SAKARYA ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ DERGİSİ

Sakarya University Journal of Science
SAUJS

e-ISSN 2147-835X Period Bimonthly Founded 1997 Publisher Sakarya University
http://www.saujs.sakarya.edu.tr/

Title: CFD Analysis of Convection Heat Transfer in Corrugated Channels for Different Inclination Angle

Authors: Haydar KEPEKÇİ, Erman ASLAN

Recieved: 2022-02-07 00:00:00

Accepted: 2022-03-08 00:00:00

Article Type: Research Article

Volume: 26
Issue: 2
Month: April
Year: 2022
Pages: 333-341

How to cite
Haydar KEPEKÇİ, Erman ASLAN; (2022), CFD Analysis of Convection Heat Transfer in Corrugated Channels for Different Inclination Angle. Sakarya University Journal of Science, 26(2), 333-341, DOI: 10.16984/saufenbilder.1069682
Access link
https://dergipark.org.tr/tr/journal/1115/issue/69580/1069682

Sakarya University Journal of Science 26(2), 333-341, 2022

CFD Analysis of Convection Heat Transfer in Corrugated Channels for Different Inclination Angle

Haydar KEPEKÇİ*[1], Erman ASLAN[2]

Abstract

Three different geometries have been used in this study, which investigated the effect of inclination angle on convective heat transfer in corrugated channels. The corrugated channel geometries used have inclination angles of 30°, 45°, and 60°. The finite volume method has been used in the study with numerical methods. k-ω, SST, and transition SST have been used as turbulence models. The mesh file used in the analysis consists of 192000 cells. The results obtained from the calculations using a corrugated channel with a 30° inclination angle have been compared with the experimental data. As a result of this comparison, the turbulence model to be used for this study has been determined as SST. SST turbulence model has been used in the analyzes made using a corrugated channel with 45° and 60° inclination angles and the results have been compared with each other. The Reynolds number ranges from 2225 to 7380. The Nusselt number and friction factor have been calculated using the data obtained as a result of the analysis. Based on the calculated values, it has been determined that the heat transfer increases as the angle of inclination increases in the corrugated channels. It has been also observed that the Nusselt number increased as the Reynolds number increased. It has been also seen that the analyzes for high Reynolds number gave results closer to the experimental data.

Keywords: Corrugated channel, inclination angle, heat transfer, turbulence models, Nusselt number.

1. INTRODUCTION

The amount of energy we use is increasing day by day due to the fact that technological devices are well-established in our lives. This increase in demand has led to an increase in energy costs. As a result of the home-office working system, which has become widespread with the Covid-19 pandemic, the use of air conditioning devices has also increased in order to provide thermal comfort in the building [1]. The use of these devices has been also reflected as a heavy burden on electricity bills. As a solution to this situation, the option of increasing the thermal performance of air conditioning devices that provide heat transfer has come to the fore. Heat exchangers have a wide area of use apart from air conditioning systems [2]. Examples of these are petroleum-chemical industries, refineries, food industries, and power plants. Traditional heat exchangers need to be

* Corresponding author: haydar.kepekci@nisantasi.edu.tr
[1] Nişantaşı University
ORCID: https://orcid.org/0000-0002-0037-8332
[2] Kocaeli University, Faculty of Engineering, Department of Mechanical Engineering
E-mail: erman.aslan@kocaeli.edu.tr
ORCID: https://orcid.org/0000-0001-8595-6092

redesigned in order to both reduce energy costs and save energy. One of the studies carried out in this context is to increase the use of corrugated channels [3]. The use of corrugated channels is a suitable method to increase thermal performance [4, 5].

