

Askari, Ehan Sabah Shukri

Article

Performance analysis of annulus diffusing area with divergent dimpled tube

Energy Reports

Provided in Cooperation with:

Elsevier

Suggested Citation: Askari, Ehan Sabah Shukri (2020) : Performance analysis of annulus diffusing area with divergent dimpled tube, Energy Reports, ISSN 2352-4847, Elsevier, Amsterdam, Vol. 6, Iss. 2, pp. 11-18, <https://doi.org/10.1016/j.egyr.2019.11.032>

This Version is available at:

<https://hdl.handle.net/10419/243851>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



<https://creativecommons.org/licenses/by-nc-nd/4.0/>

The 6th International Conference on Power and Energy Systems Engineering (CPESE 2019),
September 20–23, 2019, Okinawa, Japan

Performance analysis of annulus diffusing area with divergent dimpled tube

Ehan Sabah Shukri Askari

Engineering Technical College-Baghdad, Middle Technical University (MTU), Baghdad, Iraq

Received 7 October 2019; accepted 22 November 2019

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 $k\text{-}\epsilon$ 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.

© 2019 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer-review under responsibility of the scientific committee of the 6th International Conference on Power and Energy Systems Engineering (CPESE 2019).

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.

E-mail address: dr.ehansabah@mtu.edu.iq.

<https://doi.org/10.1016/j.egy.2019.11.032>

2352-4847/© 2019 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer-review under responsibility of the scientific committee of the 6th International Conference on Power and Energy Systems Engineering (CPESE 2019).

Nomenclature

D_i	Diffusing channel inlet diameter, mm
D_o	Diffusing channel outlet diameter, mm
L	Diffusing channel length, mm
d_{ti}	Divergent tube inlet diameter, mm
d_{to}	Divergent tube outlet diameter, mm
L_t	Divergent tube length, mm
dm	Semi dimple diameter, mm
P	Inlet pressure, bar
V	Inlet velocity, m s^{-1}
ρ	Density, kg m^{-3}
Re	Reynolds Number

Greek Symbols

K	Turbulent kinetic energy, m^2/s^2
ε	Turbulence dissipation, m^2/s^3
l	Turbulence length scale, mm
I	Initial turbulence intensity
C_μ	k - ε model parameter
λ	Thermal conductivity
C_p	Specific heat capacity, $\text{kJ kg}^{-1} \text{K}^{-1}$

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 $k-\varepsilon$ 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].

$$K = 3/2(VI)^2 \quad (1)$$

$$I = 0.16(Re)^{-1/8} \quad (2)$$

$$\varepsilon = (C\mu^{3/4} \cdot K^{3/2})l^{-1} \quad (3)$$

$$l = 0.07L \quad (4)$$

where, V is the value of the inlet velocity, I is the initial turbulence intensity, Re is Reynolds number, $C\mu$ is a $k-\varepsilon$ 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 d_{ti} of 5 mm, an outlet diameter d_{to} of 10 mm and a total length L_t of 70 mm. The DDT is fitted with semi dimples with a diameter d_m of 5 mm. More details are listed in Table 1.

Table 1. Geometrical parameters of the tested model.

Parameters	Dimensions
Diffusing channel inlet diameter D_i , mm	15
Diffusing channel outlet diameter D_o , mm	30
Diffusing channel length L , mm	80
Divergent dimpled tube Inlet diameter d_{ti} , mm	5
Divergent dimpled tube outlet diameter d_{to} , mm	10
Divergent dimpled tube length L_t , mm	70
Semi dimple diameter d_m , 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

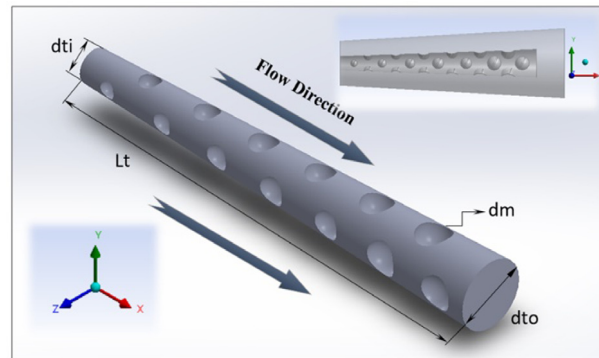


Fig. 1. Geometries parameters of DDT.

pressure is set to zero. The numerical simulations are performed with a three-dimensional, incompressible, steady-state, 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 ($1.849\text{e} - 05 \text{ kg/m s}$), Flórez-Orrego et al. [17].

