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RESEARCH ARTICLE

THE EFFECT of the USE of DIFFERENT NANOFLUIDS on the HEAT TRANSFER PERFORMANCE of a HEAT EXCHANGER

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ABSTRACT

The most important problem of heating and cooling systems is the removal of heat from the system. Heat exchangers are the most critical equipment of such systems. However, the use of nanofluids has increased significantly in recent years due to the design limitation of heat exchangers. In this study, the effect of using different nanofluids on the heat transfer performance of a heat exchanger was numerically investigated. A 3D heat exchanger model was created and the thermal performance of the system was analyzed by using different types of fluids at different fluid velocities. Analyzes were performed using the ANSYS Fluent program. According to the results obtained, the highest heat transfer increase was obtained in MgO-TiO_2 nanofluid with 33.4% at 0.05 m/s compared to water. The highest and lowest heat transfer rates were calculated with 202.73 W for MgO-TiO_2 nanofluid and 121.59 W for PGW (propylene glycol-water mixture) fluid, respectively.

Keywords: *Heat Transfer, Hybrid Nanofluids, Heat Exchanger, Nanofluids*

1. INTRODUCTION

The need for a more efficient heat exchanger system has become increasingly important because of global warming, greenhouse gas emissions, and energy concerns. Heat exchanger performance is determined by the thermal and physical properties of heat transfer fluids. Fins, microchannels, and increasing the heat transfer area can all be used to enhance the performance of the heat exchanger. In addition, increasing the thermophysical properties of the heat transfer fluid is an important parameter in increasing the performance of heat exchangers [1-4]. For this purpose, the use of nanofluids [5-8] and hybrid nanofluids has recently increased.

In recent years, many engineering applications have been investigated with different nanofluids. Das et al. [9] investigated exergetic characteristics of a heat exchanger (shell and tube) and heat transfer using PGW (propylene glycol-water mixture)-based ZnO nanofluids varying nanoparticle volume concentration and nanofluid (shell side) flow rates in their study. The experimental results show that the heat transfer rate has been enhanced by increasing the concentration of nanoparticles and the flow rate of nanofluids. The efficiency of the heat exchanger was increased with the increase in the concentration of the volume of nanoparticles at a certain amount of nanofluid flow. In their experimental study, Sundar et al. [10] evaluated the friction factor and convective heat transfer coefficient. MWCNT-Fe_3O_4/water hybrid nanofluid was used in the experiments. And a circular tube is used at constant heat flux. Flow conditions are fully developed turbulent flow. In comparison to base fluid data, the results reveal a maximum increase in Nusselt number of 31.10% with a penalty of 1.18 times increased pumping power for particle loading of 0.3% at 22,000 Reynolds number. In another study, the use of corrugated pipes in a heat exchanger (shell and tube) was investigated using the ε-NTU method, energy/exergy analysis. The effect of using corrugated pipes on energy/exergy efficiency was investigated for different operating conditions. The results revealed that the difference between fluid outlet temperatures could be reduced instead of smooth surfaces due to fluid mixing and secondary flows obtained using corrugated surfaces [11]. Huang et al. [12] examined the pressure drop and heat transfer properties of a hybrid nanofluid mixture incorporating multi walled carbon nanotubes (MWCNTs) and alumina nanoparticles in a heat exchanger (chevron corrugated-plate), When comparing the hybrid nanofluid mixture with water and Al_2O_3/water nanofluid, results show that the hybrid nanofluid mixture has a slightly larger heat transfer coefficient. In addition, hybrid nanofluid mixtures exhibit the highest heat transfer coefficients. A Diamond-water nanofluid's (biologically friendly) heat transfer efficiency, thermophysical characteristics, and pumping power assessment were experimentally studied by Alshayji et al. [13]. The nanofluid was discovered to be an efficient heat transfer fluid in a fully developed internal laminar flow regime at all studied solid concentrations and temperatures.

This numerical study investigated the effect of using different nanofluids on heat transfer performance and pressure drop. Common metallic nanofluids and metallic and metal-carbon hybrid nanofluids were preferred. In this manner, it was aimed to determine what kind of fluid used in a heat exchanger will be more efficient for heating/cooling systems.