The instability occurring in the thermal boundary layers arises when the fluid is flowing from the corrugated surfaces. In other words, corrugated channels change the modification of the flow by means of planes perpendicular to the main flow direction, making it turbulent. Thus, they significantly increase the heat transfer compared to straight channels. In recent years, many scientists have conducted experimental and numerical studies on the effect of corrugated channels on heat transfer. Tokgoz et al. investigated the effects of two different phase shifts of wavy channels on the flow hydrodynamics and the heat transfer rate for different Reynolds numbers. They used the PIV technique while observing turbulent flows and tracking flow velocities. They found that the cavity inlets in the corrugated channels create a vortex as it accelerates the flow movement and this increases the heat transfer. They conducted both numerical and experimental studies and found that the results they found in the two cases have been compatible with each other [6]. Aliabadi and Feizabadi investigated the hydrothermal performance of the flow using a square-section corrugated channel in their study. They compared the results of their initial calculations with the data in the literature and found that they have been suitable. They then tested each region of the corrugated channel separately and found that the sidewalls prevented the development of thermal boundary layers along with the flow. They assumed that the flow has been laminar in all calculations [7].

Ajeel et al. carried out numerical analyzes to investigate the effect of a corrugated channel on thermal performance in turbulent flows in the range of 10,000-30,000 Reynolds numbers. In their analysis, they assumed that there are SiO_2 nanoparticles in the fluid medium. As a result, they found that the height-to-width ratio has a greater effect on increasing heat transfer than the pitch-length ratio [8]. Nayak and Weigand investigated the effect of corrugated channels on the mixing ratio using two different miscible liquids with different concentrations. As a result of their studies, they observed that the pressure change has a great effect on the regions that provide zero gradients throughout the fully developed regions. They also determined that a high convective zone should be created in order to increase the temperature of the liquids in the channel [9].

In their study, Ionescu and Neagu investigated the effect of the sinusoidal wavy corrugated channel model on heat transfer. In this study, a finite element method-based CFD program has been used. They kept the channel length and wavelength constant in their simulations. The modified lengths have been the width and amplitude of the channel. As a result, they have seen that the thickness of the lower wall has a great effect on the Nusselt Number in sinusoidal wavy corrugated channel geometry [10] Ahmed et al. investigated convective heat transfer numerically and experimentally by using nanofluids in trapezoidal, sinusoidal, and straight corrugated channels. The Reynolds number they used in their numerical analysis is in the range of 400-4,000 and they used the SIMPLE algorithm in the solutions. As a result, they found that the trapezoidal slotted channel provides the highest heat transfer increase, followed by the sinusoidal slotted channel and the straight slotted channel. They also found that the numerical results have been in good agreement with the experimental data [11].

Pehlivan et al. experimentally investigated the heat transfer rate using a sinusoidal slotted channel. In their study using different undulation angles, they accepted the Reynolds number between 1,500-8,000. They concluded that increasing the slotted angle accelerated the heat transfer [12]. In their study, Yin et al. investigated heat transfer and flow properties by using corrugated sinusoidal wavy channels for the different phase shifts between upper and lower wavy plates with the same diameter. During the calculations, the Reynolds number has been accepted as 2,000-10,000 and the Pr number as

0.696. As a result, they have seen that although the use of corrugated ducts increases the pressure loss, it will also increase the heat transfer due to its effect on the Nusselt number. They also found that the effect of phase shift on heat transfer is more pronounced in the high Re region of the slotted channels than in the low Re region [13]. Elshafei et al. experimentally investigated the convective heat transfer and pressure drop properties of flow in corrugated channels. Experiments have been carried out on channels with a constant groove ratio in the range of 3,220-9,420 Reynolds numbers. As a result, they found that the results of corrugated channel flow create a significant increase in heat transfer with the penalty for increased pressure drop. They also considered the effects of spacing and phase shift. They found that the friction factor increased with increasing channel spacing and phase shift. They noticed that the effect of gap changes on heat transfer has been more pronounced than phase shift change, especially at a high Reynolds number [14].