In this paper, the numerical simulations are performed with Reynolds number 62393 based on the hydraulic diameter D_h . 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.

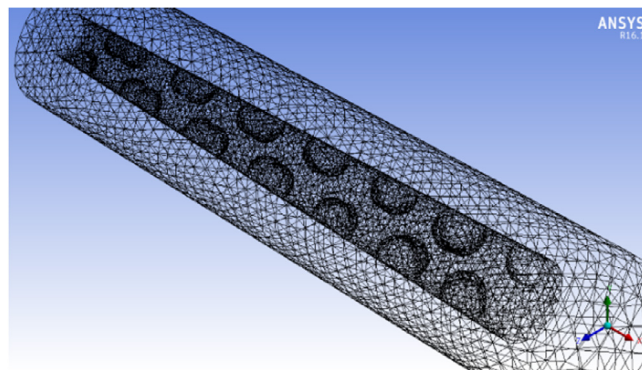


Fig. 2. Mesh generation for diffuser with $AR = 2$.

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 AR s (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.

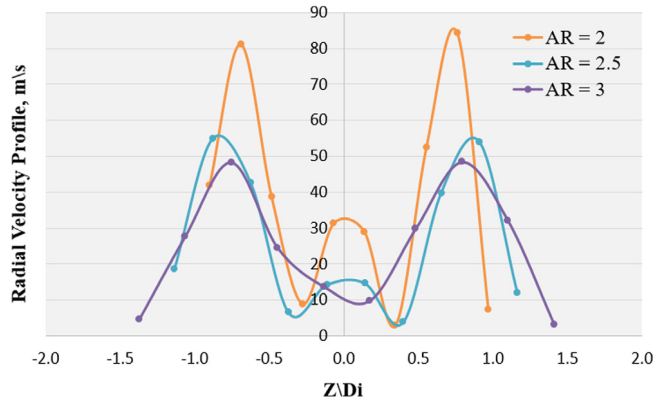


Fig. 3. The velocity profile in the radial direction of the flow for three different ARs.

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.

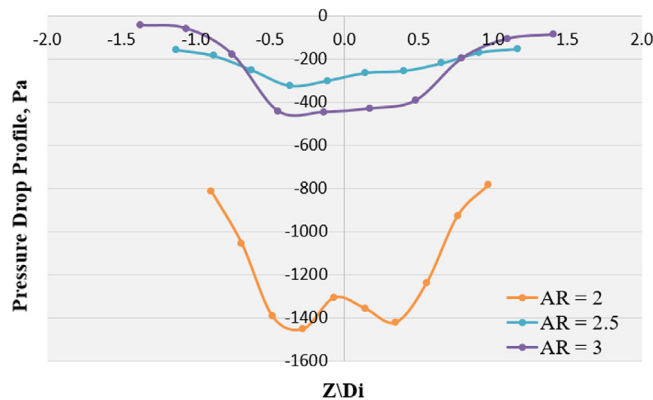


Fig. 4. The pressure drop profile in the radial direction of the flow for three different ARs.

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

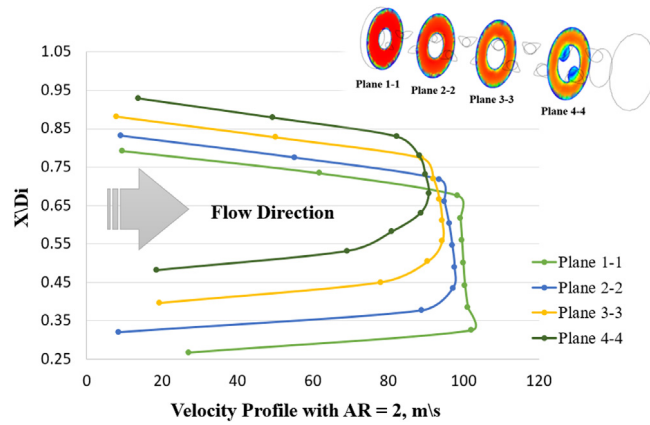


Fig. 5. Four planes velocity profile in the radial direction of the flow for AR = 2.