2. MATERIALS and METHODS

In this study, a one-tube and one-pass heat exchanger model was used for the analysis. The model of the heat exchanger is given in Figure 1. The tube section has a total length of 2184 mm and is made of copper material. The diameter of the tube is 10 mm and the wall has a thickness of 1 mm. There are 36 aluminum fins with 1mm thickness and placed with a space of 5 mm around the tube. For copper and aluminum, the properties in the Fluent database were used. The numerical studies were conducted by using commercially available software ANSYS FLUENT 18.2 [14]. It was used for pressure-based and steady-state conditions, and energy and laminar viscous models. The analyses were performed at 4 different fluid velocities (0.5, 0.6, 0.7 and 0.8 m/s) and using 5 different fluids (water, propylene glycol-water mixture/PGW [9], ZnO/PGW [9], MgO-TiO_2 [15] and multi-walled carbon nanotubes/MWCNT-Fe_3O_4 [10] hybrid nanofluids), Thermophysical properties of the materials and fluids used in the study are given in Table 1.

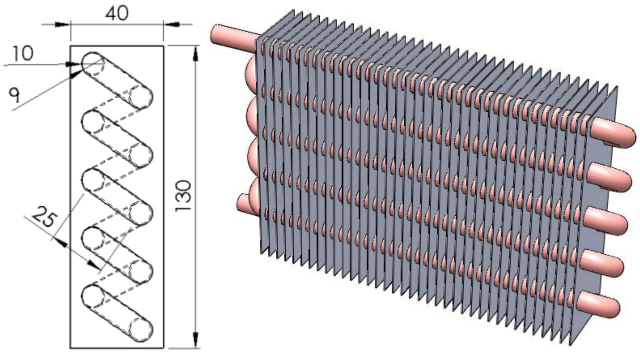


Figure 1. The schematic representation and 3-D model of heat exchanger.

The constant temperature for the tube inlet (60 ^{o}C) and constant heat transfer coefficient (h=20 W/m^{2}K) for the ambient were applied as boundary conditions. The computational domain was divided into 3.112.704 quadratic, uniform, and fine mesh. The mesh structure for the numerical model is shown in Figure 2. The average skewness for the model is 0.244.

Table 1. Thermophysical properties of materials and fluids.

Material	**ρ (kg/m^3)**	**c_p (J/kg·K)**	**k (W/m·K)**	**μ (Pa·s)**
Aluminum	2719	871	202.4	-
Copper	8978	381	387.6	-
Water	998.2	4820	0.6	0.001003
PGW(40:60)	1026.5	3747.186	0.388	0.58
ZnO/PGW	2247.8	1612.055	0.6752	1.01384
MgO-TiO$_2$	2870	8420	4.768	0.98
MWCNT-Fe$_3$O$_4$	1002.3	4182.66	0.6734	0.91

The calculations are based on the assumptions expressed as follows: materials and fluids have constant and uniform properties, fluids have been incompressible, and the inlet temperature of fluids has been constant.