Ahmed et al. numerically investigated the forced convection heat transfer of a copper-water nanofluid in a trapezoidal corrugated channel. The momentum and energy equations they used have been discretized using the finite volume approach and they have been solved iteratively using the SIMPLE technique. As a result, they found that as the wavelength of the corrugated channel decreases, the average Nusselt number increases, and the pressure drop decreases [15]. Naphon conducted an experimental study to see the heat transfer and pressure drop in the corrugated channel under constant heat flux. Three channels with two opposing corrugated plates have been used during the experiments. The inclination angles of the channels, each of which has a height of 12.5 mm, have been chosen as 20°, 40° and 60°. Experiments have been made for the Reynolds number range of 500-1,400. As a result, he found that the corrugated surface has a significant effect on increasing the heat transfer and pressure drop due to the presence of recirculation zones [16].

The aim of this study is to determine the effect of inclination angle on convective heat transfer in corrugated channels. For this reason, numerical analyzes have been made using three different corrugated channel geometries and the results have been compared among themselves. First, numerical calculations have been made for the corrugated channel with a 30° inclination angle. During these calculations, different turbulence models have been used, namely k-ω, SST, and transition SST. The results obtained from these analyzes have been compared with the experimental data [17]. By determining the turbulence model that gives the closest result to the experimental data, analyzes have been made for corrugated channels with 45° and 60° inclination angles. Finally, the obtained results have been compared with each other and the effect of inclination angle on heat transfer has been investigated.

2. NUMERICAL METHOD

During this study, buoyancy forces have been not taken into account while performing numerical analysis. Geometry has been considered as two-dimensional while calculations have been made. Corrugated channels with different inclination angles have been drawn in the SolidWorks program and the mesh file created by dividing into grids has been created using the Pointwise program. This study has been carried out with numerical method and ANSYS Fluent, one of the most common computational fluid dynamics (CFD) programs in the market, has been used. The use of CFD analysis has been increasing in recent years. The reason for this is that it is cheaper and more practical than experimental studies. One of the most important parameters in all scientific studies is time [18]. The use of CFDs provides significant time savings. The most commonly used turbulence models in programs with CFD codes suitable for different flow characteristics are those based on Reynolds Average Navier Stokes [19]. There are basically two of these models, k-ω, and k-ε. The k-ε model gives more accurate results in regions where the boundary layer is weak, and the k-ω model in other regions. The SST model, which emerged as a combination of these two models, is frequently preferred among RANS-based methods [19]. While entering convergence criteria values, 10-8 is taken for energy equations, while this value is determined as 10-6 for other equations. It is assumed that the turbulence intensity at the entrance of the channel is 4% and the mixing length is equal to 30% of the hydraulic diameter. These values have been obtained with experimental data.

2.1. General situation definition

The appearance of the symmetrical corrugated channel with different inclination angles used in this study is shown in Figure 1. 30°, 45°, and 60° have been selected as the inclination angle values. The a, b, and Hmin lengths of the channels used in the study have been taken from the experimental study as 5 [mm], 2.5 [mm], 5 [mm], respectively. The length S is obtained from the drawn channel geometries as 17.32 [mm] for 30°, 10.231 [mm] for 45°, and 5.77 [mm] for 60°. The development of the flow in the channel and the temperature distributions have been observed and the effect of different inclination angles on increasing the heat transfer has been examined. During the study, the Reynolds number varies between 2,100 and 7,600. Prandtl number (Pr) has been accepted as 0.7 in all analyzes.

