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Heat Transfer Analysis of a Plate Heat Exchanger with a Combination of Ribs and Dimples using CFD

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ABSTRACT

The advancements and improvements in all heat transfer equipment's are primarily intended to save energy and reduce project capital investment expenses (energy or material). A better heat exchanger is one that can transfer a high heat rate while using a low pumping power and at a cheap cost. Passive heat transfer enhancement techniques have various benefits over other heat transfer enhancement techniques, including low cost, ease of fabrication, and installation. Rib turbulators can enhance heat transmission significantly, but they generally come at a considerable cost in terms of pressure loss. Dimple techniques have lately gained popularity because to their ability to promote heat transmission while imposing a minor pressure penalty. When dimple surfaces are mixed with nanofluids, some studies have seen increased heat transmission, but the key concern is an increase in the system's friction factor, which is also regulated within acceptable ranges. The thermal characteristics of a heat exchanger with a combination of dimple ribs were evaluated using a 3-dimensional numerical (3-D) simulation. The subject of this study is the handling of air flow velocity through the channel, which was changed from 3.97 to 5.80 m/s. The simulation programme ANSYS 19.2 was used to investigate the heat transfer physiognomies of a heat exchanger managing a combination of dimple ribs. The numerical findings revealed that the combination of dimple ribs greatly improved heat transmission over the dimple alone. In comparison, the average Nusselt number of a channel with dimpled Plate is 4.28 percent more than that of a channel with dimpled ribs.

KEYWORDS: *Surface enhancement, dimples and ribs, heat transfer characteristic, friction factor, Nusselt number, thermal performance, CFD*

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I. INTRODUCTION

As a result of the global energy crisis, which is one of the most critical problems due to the large and continuous increase in consumption, the increasing scarcity of energy resources, and the high cost, many researchers have worked to improve the efficiency of thermal systems and reduce the size and thus energy consumption rates.

The process of improving a system's heat transfer rate and thermohydraulic performance via the use of diverse tactics is known as heat transfer enhancement. Heat transfer enhancement methods are used to improve heat transfer without significantly affecting system performance, and they are applicable to a wide range of applications where heat exchangers are used for functions such as air conditioning, refrigeration, central heating systems, cooling automotive components, and many other applications in the chemical industry.

Heat transfer enhancement techniques are classified into three types: passive, active, and compound. Passive approaches, on the other hand, do not necessitate the use of extra energy to increase the system's thermohydraulic performance. Active techniques require external power to enter the process; nevertheless, active methods do not require any extra energy to increase the system's thermohydraulic performance.

Passive techniques do not require external power; rather, the geometry or surface of the flow channel is changed to optimize the thermohydraulic performance of the systems. Inserts, ribs, and rough surfaces are utilised to promote fluid mixing and turbulence in the flow, which increases the total heat transfer rate. Passive heat transfer enhancement techniques have various benefits over other heat transfer enhancement techniques, including low cost, ease of fabrication, and installation.

Rib turbulators can enhance heat transmission significantly, but they generally come at a considerable cost in terms of pressure loss. Dimple techniques have lately gained popularity because to their ability to promote heat transmission while imposing a minor pressure penalty. When dimple surfaces are mixed with nanofluids, some studies have seen increased heat transmission, but the key concern is an increase in the system's friction factor, which is also regulated within acceptable ranges.

II. LITERATURE REVIEW

Several studies have reported on the formulation of nanofluids using various types of nanoparticles, as well as their capacity to conduct convective heat transfer.

Maxwell (1873) was the first to report the thermal conductivity enrichment of ordinary fluids in the presence of the problems of sedimentation, plugging, and erosion in flow tracks [1]. **Masuda et al. (1993)** then investigated the augmentation of thermal conductivity with the inclusion of micro-sized solid particles into the base fluid (single phase), but they met the same difficulties of sedimentation, increased pumping power, erosion, and clogging [2]. **Hamilton-Crosses (1962)** also made a contribution by expanding on Maxwell's work and developing a more precise model to predict the thermophysical characteristics of particles floating in fluids [3].

Choi's work transformed the world of heat transporting fluids in 1995 when he created nanofluids with superior thermal transport capabilities and higher stability than fluids containing milli and micro sized solid particles [4].With this invention, researchers started to investigate the nanofluids with great interest.

Pak and Cho (1998) conducted heat transfer and friction factor experiments for Al_2O_3/water and TiO_2/water nanofluids in the Reynolds number range from 104 to 105 and the particle concentration ranging from 0% to 3% and observed heat transfer enhancement compared to the base fluid (water); they also propose newly-developed Nusselt number correlation [5].

Wen and Din (2004) conducted heat transfer experiments for Al_2O_3/water nanofluid in a tube under laminar flow and they observed heat transfer enhancement of 47% at 1.6% volume fraction as compared to the base fluid (water) [6].

Williams et al. (2008) reported convective heat transfer enhancement with alumina/water and zirconia/water nanofluids flow in a horizontal tube under turbulent flow [7].

Duangthongsuk and Wongwises (2010) found heat transfer enhancement of 20% and 32% for 1.0% vol of TiO_2/water nanofluid flowing in a tube at Reynolds numbers of 3000-18000, respectively [8].

Ghozatloo et al. (2014) obtained heat transfer enhancement of 35.6% at a temperature of 38 °C for 0.1 wt% of graphene/water nanofluids flow in a tube under laminar flow [9].

Chandrasekhar et al. (2017) experimentally investigated and theoretically validated the behavior of Al_2O_3/water nanofluid that was prepared by chemical precipitation method. For their investigation, Al_2O_3/water at different volume concentrations was studied. They concluded that the increase in viscosity of the nanofluid is higher than that of the effective thermal conductivity. Although both viscosity and thermal conductivity increases as the volume concentration is increased, increase in viscosity predominate the increase in thermal conductivity. Also various other theoretical models were also proposed in their paper [10].