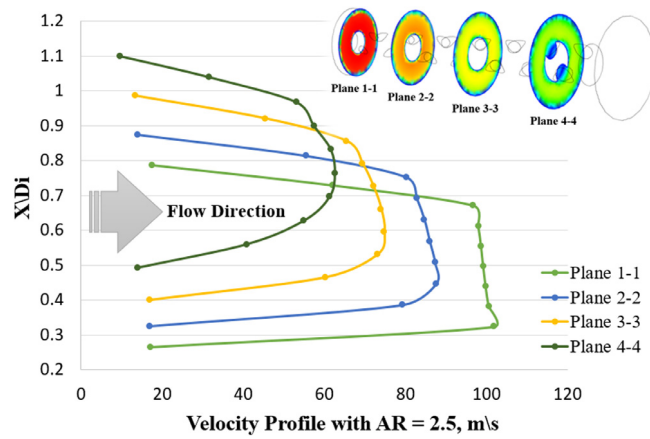


Fig. 6. Four planes velocity profile in the radial direction of the flow for AR = 2.5.

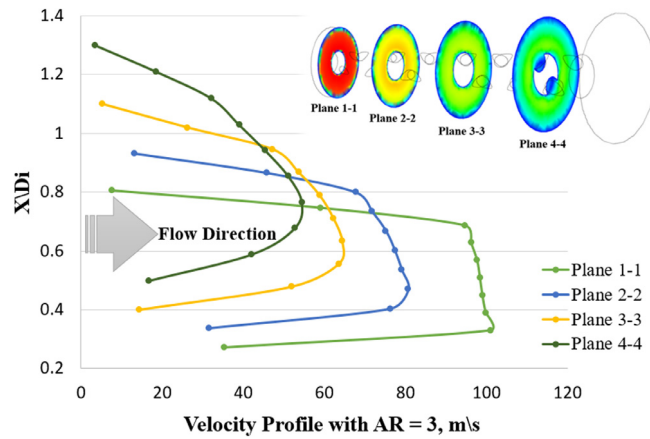


Fig. 7. Four planes velocity profile in the radial direction of the flow for AR = 3.

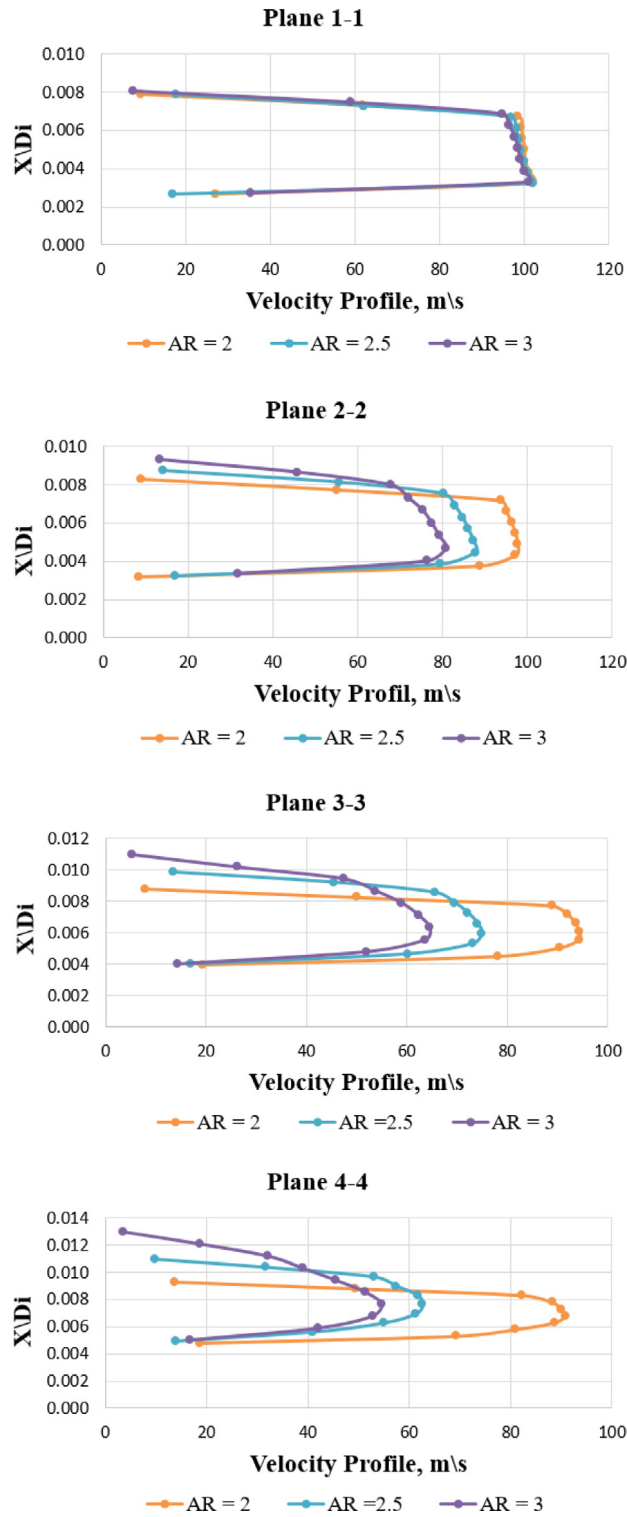


Fig. 8. Velocity profile comparison.