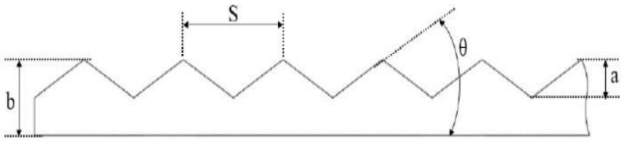

Figure 1 Corrugation channel with the parameters [20]

Maximum channel height is taken by,

$H_{max} = 2b$

The minimum channel height is described as,

$H_{min} = 2(b - a)$

2.2. Meshing

In order to be able to solve using the CFD program, it is necessary to create a mesh file by dividing the workpiece into grids [21]. More than one mesh file is created and analyzes are made using the same parameters. The results of the analyzes obtained are compared among themselves, and the file with less grid than those that give close results is selected and used in numerical analyzes using different parameters. This process is called mesh independence [21]. Mesh independence has been not performed in this study. The reason for this is that it is known that a mesh file containing 192,000 grid cells has been used in a similar study done before. Time is saved by not repeating the same process. It is necessary to pay attention to some parameters in the process of creating a mesh file. One of them is the y+ value. The y+, which means the mesh fineness in the area close to the wall, indicates the sensitivity of the created mesh file. As the sensitivity of the y+ value increases, the accuracy of the results obtained from the CFD analysis also increases [22]. In this study, the y+ value has been determined as 0.6. The small value of this value increased the sensitivity of the results of the analysis. A close view of the grid cells created in the mesh file is given in Figure 2.

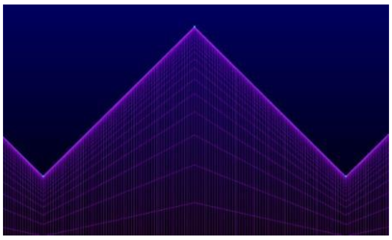

Figure 2 The close-up of mesh cells

2.3. Dimensionless Numbers

In this study, two different parameters have been selected and calculated in order to evaluate the effect of the peak angle of the corrugated channels on the heat transfer. These have been determined as Nusselt number and friction factors. The results obtained from the numerical analyzes have been compared with the experimental data. When the experimental setup has been examined, it has been observed that the flow in the corrugated channel became regular in the last three nodes. For this reason, the values used in calculating the Nusselt number and friction factor have been taken from those regions at the end of the numerical analysis.

The calculation of the Nusselt number (Nu) is given in Eq. 1;

$$Nu = \frac{h.D_h}{k} \tag{1}$$

k and h represent thermal conductivity and heat transfer coefficient, respectively [20].

The formula for the heat transfer coefficient (h) calculated by integrating the last three cycles of the channel is given in Eq. 2;

$$h = \frac{1}{3S}\int_0^S h_x d_x \tag{2}$$

The calculation of the friction factor (f) is given in Eq. 3;

$$f = -\frac{dP}{dx} D_h / \frac{1}{2}\rho {u_o}^2 \tag{3}$$

ρ and u_o represent density and velocity, respectively [20].

3. RESULTS

In Figure 3. the predictions of the axial velocity distribution of the calculations made with the SST turbulence model in three corrugated channel geometries are channels with (a) 60°, (b) 45° and (c) 30° inclination angles. During the calculations in which these figures have been taken, the velocity and Reynolds number have been accepted as 6.8 m/s and 7380, respectively. It is seen that the place where the flow fully develops is the cycle in the last parts of the channel. It has been determined that the flow in the corrugated channel with a 60° inclination angle is higher velocity than the flow in the other two-channel geometries. In the analyzes made, it has been seen that the corrugated channel geometry with a 45° inclination angle is also faster than the flow in the channel with a 30° inclination angle. In addition, it is seen that the turbulent region in the corrugated channel with an inclination angle of 60° is wider than the other channels. Therefore, the flow with the highest Nusselt number is obtained from the corrugated channel with a 60° inclination angle, followed by the flows in the corrugated channels with 45° and 30° inclination angles, respectively.