Rohit S. Khedkar et al. (2017) experimental study on concentric tube heat exchanger for water to nanofluids heat transfer with various concentrations of nanoparticles in to base fluids and application of nanofluids as working fluid. Overall heat transfer coefficient was experimentally determined for a fixed heat transfer surface area with different volume fraction of Al_2O_3 nanoparticles in to base fluids and results were compared with pure water. It observed that, 3 % nanofluids shown optimum performance with overall heat transfer coefficient 16% higher than water [11].

Akyürek et al. (2018) experimentally investigated the effects of Al_2O_3/Water nanofluids at various concentrations in a concentric tube heat exchanger having a turbulator inside the inner tube. Comparisons were done with and without nanofluid in the system as well as with and without turbulators in the system. Results were drawn and a number of heat transfer parameters were calculated on the basis of observed results. Various heat characteristics such as change in Nusselt number and viscosity with respect to Reynolds number, behaviours of nanofluid at various volume concentrations, changes in heat transfer coefficient, effect of the difference of pitch of turbulators on the heat transfer of nanofluid etc. were studied. They concluded that there exists a relationship between the varying pitches and the turbulence in the flow caused i.e. when the pitch is less there is more turbulence and vice versa [12].

Dimpled surfaces are recommended as a typical heat transfer enhancement passive approach because to their light weight, low pressure drops values, simplicity of production, and cheap maintenance costs. The potential of dimple surface approach in diverse thermal systems has been investigated via several experiments and computer analyses.

Griffith et al. (2015) The rate of heat transfer in rotating rectangular cooling channels was explored, and it was observed that channel orientation had a different impact, with the trailing-edge channel growing in Nusselt at the same rate as the orthogonal channel. Furthermore, the dimpled channel performs similarly to a 45-degree angled rib channel in terms of spanwise heat transmission, but with less variation [13].

Lauffer et al. (2017) Heat transfer studies were carried out utilising heater foils and a steady-state apparatus with liquid crystals on a rectangular dimpled channel with a 6-aspect ratio. Localized rib designs were revealed to boost heat transmission in these important locations while decreasing strain dramatically [14].

Chang et al. (2019) For four sets of dimple fin channels with rectangular cross sections, a channel aspect ratio (AR) of 6, and three varied fin length (L) to channel hyd, heat transmission and friction factor were evaluated. Using Reynolds numbers ranging from 1500 to 11,000 and Re on heat transfer upon channel with dimpled fins, Da (d), ratios (L=d) 8.9, 6.2, and 3.5, respectively. For both Re and L=d, the convex–convex dimpled fin channel showed the maximum Heat Transfer Enhancement [15].

Josephine et al. (2019) the experimental analysis of the influence of dimpled layouts on flow and heat transfer properties is presented in this paper. Three plate surfaces (smooth, equally distributed spherical dimples, and irregularly distributed spherical dimples) were created and put in a channel one after the other. The average Nusselt number increases with the Reynolds number as a result of heat interaction with the airflow. Over the smooth channel, the equally and unevenly dimpled plate channels experienced a 75.7 percent and 91.8 percent increase in Nusselt number, respectively. The flow friction coefficients of the uniformly and unevenly dimpled plate channels were only 0.59 percent and 0.67 percent higher than those of the smooth plate channel, respectively [16].

III. METHODOLOGY

The thermal characteristics of a heat exchanger with a combination of dimple ribs were evaluated using a 3-dimensional numerical (3-D) simulation. The objective of this study is the handling of air flow velocity through the channel, which was changed from 3.97 to 5.80 m/s. The simulation programme ANSYS 19.2 was used to investigate the heat transfer physiognomies of a heat exchanger managing a combination of dimple ribs.

The geometry of the Plate Heat Exchanger utilised in the simulation study was collected from one of the research scholars, Josephine et al. (2019), with specific measurements. The plate was made of mild steel and measured 220mm in length, 140mm in width, and 10mm in thickness. On the upper surface of the plates, eleven rows of spherical dimples with print diameters of 15 mm and depths of 5 mm were generated in a stream-wise orientation with a longitudinal pitch of 19.5 mm. On the upper side of the plate, eleven rows of spherical dimples with print diameters of 15 mm and depths of 5 mm were generated, with a rib on the lower side of the plate. ANSYS was used to construct the model (fluent).

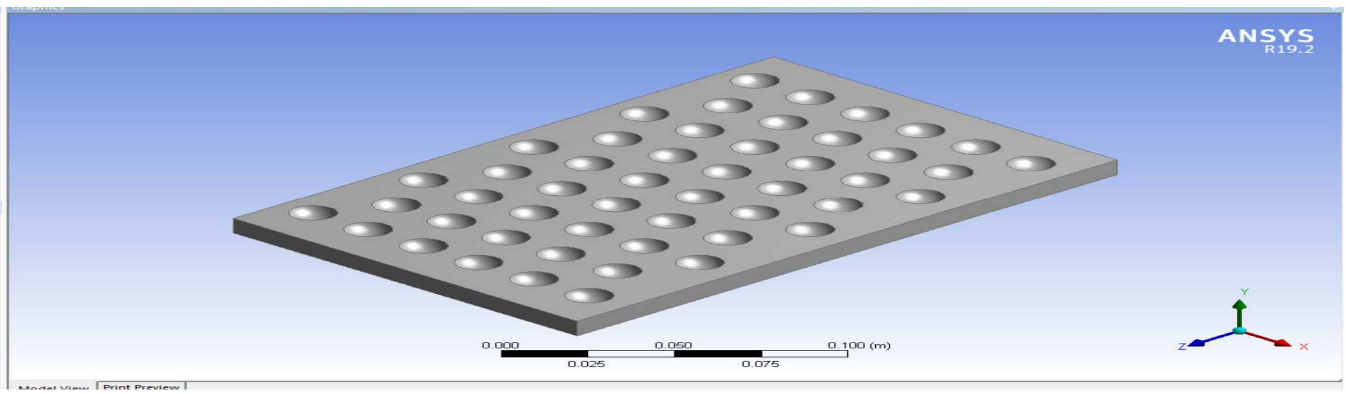

Figure 1. Geometry of the Plate Heat Exchanger with spherical dimples created on the upper side of the plate (Josephine et al. (2019).

