Helical Screw-Tape Influence on Swirl Flow Profile in a Diffuser

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Abstract – *In this research, a numerical study is performed to model the airflow behavior in an annular diffuser with a swirl generator. For this purpose, helical screw-tape inserted around the cylindrical hub with different swirl number (Sn) is used. Three swirl numbers (2.8, 3.9 and 5.8) are analyzed. The simulations are carried out with air as the working fluid and Reynolds number (Re) 1.2 x10^5. The analysis of the flow structure shows that swirling flow is induced in the diffuser. This swirling flow leads to acceptable air mixing between the core flow and the near diffuser wall regions. The numerical results indicated that swirling flow induced by swirl number 5.8 enhanced the velocity distribution better than the other tested swirl numbers.*

Key Words: CFD, annular diffuser, helical screw-tape, swirl number, velocity distribution.

1. INTRODUCTION

Swirling flows, which make fluid mixing possible, are widely used in different engineering applications such as combustors, hydro-cyclones or inline swirl element separators [1]. The use of the swirling flow is to provide and to increase the centrifugal force. These days, the analysis of swirl flow show great interest. There are in the literature, countless works on swirl flow that generated by different methods [2 - 3]. The influence of the inlet swirl on the flow development has been confirmed by the researchers [4 - 5]. Therefore, results revealed the improvement of pressure recovery coefficient due to the swirling flow insertion. Most attention has been given to strong recirculating swirling flow in diffusers, for their extensively used in fluid mechanical devices. The intensity of swirl flow is characterized by swirl number (Sn) which is known as the ratio of the axial flux of tangential momentum to the axial flux of axial momentum [6]. As accomplished study by Singh et al. [5] the range of the inlet swirl intensity was investigated to get the best performance of annular diffuser with different geometries but having the same equivalent cone angle. The optimum development was to increase the pressure recovery coefficient that considered as the measure of diffusers performance and to decrease the pressure loss coefficient. Findings reached a good agreement with the study target. Abdalla et al. [7] introduced an experimental study for the effect of swirling inlet flow on the performance of annular diffusers. Five annular diffusers were tested with different casing wall angles.

The performance of the tested diffusers was experimentally obtained in the presence of free-swirl and forced-swirl flows. In the aforementioned cases of swirl generators, the pressure coefficient of annular diffusers increased with increasing the inlet swirl angle. Swirling flows are widely used in industrial combustion devices such as gas turbine combustors, furnaces, burners to provide power generation. It has a dominant effect on the mixing process in gas turbine combustion chamber.

Eldrainy et al. [8 - 9] examined the effect of different swirler geometries on the flow dynamics inside a micro gas turbine combustion chamber model. Designing air swirler to produce stable and efficient combustion with low-pressure losses was a challenge. Axial flat vane swirler with different vane angles was tested to show the effect of vane angle on the internal flow field. The simulated results confirmed that weak swirl with low swirl number was not sufficient to produce a strong centrifugal force. Consequently, if the swirler vane angle increased, both swirl number and flow deflection angles were increased. Moreover, extra pressure reduction occurred, and the reversed flow was increased as well, so as a conclusion, with high deflection angles, turbulence intensity increased and the fuel-air mixing would be promoted [8]. Furthermore, Eldrainy et al. [9] confirmed that swirl number under 0.4, recirculation would not be observed. Therefore, mixing applications should be designed for swirl number more than 0.6. Thus, controlling such parameters, the mixing process can be improved. Swirling flow is one of the passive techniques. Since it is usually accompanied with high tangential velocity and turbulence intensity, which provides an additional mechanism to increase the heat transfer [10 - 12], it has been studied to enhance heat transfer in many industrial applications. Many types of swirl generators have been studied to improve heat transfer and temperature distribution inside flow passages. This include fixed vanes with different blade angles in the inlet flow [13 - 15], twisted tapes [16 - 18], helical screw-tapes [19 - 21], struts [22 - 23], pins [25] and conical rings [26 - 27] These types of turbulators are the most favorable passive techniques because they are inexpensive and can be easily used in the existing system.

Most of these works mentioned above mainly concentrated on the flow characteristic in pipes and tubes rather than in diffusers. In this study, a numerical study was performed to investigate the flow behavior in an annular diffuser. A circular hub equipped with inserted helical screw-tape is adapted to act as a swirl generator.

