср	Specific heat capacity, kJ kg ⁻¹ K ⁻¹

Many researchers utilized a dimpled tube to enhance heat transfer coefficients and the flow performance by numerical and experiment [1–5]. Aroonrat and Wongwises [6] studied the influence of the dimpled tube on the heat transfer rate and pressure drop of R-134a during condensation in the heat exchanger. The inner tubes of the heat exchanger consist of one smooth tube and one dimpled tube, which was made from copper. The study showed that the heat transfer coefficient and frictional pressure drop obtained from a dimpled tube were higher than that of the smooth tube. In addition, the Nusselt number enhanced around 1.3–1.4 times in comparison to the smooth tube as the Reynolds number increases.

Dimples were used in the modern gas turbine as cooling techniques [7,8] to cool down the temperature of the flow around the turbine blades. Wenwu et al. conducted an experimental investigation to study the characteristics of the turbulent boundary layer flow over dimpled surfaces as cooling techniques. Then, the findings were compared to those over conventional flat plates [7]. The results revealed that the friction factor of the dimpled surface would be about 30%–80% higher than that of the flat surface, depending on the Reynolds number of the test cases. In comparison with those over the flat surface, the flow characteristics of the turbulent boundary layer flow around the dimpled surface were found to be with high turbulence kinetic energy.

Many investigations were involved with dimples. Dimples were very interesting because they could generate recirculation flow and horseshoe vortices including the hole on the surface allowing the fluid to flow across it to enhance heat transfer [8]. The main physical mechanisms causing this enhancement were the generation and extension of the strong longitudinal vortices in the hole, which were reactive with the thermal boundary layer [9].

Unlimited researches were conducted to characterize the hydrodynamic performance of dimpled tubes compared to the ones without dimples [10–13]. Abraham and Maki [14] conducted a numerical simulation of laminar flow in a dimpled pipe to determine the relationship between hydrodynamic resistance and dimple geometry. The simulations considered for dimple sizes that range from 0 mm (a smooth pipe) to 2 mm. The results revealed that for dimples whose sizes were small enough to prevent recirculation, the flow resistance was constant with dimple size. Once the dimples became sufficiently large, the recirculation increased. Which resulted in additional pressure losses for the flow and consequently in a decrease of flow rate. Therefore, conclusions had been made that the size of the dimple played a significant role in the flow.

The velocity structures and the pressure drop can be enhanced by introducing the flow disturbance through dimples. This paper focuses on flow manner analysis and flows field characteristics. Through this study, three different area ratios ARs (2, 2.5 and 3) for the diffusing channel have been developed using Solidwork and CFD simulations. There are performed to find the velocity distribution profile and pressure drop using software ANSYS. The numerical results, mainly the radial velocity profile and pressure drop profile for the dimpled tube through a diffusing channel are obtained. Numerical findings for three tested ARs (2, 2.5 and 3) which is the ratio of the outlet to the inlet cross-sectional area of the annular diffuser are compared with each other for Reynolds number (Re) 62 393.

2. Numerical setup

For studying the velocity and pressure drop structures around DDT, three different area ratios are simulated. SolidWorks designed all the models. Moreover, the present analysis work has been carried out in CFD using commercial software ANSYS 16.1. The recommended turbulence model in this study is the standard k- ε model. The model is suitable for predicting the flow characteristics, which consist of adverse pressure gradients and separated flow [15,16].

2.1. Turbulent model

The turbulence kinetic energy k and its rate of dissipation ε are obtained from the following equations [17,18].

$K = 3/2(VI)^2$	(1)
$I = 0.16(Re)^{-1/8}$	(2)
$\varepsilon = (C\mu^{3/4}.K^{3/2})l^{-1}$	(3)
l = 0.07L	(4)

where, V is the value of the inlet velocity, I is the initial turbulence intensity, Re is Reynolds number, $C\mu$ is a k- ε 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 Dh.

2.2. Dimpled tube structure

A conventional diffusing channel with divergent dimpled tube (DDT) is used in the Computational Fluid Dynamics CFD. Air with temperature 298 K flows around the dimpled tube through the diffusing channel as shown in Fig. 1. The divergent dimpled tube DDT has an inlet diameter dti of 5 mm, an outlet diameter dto of 10 mm and a total length Lt of 70 mm. The DDT is fitted with semi dimples with a diameter dm of 5 mm. More details are listed in Table 1.

Table 1. Geometrical parameters of the tested model.