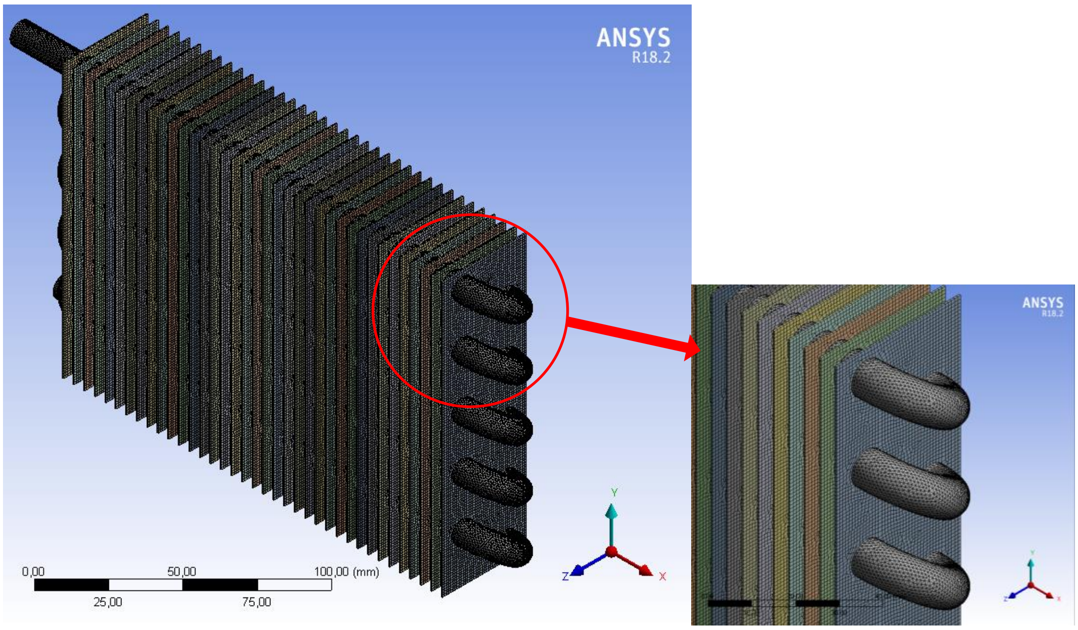


Figure 2. The mesh structure of 3-D numerical model of heat exchanger.

With the CFD (computational fluid dynamics) commercial package program (ANSYS Fluent 18.2), the heat transfer and flow through the geometry have been analyzed using partial derivative equations obtained from the conservation laws of continuity, momentum, and energy. Since the single phase approach is used in the study, the equations can be used for all fluids (nanofluids and hybrid nanofluids), Continuity, momentum, and energy equations, respectively [16];

$$\nabla(V_m)=0 \tag{1}$$

$$\nabla\rho(V_m V_m)=-\nabla P+\nabla\mu(\nabla V_m) \tag{2}$$

$$\nabla\rho c_p(V_m T)=\nabla k(\nabla T) \tag{3}$$

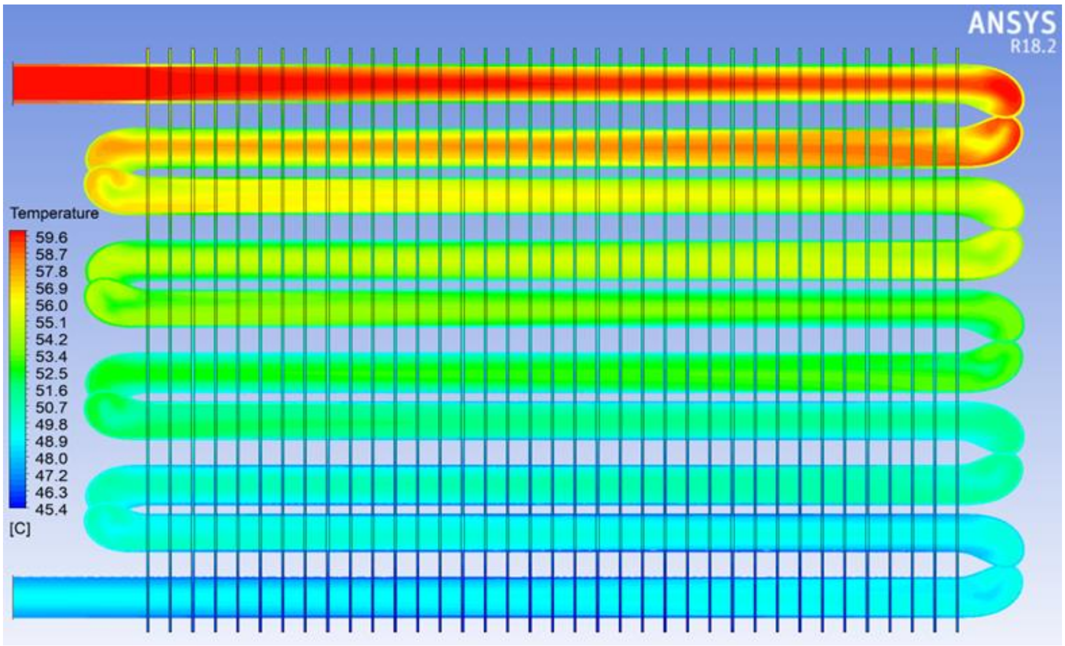
where ρ is the density (kg/m^3), c_p is the specific heat (J/kgK), μ is the dynamic viscosity (Pas), k is the thermal conductivity (W/mK), P is the pressure (Pa), V is the velocity (m/s) and T is the temperature (^{o}C),