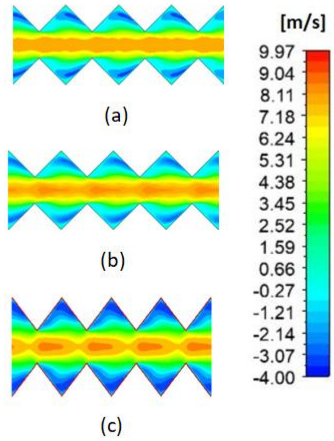

Figure. 3 Axial velocity by SST turbulence model for the corrugated channel (a) with a 60° inclination angle, (b) with a 45° inclination angle, (c) with a 30° inclination angle

In Fig. 4. the predictions of the temperature distribution of the calculations made with the SST turbulence model in three corrugated channel geometries are channels with (a) 60°, (b) 45°, and (c) 30° inclination angles. During the calculations in which these figures have been taken, the velocity and Reynolds number have been accepted as 6.8 m/s and 7380, respectively. It is seen that the place where the flow fully develops is the cycle in the last parts of the channel. The last sections of the corrugated channels are called the recirculation zone, and it is seen that the cold fluid coming from the channel mixes more intensely with the hot fluid near the boundary layer. This situation causes the highest temperature change values in the channels to be encountered at the wall edges. It is seen that the temperature gradients increase in the recirculation regions in parallel with the increase in the angle of inclination in the corrugated channels. These wall temperatures are among the factors that increase heat transfer. Therefore, the flow with the highest heat transfer efficiency has been seen in the corrugated channel with a 60° inclination angle, followed by the corrugated channel with a 45° and 30° inclination angle, respectively.

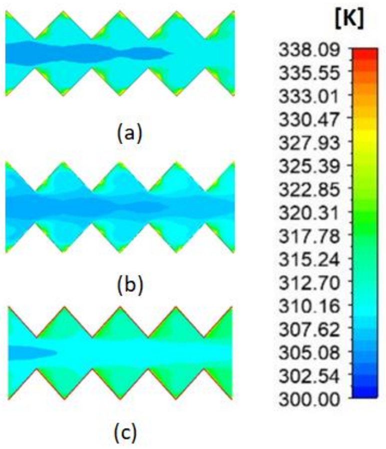

Figure 4 Temperature by SST turbulence model for the corrugated channel (a) with a 60° inclination angle, (b) with a 45° inclination angle, (c) with a 30° inclination angle

In order to compare the data obtained from this study with the experimental results (Aslan et al., 2016), the analyzes for the corrugated channel with a 30° inclination angle have been used. It has been researched which turbulence model would give the best results and it has been aimed to determine the model to be preferred in the next analysis. The turbulence models used in comparison with the experimental results have been determined as k-ω, SST, and transition SST. Nusselt number and friction factor values obtained from the numerical analysis results using these turbulence models have been compared with the experimental data and are given graphically in Figure 5 and Figure 6, respectively. In Figure 5, the Nusselt number increased in parallel with the Reynolds number. In addition, it has been determined that the results obtained from the analyzes using the high Reynolds number are more accurate than the analyzes using the low Reynolds number. This inference has been made by looking at the Reynolds values in Figure 5, where the Nusselt number obtained by calculating from the results of the numerical analysis approaches the experimental values. When the graph given in Figure 6 is examined, it is seen that the friction factor values obtained from the analyzes using different turbulence methods increase in parallel with the Reynolds number. It has been observed that the values obtained from the transition SST turbulence model have been much higher than the experimental data and the values obtained from the k-ω model have been much lower than the experimental data. It has been determined that the friction factor values obtained from the SST turbulence model are more successful in approaching the experimental data than other turbulence models. It has also been observed that numerical analyzes at high Reynolds numbers give more accurate results. In addition, both Figure 5 and Figure 6 show that the closest values to the experimental results have been obtained from the numerical analyzes using the SST turbulence model. For this reason, SST has been chosen as the turbulence model in the analyzes made for the corrugated channel with 45° and 60° inclination angles.