Nomenclature

Di	Annular diffuser inlet diameter, mm
Do	Annular diffuser outlet diameter, mm
D_h	Hydraulic diameter, mm
L	Annular diffuser length, mm
d	Hub diameter, mm
H	Helical screw-tape height, mm
P	Pitch length, mm
Pi	Inlet pressure, bar
Po	Outlet pressure, bar
u_i	Inlet velocity, $m.s^{-1}$
T	Static temperature, K
ρ	density, $kg.m^{-3}$
Re	Reynolds Number
	Greek Symbols
k	Turbulent kinetic energy
ε	Turbulence dissipation
l	Turbulence length scale
I	Initial turbulence intensity
Cμ	*k-ε* model parameter
λ	Thermal conductivity
C_p	Specific heat capacity, $Kj.kg^{-1}\ K^{-1}$

2. PHYSICAL AND SIMULATION MODELS

2.1 Helical Screw-Tape Geometries

The schematic of the annular diffuser fitted with helical screw-tape is shown in Fig. 1. The geometric parameters of the physical model are presented in Table 1. Air with an inlet temperature of 298 K is used as a working fluid. Three different swirl numbers (Sn = 2.8, 3.9 and 5.8) as shown in Fig. 2 are numerically simulated.

Moreover, it is set that the physical properties of the working fluid (air) have been considered as the density (1.168 kg/m^3), the dynamic viscosity (1.848e − 05 kg/m.s) and the static pressure at the outlet are set as zero. In this work, the following assumptions can be applied as follows:

- The turbulent incompressible flow with constant physical properties is used.
- Steady flow.
- Inlet Reynolds number is (Re = 1.2 x 10^5) based on the hydraulic diameter of the annular diffuser (D_h).
- The physical properties of the air at the diffuser inlet are constant.

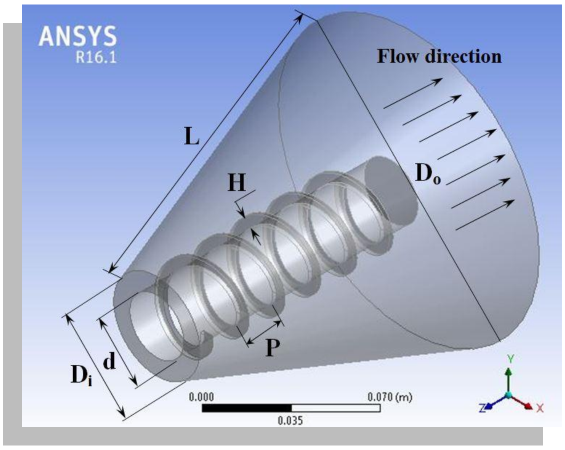

Fig -1: Physical model geometries

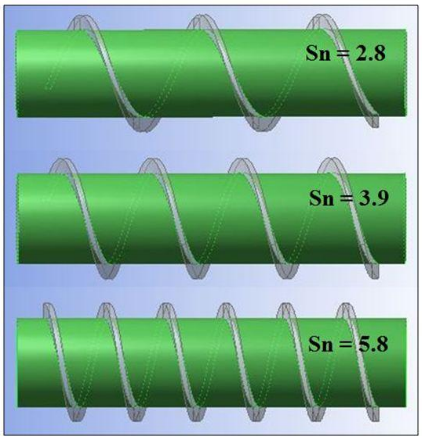

Fig -2: CAD drawing for three different swirl numbers (Sn)

Table -1: Geometry definitions

Parameters	Dimension [mm]
Annular diffuser inlet diameter, Di	48
Annular diffuser outlet diameter, Do	145
Annular diffuser length, L	140
Annular diffuser hub diameter, d	30
Helical screw-tape height, H	30
Helical screw-tape thickness, t	2
Swirl number, Sn	2.8, 3.9 and 5.8

2.2 CFD Governing Equations

The continuity and the momentum equations are the mathematical equations that used to describe the flow of fluids. These equations describe the conservation of mass, momentum, and energy which are also known as the Navier-Stokes equations.

- Continuity Equation

$$\frac{\partial}{\partial x_i}(r\rho u_i) = 0 \qquad (1)$$

- Momentum Equation:

$$\frac{\partial}{\partial x}(r\rho u_i u_j) = -r\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left[r\left(\mu\frac{\partial u_i}{\partial x_j} - \rho\overline{\acute{u}_i \acute{u}_j}\right)\right] \qquad (2)$$

- Energy Equation:

$$\frac{\partial(\rho\bar{T})}{\partial x_i} + \frac{\partial(\rho\bar{u}_i\bar{T})}{\partial x_i} = \frac{\partial}{\partial x_i}\left(\frac{\lambda}{C_p}\frac{\partial(\bar{T})}{\partial x_i}\right) \qquad (3)$$

2.3 Numerical Method

3D models with three different swirl numbers (Sn) are utilized to describe fluid flow characteristics in an annular diffuser fitted with helical screw-tape under inlet constant condition. The velocity at the inlet is selected as 100 m/s in a turbulent flow regime.