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.

Acknowledgments

The author would like to thank the Engineering Technical College-Baghdad, Middle Technical University MTU, Baghdad, Iraq for providing assistance and support for this research.

References

- [1] Chang SW, Chiang KF, Yang TL, Huang CC. Heat transfer and pressure drop in dimpled fin channels. *Exp Therm Fluid Sci* 2008;33:23–40.
- [2] Kore SS, Satishchandra VJ, Narayan KS. Experimental investigations of heat transfer enhancement from dimpled surface in a channel. *Int J Eng Sci Technol* 2011;3:6234–77.
- [3] Xie G, Sunden B, Zhang W. Comparisons of pins/dimples/protrusions cooling concepts for a turbine blade tip-wall at high Reynolds numbers. *J Heat Transfer* 2011;133:9, Article ID 061902, 9 pages.
- [4] Rao Y, Xu Y, Wan C. An experimental and numerical study of flow and heat transfer in channels with pin fin-dimple and pin fin arrays. *Exp Therm Fluid Sci* 2012;38:237–47.
- [5] Bi C, Tang GH, Tao WQ. Heat transfer enhancement in mini-channel heat sinks with dimples and cylindrical grooves. *Appl Therm Eng* 2013;55:121–32.
- [6] Aroonrat K, Wongwises S. Experimental study on two-phase condensation heat transfer and pressure drop of R-134a flowing in a dimpled tube. *Int J Heat Mass Transfer* 2017;106:437–48.
- [7] Zhou W, Rao Y, Hu H. An experimental investigation on the characteristics of turbulent boundary layer flows over a dimpled surface. *J Fluids Eng* 2016;138. 021204, 1-13.
- [8] Chimres N, Wangb CC, Wongwises S. Optimal design of the semi-dimple vortex generator in the fin and tube heat exchanger. *Int J Heat Mass Transfer* 2018;120:1173–86.
- [9] Pathan A, Deshmukh DA, Pawar RS. Experimental investigation of heat transfer enhancement through elliptical dimples for divergent channel. *Int J Adv Res Innov Ideas Ed* 2017;3:2395–4396.
- [10] Chang SW, Chiang K, Chien Chou T. Heat transfer and pressure drop in hexagonal ducts with surface dimples. *Exp Therm Fluid Sci* 2010;34:1172–81.
- [11] Li M, Khan TS, Al-Hajri E, Ayub ZH. Single phase heat transfer and pressure drop analysis of a dimpled enhanced tube. *Appl Therm Eng* 2016;101:38–46.
- [12] Huang Z, Yao Li Z, Lei Yu G, Quan Tao W. Numerical investigations on fully-developed mixed turbulent convection in dimpled parabolic trough receiver tubes. *Appl Therm Eng* 2017;114:1287–99.
- [13] Wanga S, Dua W, Luo L, Qiu D, Zhang X, Li S. Flow structure and heat transfer characteristics of a dimpled wedge channel with a bleed hole in dimple at different orientations and locations. *Int J Heat Mass Transfer* 2018;117:1216–30.
- [14] Abraham J, Maki R. Hydrodynamics of laminar flow through dimpled pipes. *MOJ Civil Eng* 2018;4(3):150–4.
- [15] Lotfi B, Zeng M, Sunden B, Wang Q. 3D numerical investigation of flow and heat transfer characteristic in smooth wavy fin-and-elliptical tube heat exchangers using new type vortex generators. *Energy* 2014;73:233–57.
- [16] Shukri ES, Abdullah BH, Ali OM. Velocity distribution in an annular diffuser fitted with twisted hub for different area ratios. In: 4th International conference on power and energy systems engineering, vol. 141; 2018. Berlin, Germany. p. 639–43.
- [17] Flórez-Orrego D, Arias W, López D, Velásquez H. Experimental and CFD study of a single phase cone-shaped helical coiled heat exchanger: an empirical correlation. In: Proceedings of the 25th international conference on efficiency, cost, optimization, simulation and environmental impact of energy systems; 2012. p. 375–94.
- [18] Shukri ES. Helical screw-tape influence on swirl flow profile in a diffuser. *Int Res J Eng Technol* 2018;5:1361–6.