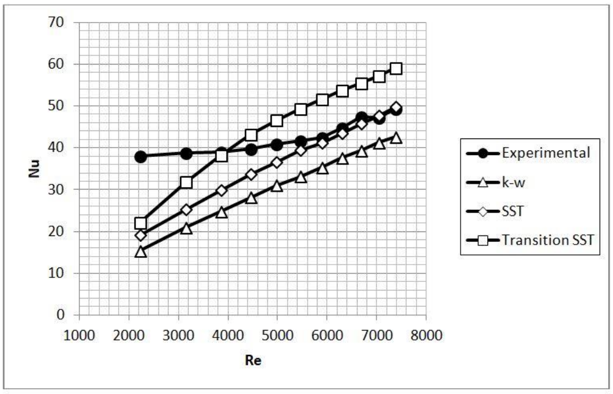

Figure 5 Comparison of Nusselt numbers from different turbulence methods

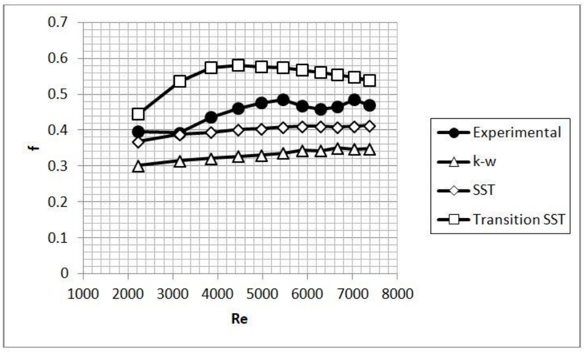

Figure 6 Comparison of friction factor from different turbulence methods

Figure 7 shows the Nusselt numbers obtained as a result of the calculations of corrugated channels with 30°, 45°, and 60° inclination angles using the SST turbulence method. According to this graph, the Nusselt number increases as the inclination angle increases in corrugated channels. In this case, it is concluded that the heat transfer is more efficient in channels with high inclination angles.

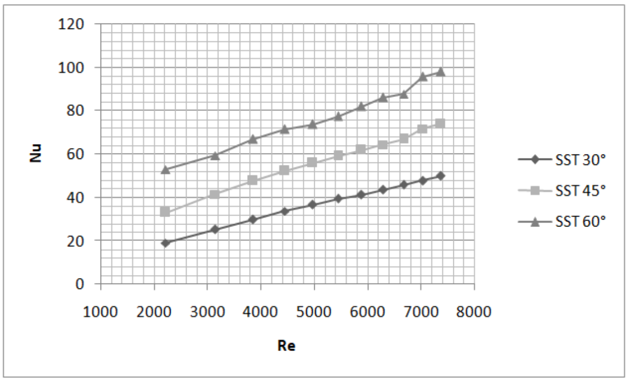

Figure 7 Comparison of Nusselt numbers from different inclination angles methods

In Figure 8, the friction factor values obtained as a result of the calculations of corrugated channels with 30°, 45°, and 60° inclination angles using the SST turbulence method are shown in the graph. According to this graph, the friction factor value decreases as the inclination angle increases in corrugated channels. In addition, in the analyzes made for high Reynolds number, it is seen that the friction factor value gives close results. This has been interpreted as the effect of inclination angle on the friction factor losing its importance when the velocity of the flow increases in corrugated channels.