For this model investigation, the commercial software ANSYS 16.1 is used as the computational fluid dynamics tool. The time-independent incompressible Navier Stokes equations are solved using finite volume technique.

The numerical analyses were performed in three dimensional domains applying standard k-ε model as a turbulence model. The k-ε turbulence model is adopted in the current study because it can provide superior performance for flows involving rotation, boundary layers effect and recirculation [28]. The turbulence kinetic energy k and its rate of dissipation ε were obtained from the following transport equations [29].

$$K = 3/2\ (VI)^2 \qquad (4)$$

$$I = 0.16\ (Re)^{-1/8} \qquad (5)$$

$$\varepsilon = (C\mu^{3/4}.\ K^{3/2})\ l^{-1} \qquad (6)$$

$$l = 0.07L \qquad (7)$$

where, V is the inlet velocity magnitude, I is the initial turbulence intensity, Re 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.

In this numerical study, the finite volume method has been used to discretize the partial differential equations of the model. The geometry and the corresponding mesh that are produced in the software have used the tetrahedral structure for meshing the volume. As indicated in Fig. 3, the mesh has higher concentration near helical screw-tape walls.

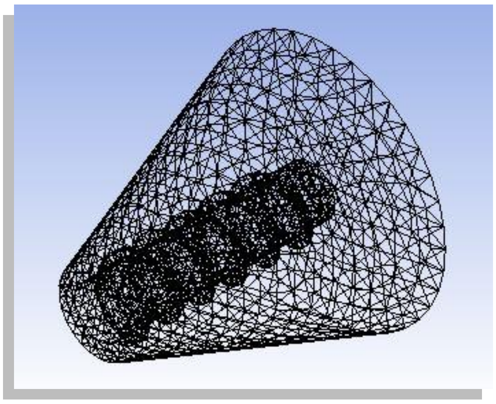

Fig. -3: Schematic view of the grid structure of the numerical model

2.4 Mesh Independent Analysis

For guaranteeing the accuracy of numerical solutions results, the grid independent test has been performed for the simulation model. This test is essential to ensure that the calculated results are independent of grid numbers.

Five different grid independence tests have been used to evaluate the effects of grid sizes on the accuracy of the numerical results. The predicted velocity profiles for the various grid tests have been compared. The percentage difference ratio for the tested velocity regarding to the average velocity has been recorded. It has been observed that 23585 elements grid is considered for the simulation.

3. RESULTS AND DISCUSSIONS

3.1 Velocity Distribution Induced by Helical Screw-Tape Inserts

The radial velocity distribution in the annular diffuser inserted with helical screw-tape is shown in Figs. 4-6. These Figs show the tangential velocity contours for three values of swirl number Sn 2.8, 3.9 and 5.8 at inlet Reynolds number (Re) 1.2 x10[5].

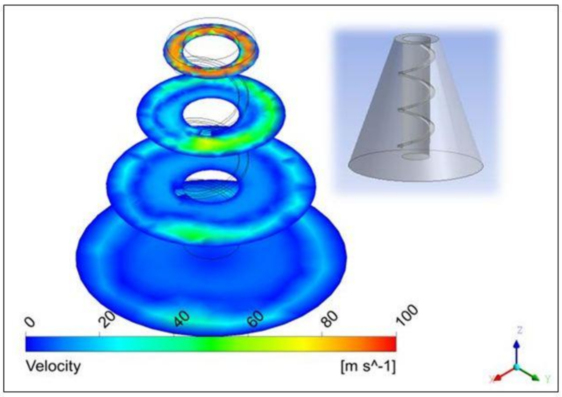

Fig. -4: Velocity contours in four different planes of the annular diffuser with swirl number Sn = 2.8

Swirl flow and centrifugal forces will be generated by helical screw-tape inserts. These forces cause a tangential velocity component with more mixing. As displayed in Figs. 4-6, the velocity is highly distributed close to the diffuser wall. The swirling flow moves from the core region towards the annular diffuser wall surface as the swirl number increases. This mainly means that the disturbance of the flow in the annular diffuser will be transferred from the flow core to the diffuser wall. The turbulence increased around the helical screw-tape. Therefore, it increases the velocity gradient, which allows a better flow mixing. Mixing enhancement depends on the flow moves from the core to the surface that induced by the helical screw-tape inserts. Moreover, this indicates that the velocity distribution rate increases by increasing the swirl number. The increase of swirl number is leading to the increase of turbulent intensity which is enhanced the distribution rate.