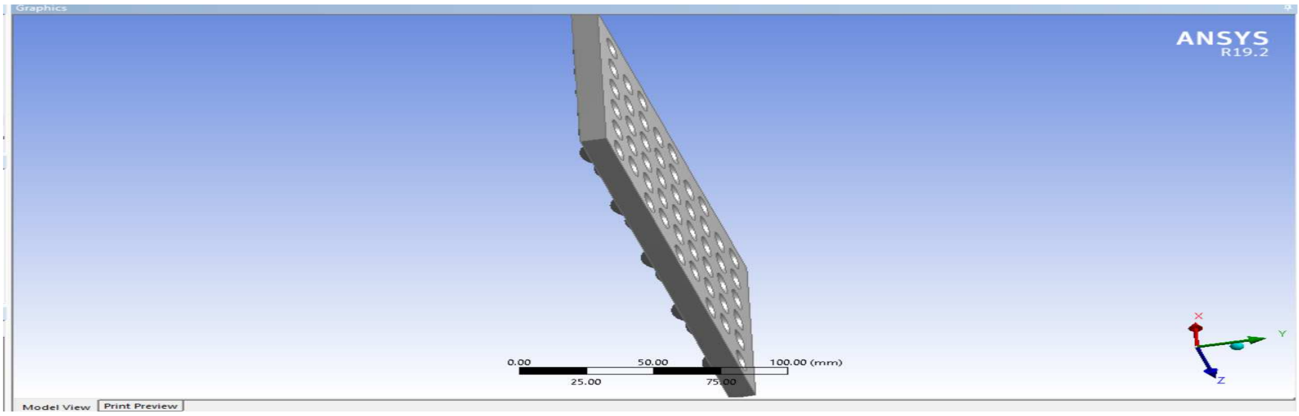

Figure 2. Geometry of the Plate Heat Exchanger with spherical dimples created on the upper and having rib on the lower side of the plate (Proposed work).

Table 1. Mesh details

The applied design	Number of nodes and elements
Josephine et al. (2019 Work	21157 and 99258
Proposed Work	30411 and 145212

To compute, the Fluent 19.2 program was used. A finite element method was used in experiments to distinguish the governing equations. The researchers used a simpler algorithm for this convective term, and the second order upwind method was used to relate pressure and velocity calculations.

Turbulence was solved using a regular k-epsilon equation in conjunction with flow and energy equations.

The velocity of the input air flow through the channel was varied between 3.97 and 5.80 m/s. The discretized flow domain was configured with suitable boundary conditions. Inlets were assigned input air flow boundary conditions, while outlets were assigned pressure outlet boundary conditions. Plate is heated using 400 W heating element.

IV. RESULTS AND DISCUSSIONS

Computational models provide thorough and well-founded results. Numerical representations of physical measurements, on the other hand, must be verified. The dimpled plate model is used to validate the numerical model, and the findings are compared to data by Josephine et al. (2019), who investigated flow and heat transfer in a channel with a dimpled plate.

4.1. Contours for channel with dimpled plate at different air flow velocity = 3.97 m/s

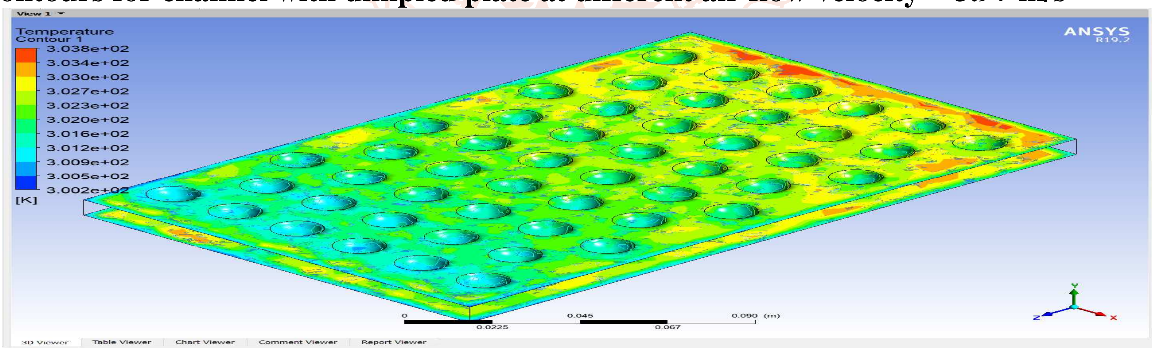

Figure 3. Temperature contour view 1 at air flow velocity = 3.97 m/s for channel with dimpled Plate.