Parameters	Dimensions
Diffusing channel inlet diameter Di, mm	15
Diffusing channel outlet diameter Do, mm	30
Diffusing channel length L, mm	80
Divergent dimpled tube Inlet diameter dti, mm	5
Divergent dimpled tube outlet diameter dto, mm	10
Divergent dimpled tube length Lt, mm	70
Semi dimple diameter dm, mm	5
Area ratios AR, (A _{outlet} \A _{inlet})	2, 2.5, 3

2.3. Boundary conditions and mesh processing

The inlet boundary is set at the entrance of the diffusing channel with air as a working fluid. At the inlet, the flow has a uniform velocity of 100 m/s and the inlet temperature is fixed as 298 K. In addition, the relative outlet



Fig. 1. Geometries parameters of DDT.

pressure is set to zero. The numerical simulations are performed with a three-dimensional, incompressible, steadystate, turbulent flow system. It is set that the physical properties of the working fluid (air) have been considered as the density (1.184 kg/m^3) and the dynamic viscosity (1.849e - 05 kg/m s), Flórez-Orrego et al. [17].

In this paper, the numerical simulations are performed with Reynolds number 62393 based on the hydraulic diameter Dh. For the simulations cases, the structured tetrahedral mesh is generated using the commercial software ICEM version 16.1. Fig. 2 presents a schematic of the grid generation for the dimpled tube in a diffusing channel. This software is designed to automatically generate meshes in complex 2D and 3D software.



Fig. 2. Mesh generation for diffuser with AR = 2.

3. Results and discussions

This study consists of the investigation of the effect of three different area ratios AR (2, 2.5 and 3) of the DDT on the flow characteristics. The effect of these area ratios on the velocity and pressure drop structure is described as follows.

3.1. The effect of different area ratios of the DDT on the velocity profile

In this part of the study, the velocity profile for three different ARs (2, 2.5 and 3) in a plane near the outlet are displayed in Fig. 3. The simulation results in the radial direction show that with increasing area ratio the velocity magnitude decreases. Since the area ratio is defined as the outlet area to the inlet area of the diffusing channel then it is obviously a reasonable finding. The velocity values are proportional to the sectional area of the diffusing channel. For these types of channels, increases in size in the direction of flow provides a decrease in velocity value. The highest velocity distribution is obtained by AR = 2 and the smallest is obtained by AR = 3. This phenomenon can improve velocity distribution performance.



Fig. 3. The velocity profile in the radial direction of the flow for three different ARs.

3.2. The effect of different area ratios of the DDT on the pressure profile

The pressure distributions for different ARs in a radial plane near the outlet of the diffusing channel are shown in Fig. 4. As expected from this figure, the pressure drop of the air is increased with an increasing the sectional area in the flow direction. Because that increasing area ratio of the diffusing channel will generate higher boundary layers separation and enhances the flow mixing between the near dimple wall region and mainstream region compared with smaller area ratios. This fact is mainly because of the friction factor grows much faster in AR = 3 than the other tested ARs with the inlet Reynolds number 62 393. Furthermore, the insertion of the dimples through the flow area will improve the flow mixing and consequently improving the pressure distribution.



Fig. 4. The pressure drop profile in the radial direction of the flow for three different ARs.

3.3. Characteristics of the velocity profile for different radial plans

Figs. 5–7 present the effect of different area ratios AR on the velocity profile in a diffusing channel with a DDT. Each figure displays the velocity distribution in different planes through the diffusing area in the radial direction. From these figures, the velocity distribution profile of the plane 1–1 shows a slight increasing behavior near the inlet. For the downstream flow, the velocity profile value decreases as display in plane 2–2, plane 3–3 and plane 4–4. In general, the results show that an increase in area ratio AR causes the velocity profile values to decrease and this is clearly shown in Fig. 8. This phenomenon occurred because an increase of the area ratio AR decelerates the airflow velocity because the flow cross-sectional area increases (mass conservation law).

In addition, the flow will be affected by the different area ratios on the one hand and the insertion of the DDT on the other. Flow into the dimpled tube is interesting due to the surface of the dimple that can induce swirl shape



Fig. 5. Four planes velocity profile in the radial direction of the flow for AR = 2.



Fig. 6. Four planes velocity profile in the radial direction of the flow for AR = 2.5.



Fig. 7. Four planes velocity profile in the radial direction of the flow for AR = 3.



Fig. 8. Velocity profile comparison.

through its area. In addition, when the airflows into the dimpled surface, the surface of the dimple impinge the flow and generates secondary flow by distributing and mixing the boundary layers. Thus, results in making the air separated and these can improve the airflow mixing turbulent intensity and improve the velocity distribution.

4. Conclusion

The numerical investigations on the velocity structure and pressure drop of airflow around the dimpled tube in a diffusing channel with different area ratios is performed. The details of velocity profile and pressure drop of the flow for different area ratios ARs are provided to explain the flow field structure. In addition, the effect of the dimpled tube and diffusing channel with different area ratios ARs on velocity distribution are provided and discussed. The most important conclusions from this study are drawn as followings:

- The velocity values decrease as the area ratio AR increases, therefore the highest velocity value is provided by AR = 2 and the smallest is provided by AR = 3.
- The diffusing channel with the highest area ratio yields the maximum value of the pressure drop, thus the pressure drop of the air is increased with an increasing the area ratio of the diffusing channel.
- The results reveal that with the help of dimples, the boundary layer thickness is reduced and the flow mixing is enhanced.

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