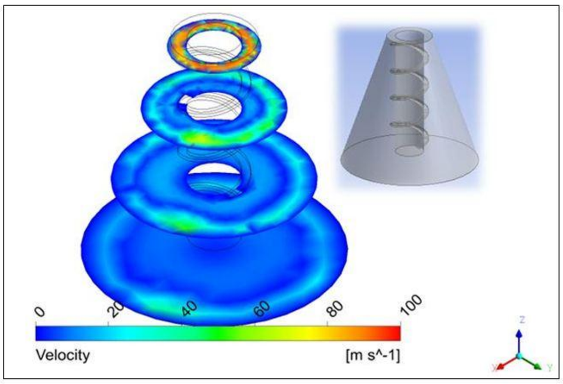

Fig. -5: Velocity contours in four different planes of the annular diffuser with swirl number Sn = 3.9

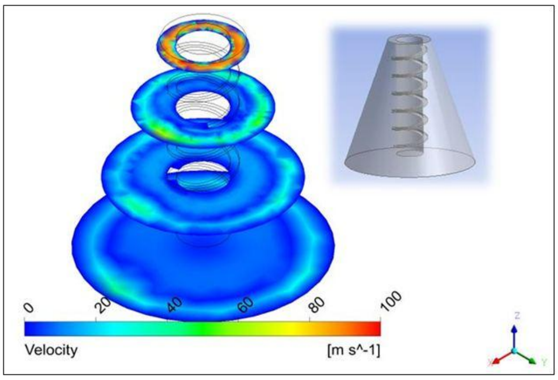

Fig. -6: Velocity contours in four different planes of the annular diffuser with swirl number Sn = 5.8

Fig. 7 represents the influence predicted of the helical screw-tape on velocity distribution in the radial direction of the flow for different swirl numbers.

In this figure, the tested planes were chosen at the diffuser outlet and the influence of the helical screw-tape insertion is clearly seen, especially in the range from (r/D) (0.2 – 0.6).

It can be visualized that the existence of the helical screw-tape in the annular diffuser produces more turbulent flow that enhanced the velocity distribution in the radial direction toward the diffuser wall. Moreover, with different swirl numbers, the velocity will be distributed in different rates.

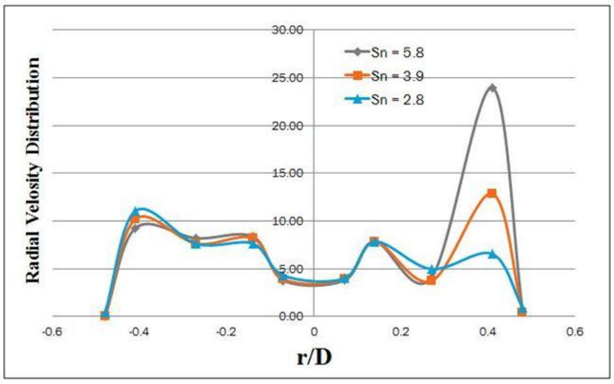

Fig. -7: Velocity distribution in the radial direction

It can be understood from the results that the use of helical screw tape inserts with different swirl numbers causes velocity distribution enhancement.

3.2 Pressure Distribution Induced by Helical Screw-Tape Inserts

Fig. 8 shows the effects of the swirl number on the static pressure. It displays the variation of static pressure in the radial direction at outlet plane.

In order to investigate the static pressure variation in this work, three different swirl numbers are numerically studied.

As it is illustrated in this figure, the pressure distribution of the flow in the annular diffuser with helical screw-tape hub insert is almost the same for the three swirl numbers. There is no significant difference between the three swirl numbers. However, swirl number 5.8 records a little bit different pressure variations.