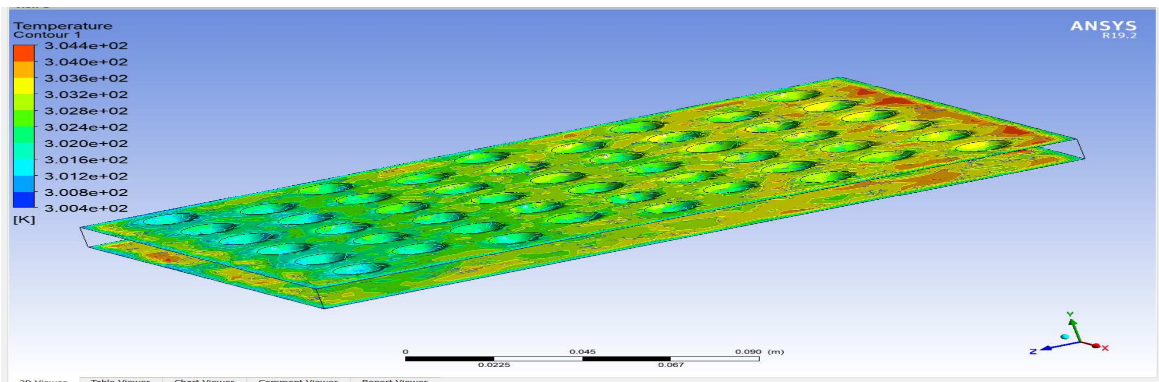

Figure 4. Temperature contour at air flow velocity = 4.58 m/s for channel with dimpled Plate.

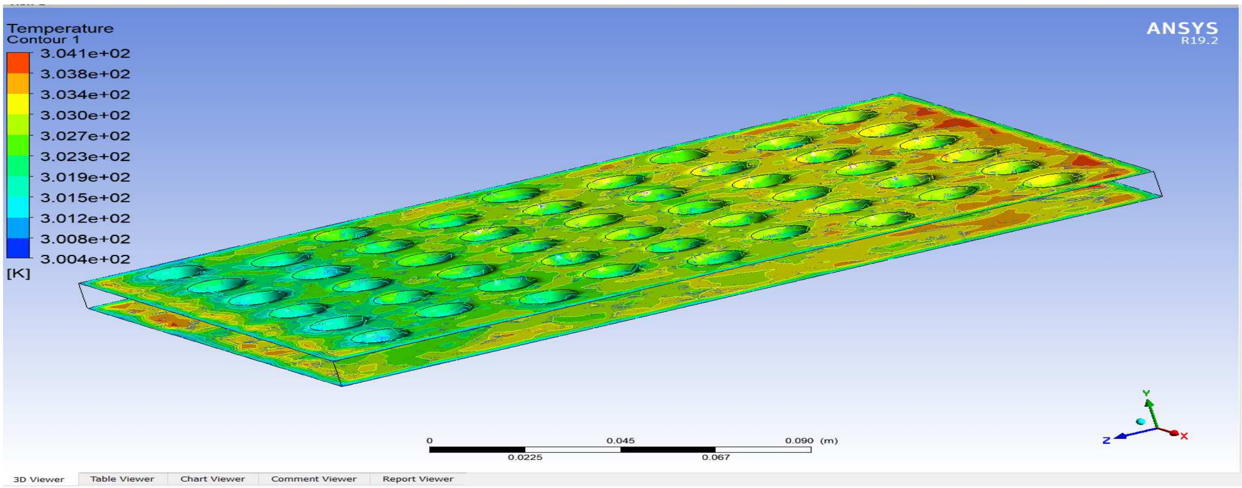

Figure 5. Temperature contour at air flow velocity = 5.19 m/s for channel with dimpled Plate.

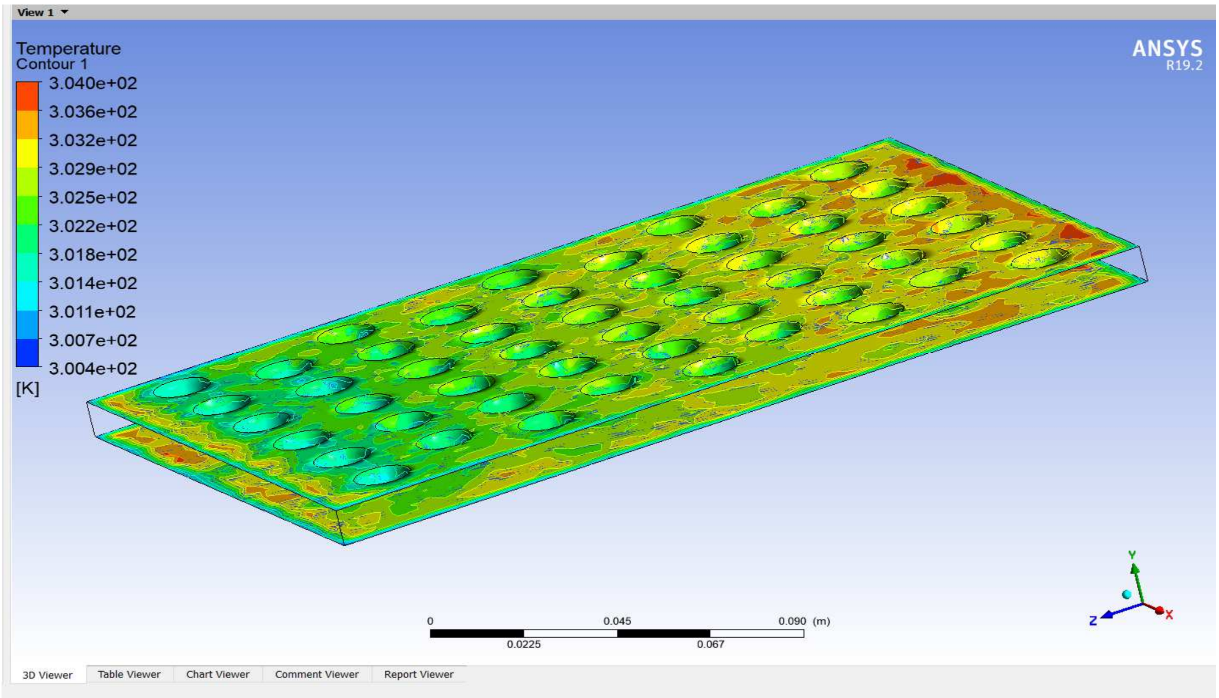

Figure 6. Temperature contour at air flow velocity = 5.80 m/s for channel with dimpled Plate.