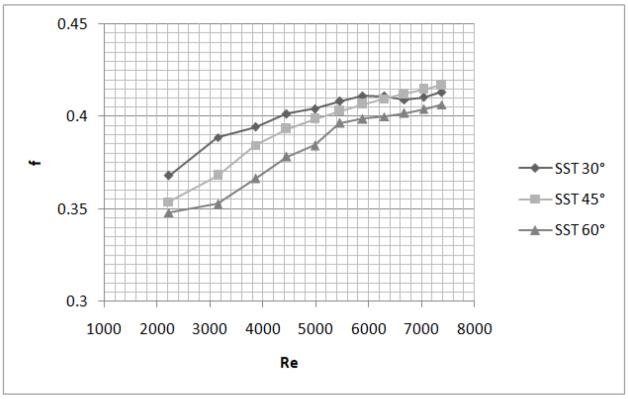

Figure 8 Comparison of friction factor from different inclination angles methods

4. CONCLUSIONS

In this study, numerical analyzes have been made by modeling corrugated channels with different inclination angles and the effect of inclination angle on heat transfer has been investigated. The inclination angles of the modeled corrugated channels have been determined as 30°, 45°, and 60°. Corrugated channel geometry with a 30° inclination angle has been drawn and analyzes have been made using three different turbulence models. These turbulence models have been chosen as k-ω, SST, and transition SST. They have been chosen because they are the most frequently used turbulence models in RANS-based studies in the literature. The Nusselt number and friction factor have been calculated using the data obtained from the analysis results. Calculated values have been compared with experimental data. As a result, it has been determined that the accuracy rate of the SST turbulence model is higher than other RANS based models. It has been decided to use the SST turbulence model in the analyzes of the corrugated channels with different inclination angles to be made from now on. Then, corrugated channel geometries with 45° and 60° inclination angles have been created and analyzes have been made using the SST turbulence model. Nusselt number and friction factor values have been calculated using the data obtained from the analyzes. The obtained values have been compared with each other. As a result of the study, the following information has been obtained;

- The inclination angle in corrugated channels is an option that can be used to increase heat transfer.
- If any numerical analysis is to be done for corrugated channels, the most suitable RANS-based turbulence model is SST.
- If the velocity of the flow is increased to increase the Reynolds number in corrugated channels, the Nusselt number will also increase and the heat transfer will increase.
- Increasing the angle of inclination in corrugated channels has a positive effect on heat transfer.
- As the inclination angle increases in the corrugated channels, the friction factor value decreases.

Many studies can be done on this subject by modifying the corrugated channel geometries. The next study will be calculations using sinusoidal channels and comparison with the results of this study.

Funding

The authors have not received any financial support for the research, authorship, or publication of this study.

The Declaration of Conflict of Interest

No conflict of interest or common interest has been declared by the authors.

Authors' Contribution

The authors contributed equally to the study.

The Declaration of Ethics Committee Approval

This study does not require ethics committee permission or any special permission.

The Declaration of Research and Publication Ethics

The authors of the paper declare that they comply with the scientific, ethical, and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.

REFERENCES

[1] M. Miranda, P. Romero, V. Valero-Amora, J. Arranz, and I. Montero, “Ventilation conditions and their influence on thermal comfort in examination classrooms in times of COVID-19. A case study in a Spanish area with Mediterranean climate”, International Journal of Hygiene and Environmental Health, vol.240, 113910, 2022.

[2] M. Astina, and M. Nugrah, “Numerical simulation of earth-air heat exchanger application for Indonesian simple house air conditioning system”, Case Studies in Thermal Engineering, Vol.28, 101371, 2021.

[3] A. C. Benim, H. Chattapadhyay, and A. Nahavandi, “Computational Analysis of Turbulent Forced Convection in a Channel with a Triangular Prism”, International Journal Thermal Sciences, vol. 50, no.10, pp. 1973-1983, 2011.

[4] I. Taymaz, E. Aslan, and A. C. Benim, “Numerical Investigation of Incompressible Fluid Flow and Heat Transfer across a Bluff Body in a Channel Flow”, Thermal Sicences, vol.19, no.2, pp.537-547, 2015.

[5] H. Chattopadhyay, and A. C. Benim, “Turbulent Heat Transfer Over a Moving Surface Due to Impinging Slot Jets”, Journal Heat Transfer – Transactions of the ASME, vol.133, no. 10, 104502, 2011.

[6] N. Tokgoz, T. Tunay, and B. Sahin, “Effect of corrugated channel phase shifts on flow structures and heat transfer rate”, Experimental Thermal and Fluid Science, vol. 99, pp.374-391, 2018..