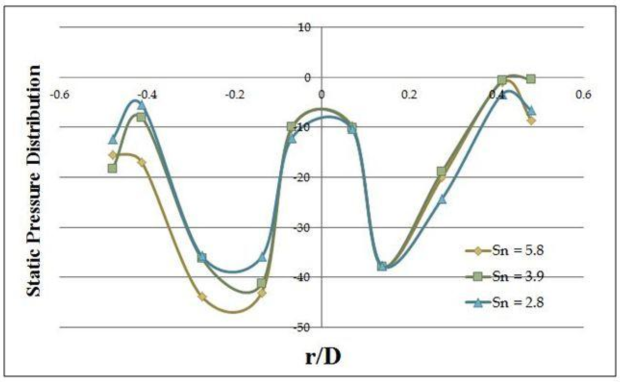

Fig. -8: Pressure distribution in the radial direction

4. CONCLUSIONS

Flow performance of the helical screw-tape inserts in turbulent flow regime with air as a working fluid through annular diffuser is carried out in this paper research. The helical screw-tape inserts with swirl numbers Sn = 2.8, 3.9 and 5.8 were used in the numerical simulations. The following conclusions from these simulations are:

- Due to the swirl flow and high turbulence intensity, the mixing of air between the diffuser wall and air at the core region induced by the generated centrifugal force has significant ability to enhance velocity distribution.
- The results show that the existence of the helical screw-tape with swirl number 5.8 enhances the velocity distribution better than swirl number Sn (2.8 and 3.9).
- For more uniform flow mixing, the helical screw-tape with swirl number 2.8 is the best.

REFERENCES

[1] R. Anugrah Putra, T. Schäfer, M. Neumann and D. Luca, "CFD studies on the gas-liquid flow in the swirl generating device," Nuclear Engineering and Design, vol. 332, 2018, pp. 213-225.

[2] M. Benisek, D. Ilic, D. Cantrak and I. Bozic, "Investigation of the turbulent swirl flow in a conical diffuser," Thermal Science, vol. 14, 2010, pp. 141–154.

[3] R. Prakash, D. Christopher and K. Kumarrathinam, "CFD analysis of flow through a conical exhaust," International Journal of Research in Engineering and Technology, vol. 3, no. 11, 2014, pp. 239– 248.

[4] H. A. Abdalla, E. A. EL. Shenawy, A. E. Kabeel and Z. M Omara, "Experimental performance analysis of annular diffusers with and without swirl," in Seventh International Congress On Fluid Dynamics & Propulsion, Proceedings, 2001, pp. 1–11.

[5] S. N. Singh, V. Seshadri, K. Saha, K. Vempati and S. Bharani, "Effect of inlet swirl on the performance of annular diffusers having the same equivalent cone Angle," Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering, vol. 220, no. 2, 2006, pp. 129–143.

[6] J. Vondál and J. Hájek, "Swirling flow prediction in model combustor with axial guide vane swirler," Chemical Engineering Transactions, vol. 29, 2012, pp. 1069–1074.

[7] H. A. Abdalla, E. Shenawy, A. E. Kabeel and Z. M Omara, "Experimental performance analysis of annular diffusers with and without swirl," in Seventh International Congress On Fluid Dynamics & Propulsion, Proceedings, 2001, pp. 1–11.

[8] Y. a. Eldrainy, J. Jeffrie and M. Ridzwan, "Prediction of the flow inside a micro gas turbine combustor," Jurnal Mechanical, no. 25, 2008, pp. 50–63.

[9] Y. A Eldrainy, H. S. Aly, K. M. Saqr and M. N. Jaafar, "A multiple inlet swirler for gas turbine combustors," Proceeding of The International Conference on Fluid Mechanics, Heat Transfer and Thermodynamics, World Academy of Science, Engineering and Technology Tokyo, Japan, vol. 3, no. 5, 2009, pp. 1260–1263.

[10] H. A. Abdalla, M. M. El-Mayit, A. A. Abd El-Hamid and A. M. El-Shazly, "Study of swirling turbulent flow and heat transfer characteristics in conical diffusers," Proceedings of Eighth International Congress of Fluid Dynamics & Propulsion, 2006.

[11] Liu and M. Sakr, "A comprehensive review on passive heat transfer enhancements in pipe exchangers," Renewable and Sustainable Energy Reviews, vol. 19, 2013, pp. 64–81.

[12] M. Sheikholeslami, M. Gorji-Bandpy and D. Ganji, "Review of heat transfer enhancement methods: Focus on passive methods using swirl flow devices," Renewable and Sustainable Energy Reviews, vol. 49, 2015, pp. 444–469.