3. RESULTS and DISCUSSION

In this study, the heat transfer performance of 5 different fluids for 4 different flow rates (0.5, 0.6, 0.7 and 0.8 m/s) at constant inlet temperature was analyzed. For this purpose, firstly, numerical analysis of water and PGW fluids, which are widely used as base fluids, were made. Afterward, heat transfer analysis of different nanofluids was performed and water was compared with the base fluid. The temperature contours of the results obtained are given in Figures from 3 to 7 at different fluid flows for all fluids (water, propylene glycol-water mixture/PGW, ZnO/PGW, MgO-TiO_2 and multi-walled carbon nanotubes/MWCNT-Fe_3O_4 hybrid nanofluids), respectively. As seen from the temperature contours in the figures, the outlet temperatures decreased as the fluid velocity increased. In other words, the temperature difference between the inlet and outlet temperatures decreased with increasing fluid velocity.

As the fluid velocity increases, it was seen that more uniform temperature distribution is obtained. It was thought that the distribution of temperature contours of water, ZnO/PGW, and MWCNT-Fe_3O_4 fluids exhibit similar characteristics, and this is due to the fact that the thermal conductivity coefficients are close to each other. It was observed that PGW with the lowest thermal conductivity coefficient is also the fluid with the lowest temperature value (41.9 ^oC) in terms of temperature contours. In MgO-TiO_2 nanofluid, the situation is the opposite, and when the thermal conductivity value is the highest, the highest temperature values (55.2 ^oC) were seen in this fluid. When the temperature contours are examined in detail, it can be seen starting from the second elbow that other fluids have higher temperature values except for water. This can be explained by the fact that water has the lowest viscosity value.

V1


ANSYS
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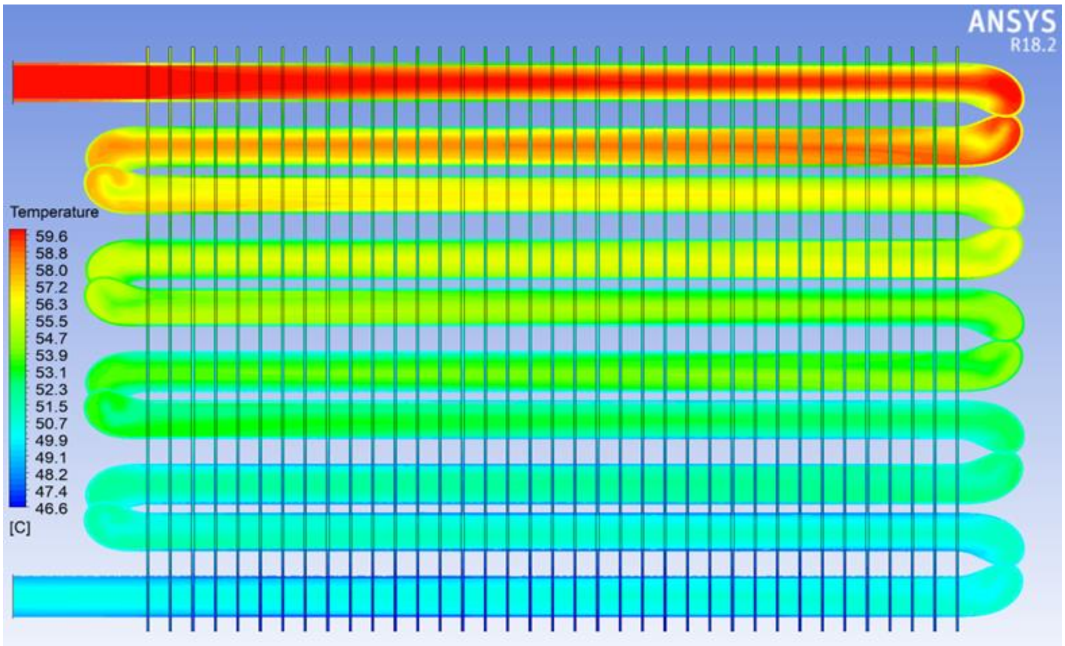
V2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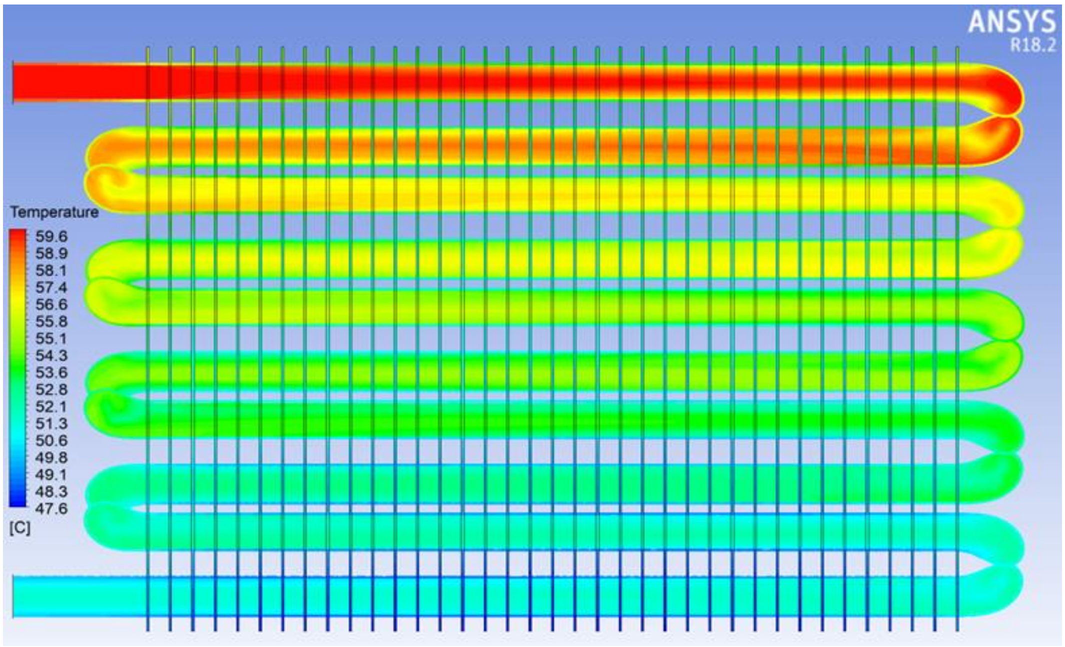
V3