[7] M. Aliabadi, and A. Feizabadi, “Compound heat transfer enhancement of helical channel with corrugated wall structure”, International Journal of Heat and Mass Transfer, vol. 146, 118858, 2020.

[8] R.K. Ajeel, W. Salim, and K. Hasnan, “Numerical investigations of heat transfer enhancement in a house shaped- corrugated channel: Combination of nanofluid and geometrical parameters”, Thermal Science and Engineering Progress, Thermal Science and Engineering Progress, vol. 17, 100376, 2019.

[9] A. Nayak, and B. Weigand, “Mixing and heat transfer in micro/nano-channel due to charged corrugated surfaces”, Applied

Thermal Engineering, vol. 170, 114979, 2020.

[10] V. Ionescu, and A. Neagu, “Modelling of fluid flow and heat transfer in a corrugated channel for heat exchanger applications”, 11th International Conference Interdisciplinarity in Engineering, 5-6 October 2017, Tirgu-Mures, Romania.

[11] M. Ahmed, M. Yusoff, K. Ching and N. Shuaib, “Numerical and experimental investigations on the heat transfer enhancement in corrugated channels using SiO2-water nanofluid”, Case Studies in Thermal Engineering, vol. 6, pp. 77-92, 2015.

[12] H. Pehlivan, I. Taymaz, Y. Islamoğlu, “Experimental study of forced convective heat transfer in a different arranged corrugated channel”, International Communications in Heat and Mass Transfer, vol. 46, pp. 106-111, 2013.

[13] J. Yin, G. Yang, and Y. Li, “The Effects of Wavy Plate Phase Shift on Flow and Heat Transfer Characteristics in Corrugated Channel”, Energy Procedia, vol. 14, pp. 1566 – 1573, 2012.

[14] E. Elshafei, M. Awad, E. El-Negiry, and A. Ali, “Heat transfer and pressure drop in corrugated channels”, Energy, vol. 35, pp. 101–110, 2010.

[15] M. Ahmed, M. Yusoff, and N. Shuaib, “Effects of geometrical parameters on the flow and heat transfer characteristics in a trapezoidal-corrugated channel using nanofluid”, International Communications in Heat and Mass Transfer, vol. 42, pp. 69–74, 2013.

[16] P. Naphon, “Laminar convective heat transfer and pressure drop in the corrugated channels”, International Communications in Heat and Mass Transfer, vol. 34, pp. 62–71, 2007.

[17] E. Aslan, I. Taymaz, and Y. Islamoglu, “Finite volume simulation for convective heat transfer in wavy channels”, Heat Mass Transfer, vol. 52, no. 3, pp. 483-497, 2016.

[18] H. Kepekci, E. Kosa, and C. Ezgi, “Modeling Study and Performance Investigation of a Thermoelectric Refrigerator”, Engineer and Machinery, vol. 62, no. 705, pp. 715-730, 2021.

[19] H. Kepekci, B. Zafer, H. Guven, “Aeroacoustics Investigations of Unsteady 3D Airfoil for Different Turbulence Models Using Computational Fluid Dynamics Software”, vol. 28, no. 10, pp. 7564-7573, 2019.

[20] E. Aslan, and H. Kepekci, “Investigation of Convective Heat Transfer and Friction Factor in Corrugated Channels with Different Inclination Angles Using Computational Fluid Dynamics”, Journal of Advanced Thermal Science Research, vol.8, pp. 21-29, 2021.

[21] H. Kepekci, and A. Asma, “Comparative Analysis Of Heat Sink Performance Using Different Materials”, American Journal of Engineering Research”, vol. 9, no. 4, pp-204-210, 2020.

[22] H. Kepekci, “Comparative Numerical Aerodynamics Performance Analysis of NACA0015 and NACA4415 Airfoils”, International Journal of Engineering,Science&Information Technology, vol. 2, no. 1, pp. 144-151, 2022.