To compute the Nusselt number value at different flow rate of inlet, CFD measurements were used. The Nusselt number of the CFD modeling have been compare to the values of the Josephine et al. (2019) measurements.

Table 2. Numerical Nusselt number comparison with experimental result from Josephine et al. (2019)

Air flow velocity (in m/s)	Nusselt Number	
	Exp. Josephine et al. (2019)	Present work
3.97	545	550.50
4.58	975	975.24
5.19	1140	1145.21
5.80	1540	1540.04

The experiment and the numerical results of the Nusselt number values agree well. As a result, we should state that the corrugated channel CFD model is right here.

4.2. Effect of spherical dimples on the upper and having rib on the lower side of the plate

The velocity of the input air flow through the channel was varied between 3.97 and 5.80 m/s. Plate is heated using 400 W heating element.

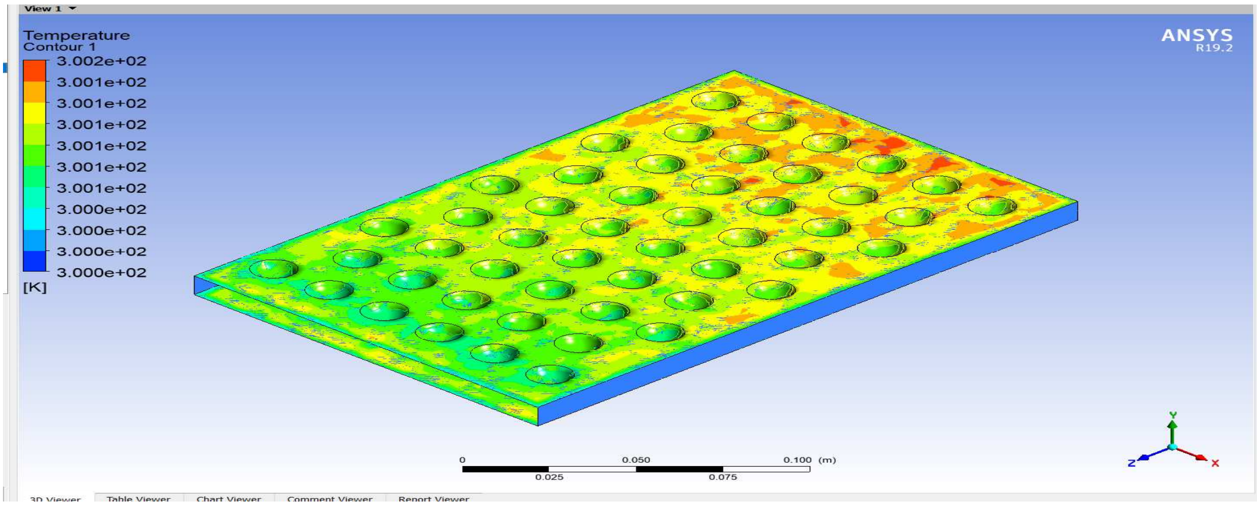

Figure 7. Temperature contour channel with spherical dimples on the upper and having rib on the lower side at air flow velocity = 3.97 m/s.

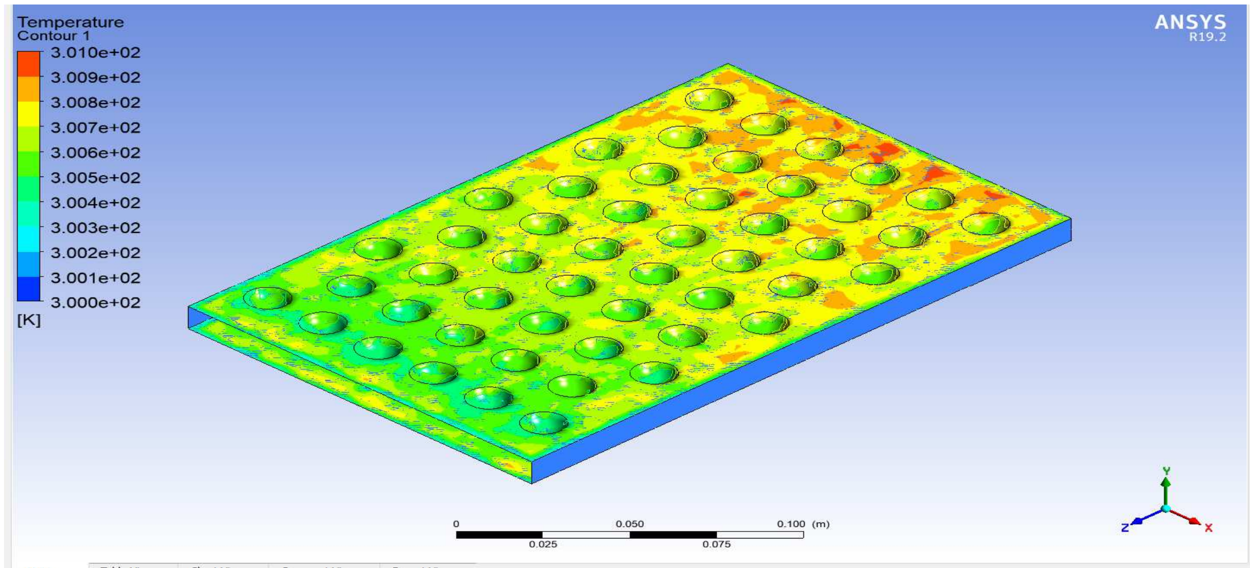

Figure 8. Temperature contour channel with spherical dimples on the upper and having rib on the lower side at air flow velocity = 4.58 m/s.