[13] Y. A Eldrainy, H. S. Aly, K. M. Saqr and M. N. Jaafar, "A multiple inlet swirler for gas turbine combustors," Proceeding of The International Conference on Fluid Mechanics, Heat Transfer and Thermodynamics, World Academy of Science, Engineering and Technology Tokyo, Japan, vol. 3, no. 5, 2009, pp. 1260–1263.

[14] Y. Eldrainy, J. Jeffrie and M. Ridzwan, "Prediction of the flow inside a micro gas turbine combustor," Jurnal Mechanical, no. 25, 2008, pp. 50–63.

[15] M. Jaafar Nazri and K. Jusoff, "Combustor aerodynamic using radial swirler," International Journal of Physical Sciences, vol. 6, no. 13, 2011, pp. 3091–3098.

[16] S. V Patil and P. V. V. Babu, "Performance comparison of twisted tape and screw tape inserts in square duct," Proceeding of The International Conference on Advanced Science, Engineering, and Information Technology, 2011, pp. 50–55.

[17] S. Bhattacharyya, T. Roy, N. Ghosh, Bandyopadhyay and P. P. Sarkar, "Convective heat transfer enhancement in low Reynold number of a circular pipe with full length," International Journal of Mechanical and Production Engineering, vol. 2, no. 9, 2014, pp. 6–10.

[18] S. Pal and S. K. Saha, "Laminar fluid flow and heat transfer through a circular tube having spiral ribs and twisted tapes," Experimental Thermal and Fluid Science, vol. 60, 2015, pp. 173–181.

[19] P. S. Rao and K. K. Kumar, "Numerical and experimental investigation of heat transfer augmentation in double pipe heat exchanger with helical and twisted tape inserts," International Journal of Emerging Technology and Advanced Engineering., vol. 4, no. 9, 2014, pp. 180–192.

[20] S. Eiamsa-ard, K. Yongsiri, K. Nanan and C. Thianpong, "Heat transfer augmentation by helically twisted tapes as swirl and turbulence promoters," Chemical Engineering and Processing: Process Intensification, vol. 60, 2012, pp. 42–48.

[21] S. Rashidi, N. Moghadas Zade and J. Abolfazli Esfahani, "Thermo-fluid performance and entropy generation analysis for a new eccentric helical screw tape insert in a 3D tube", Chemical Engineering and Processing - Process Intensification, vol. 117, 2017, pp. 27-37.

[22] S. Ubertini and U. Desideri, "Flow development and turbulence length scales within an annular gas turbine exhaust diffuser," Experimental Thermal and Fluid Science, vol. 22, no. 1–2, 2000, pp. 55–70.

[23] S. Ubertini and U. Desideri, "Experimental performance analysis of an annular di user with and without struts," Experimental Thermal and Fluid Science, vol. 22, 2000, pp. 183–195.

[24] R. Prakash, "Experimental investigations of flow through annular diffuser with and without struts," European Journal of Scientific Research, vol. 52, no. 3, 2011, pp. 366–384.

[25] S. Selvam, P. Thiyagarajan and S. Suresh, "Experimental studies on effect of bonding the twisted tape with pins to the inner surface of the circular tube," Thermal Science, vol. 18, no. 4, 2014, pp. 1273–1283.

[26] A. R. Anvari, K. Javaherdeh, M. Emami-Meibodi and A. M. Rashidi, "Numerical and experimental investigation of heat transfer behavior in a round tube with the special conical ring inserts," Energy Conversion and Management, vol. 88, 2014, pp. 214–217.

[27] P. Promvonge and S. Eiamsa-ard, "Heat transfer behaviors in a tube with combined conical-ring and twisted-tape insert," International Communications in Heat and Mass Transfer, vol. 34, no. 7, 2007, pp. 849–859.

[28] E. Anas, L. Azzedine, S. Said, E. Mustapha, Z. Abdelkabir, M. Mohamed and B. A. Abdelatif, "Numerical comparison of shell-side performance for shell and tube heat exchangers with trefoil-hole, helical and segmental baffles," Appl Therm Eng, vol.109 (Part A), 2016, pp.175–85.

[29] D. Flórez-Orrego, W. Arias, D. López, and H. Velásquez, "Experimental and CFD study of a single phase cone-shaped helical coiled heat exchanger: an empirical correlation," Proceedings of the 25th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems, 2012, pp. 375–394.

BIOGRAPHIES

Dr. Ehan Sabah Shukri is working at Middle Technical University (MTU), Baghdad, Iraq. Research interests include but not limited to heat transfer enhancement applications in diffusers including swirl flow, temperature distribution by introducing different concepts of swirl generators.