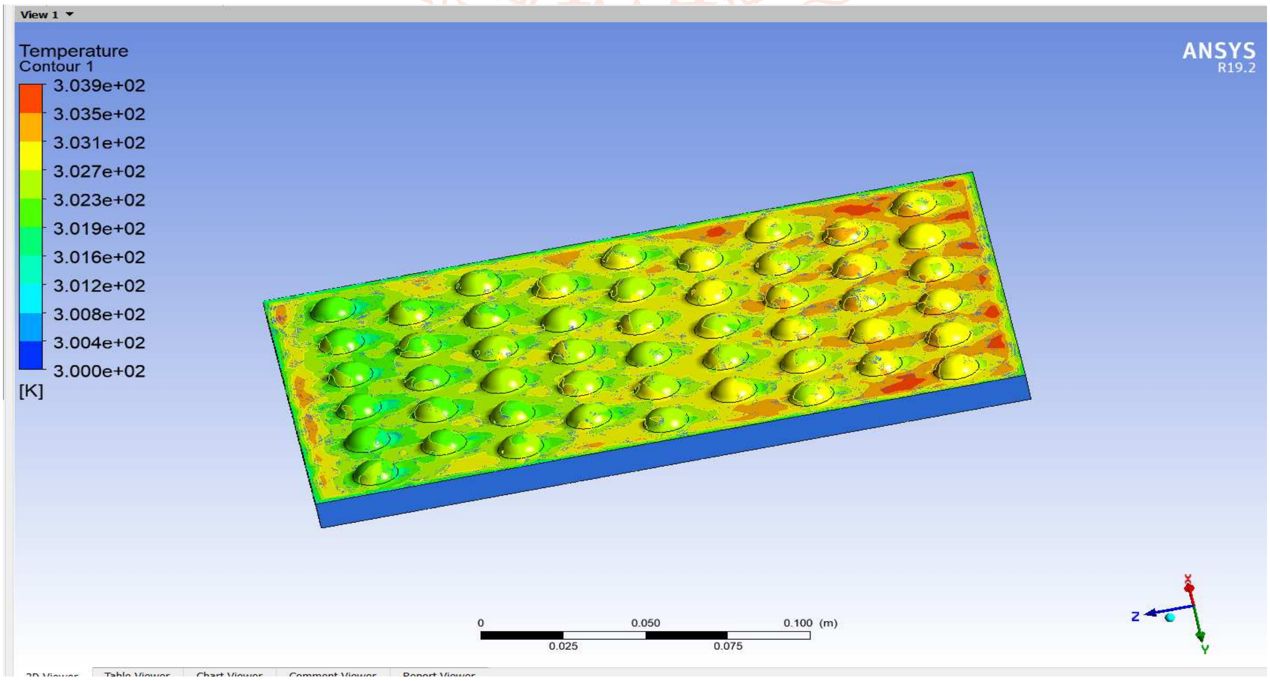

Figure 9. Temperature contour channel with spherical dimples on the upper and having rib on the lower side at air flow velocity = 5.19 m/s.

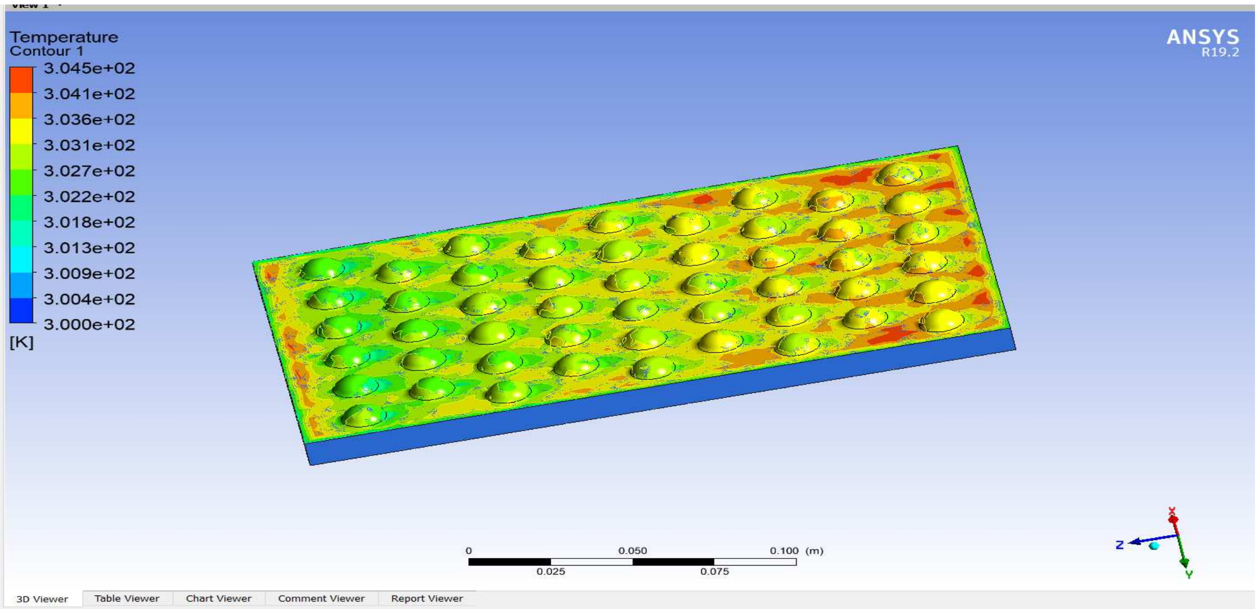

Figure 10. Temperature contour channel with spherical dimples on the upper and having rib on the lower side at air flow velocity = 5.80 m/s.

Table 3. Comparison of Nusselt number for previous work and proposed work

Air flow velocity (in m/s)	Nusselt Number	
	Exp. Josephine et al. (2019)	Proposed work
3.97	545	565.65
4.58	975	1023.45
5.19	1140	1178.70
5.80	1540	1602.34

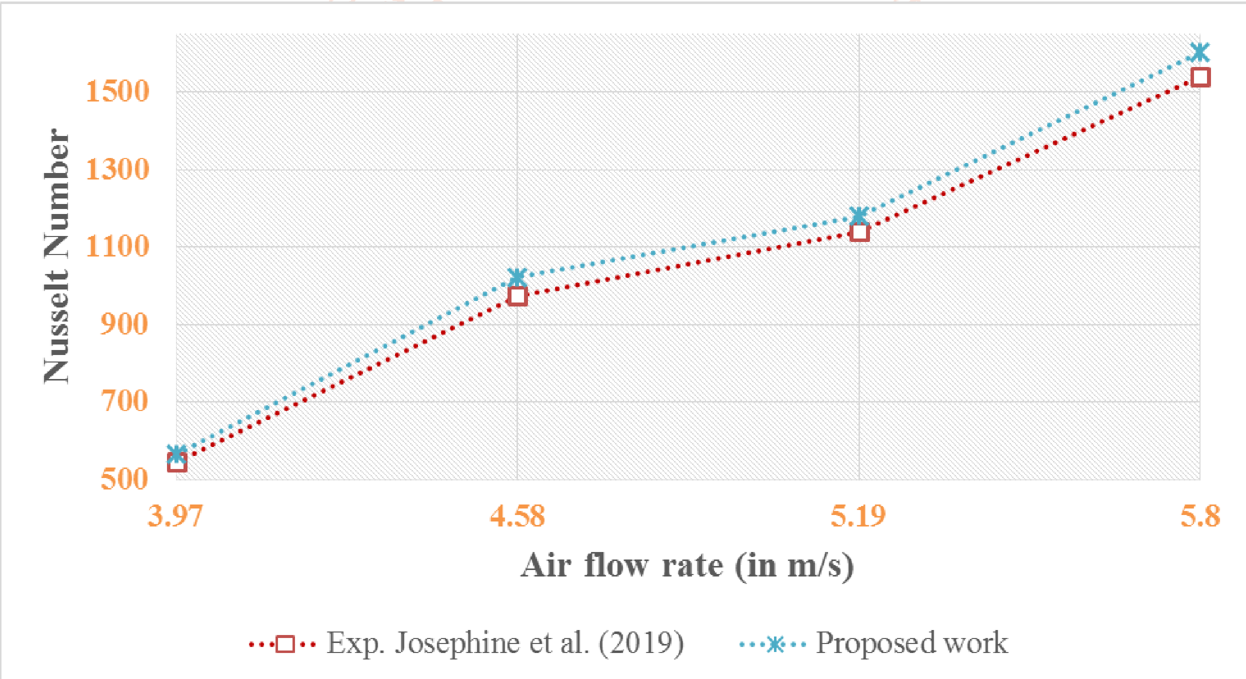

Figure 11. Comparison of Nusselt number for previous work and proposed work.

Table 4. Comparison friction factor for previous work and proposed work

Air flow velocity (in m/s)	Nusselt Number	
	Exp. Josephine et al. (2019)	Proposed work
3.97	0.2552	0.2550
4.58	0.2565	0.2562
5.19	0.2566	0.2563
5.80	0.256	0.2557

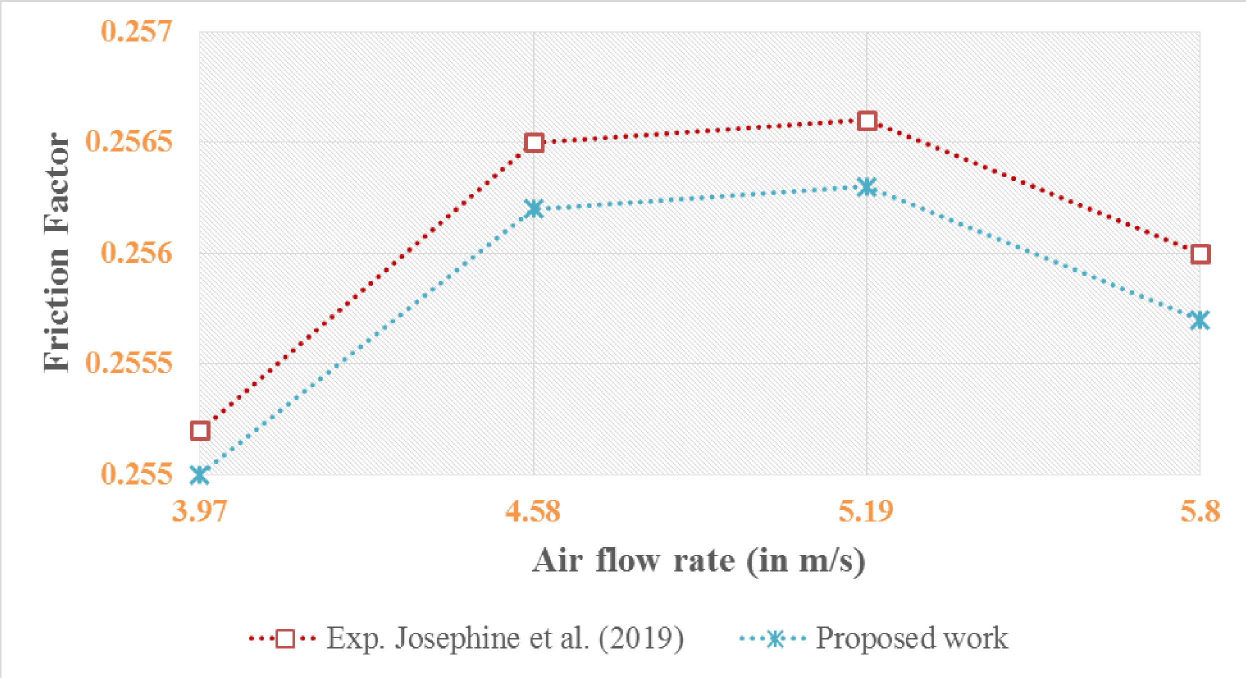

Figure 12 Comparison of friction factor for previous work and proposed work

V. CONCLUSIONS

The current study investigates the ability of a commercial CFD code to predict flow and heat transfer characteristics on a Plate Heat Exchanger with spherical dimples created on the upper and rib on the lower side of the plate, air is used as the working fluid, and the flow through the channel was varied between 3.97 and 5.80 m/s. A 400 W standardized heat stream was introduced.

The following are the study's findings:

1. The numerical findings revealed that the combination of dimple ribs greatly improved heat transmission over the dimple alone.
2. In comparison, the average Nusselt number of a channel with dimpled Plate is 4.28 percent more than that of a channel with dimpled ribs.
3. In contrast, the friction factor of a channel with dimpled Plate is 8.12% lower than that of a channel with dimpled ribs.

REFERENCES

[1] J. Maxwell, A Treatise on Electricity and Magnetism: Vol II 1 (1873) 333–335.

[2] H. Masuda, A. Ebata, K. Teramae, N. Hishinuma, Alteration of thermal conductivity and viscosity of liquid by dispersing ultra-fine particles. Dispersion of Al2O3, SiO2 and TiO2 ultra-fine particles, Netsu Bussei. 7 (1993) 227–233, https://doi.org/10. 2963/jjtp.7.227.

[3] R.L. Hamilton, Thermal conductivity of heterogeneous two-component systems, Ind. Eng. Chem. Fundam. 1 (1962) 187–191, https://doi.org/10.1021/ i160003a005.

[4] S.U.S. Choi, J.A. Eastman, Enhancing thermal conductivity of fluids with nanoparticles, ASME Int. Mech. Eng. Congr. Expo. 66 (1995) 99–105, https://doi.org/10.1115/ 1.1532008.

[5] Pak BC, Cho YI. Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles. Exp Heat Transfer 1998; 11:151–70.

[6] Wen D, Ding Y. Experimental investigation into convective heat transfer of nanofluid at the entrance region under laminar flow conditions. Int J Heat Mass Transf 2004; 47:5181–8.

[7] Williams WC, Buongiorno J, Hu LW. Experimental investigation of turbulent convective heat transfer and pressure loss of alumina/water and zirconia/water nanoparticle colloids (nanofluids) in horizontal tubes. J Heat Transf 2008; 130:42412–9.

[8] Duangthongsuk W, Wongwises S. An experimental study on the heat transfer performance and pressure drop of TiO_2-water nanofluids flowing under a turbulent flow regime. Int J Heat Mass Transf 2010;53:334–44.

[9] Ghozatloo A, Rashidi A, Shariaty-Niassar M. Convective heat transfer enhancement of graphene nanofluids in shell and tube heat exchanger. Exp Therm Fluid Sci 2014;53:136–41.

[10] M. Chandrasekar, S. Suresh, A. Chandra Bose, “Experimental investigations and theoretical determination of thermal conductivity and viscosity of Al2O3/water nanofluid”,

Experimental Thermal and Fluid Science, 34 (2017) 210–216

[11] Shriram S. Sonawane, Rohit S. Khedkar, Kailas L. Wasewar," Study on concentric tube exchanger heat transfer performance using Al2O3 – water based nanofluids", International Communications in Heat and Mass Transfer 49 (2013) 60–68@ 2013 Elsevier Ltd.

[12] Akyürek, E.F., Geliş, K., Şahin, B., Manay, E., Experimental Analysis for Heat Transfer of Nanofluid with Wire Coil Turbulators in a Concentric Tube Heat Exchanger, Results in Physics (2018), doi: https://doi.org/10.1016/j.rinp.2018.02.067.

[13] T.S. Griffith, L. Al-Hadhrami, J.C. Han, Heat transfer in rotating rectangular cooling channels (AR = 4) with dimples, J. Turbomach. 125 (3) (2015) 555–563, https://doi.org/10.1115/1.1571850.

[14] D. Lauffer, B. Weigand, R. Liebe, A study on local heat transfer enhancement in a rectangular dimpled channel with a large aspect ratio, Proc. ASME Turbo Expo 3 PART A 2017 131–139 10.1115/GT2005-68089.

[15] S.W. Chang, K.F. Chiang, T.L. Yang, C.C. Huang, Heat transfer and pressure drop in dimpled fin channels, Exp. Therm. Fluid Sci. 33 (1) (2019) 23–40.

[16] Josephine Oluwaremilekun Oluyale, Moses Omolayo Petinrin, Adeyinka Ayoade Adegbola, Felix Adedayo Ishola, Experimental investigation of flow and heat transfer in a channel with dimpled plate, Journal of Physics: Conference Series, 1378 (2019) 022034.