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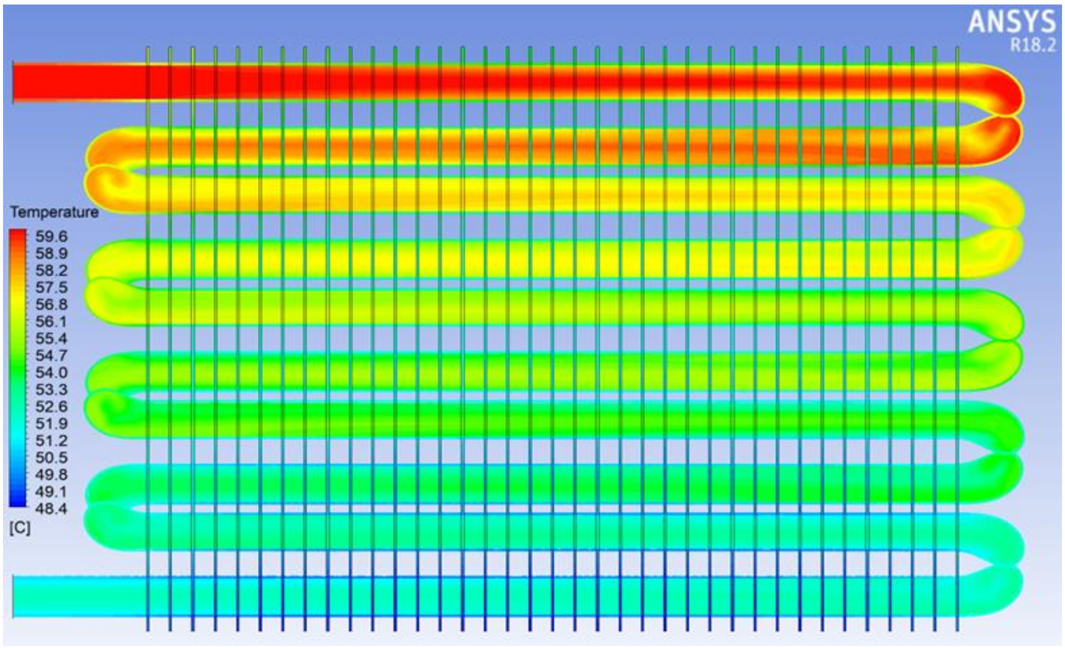
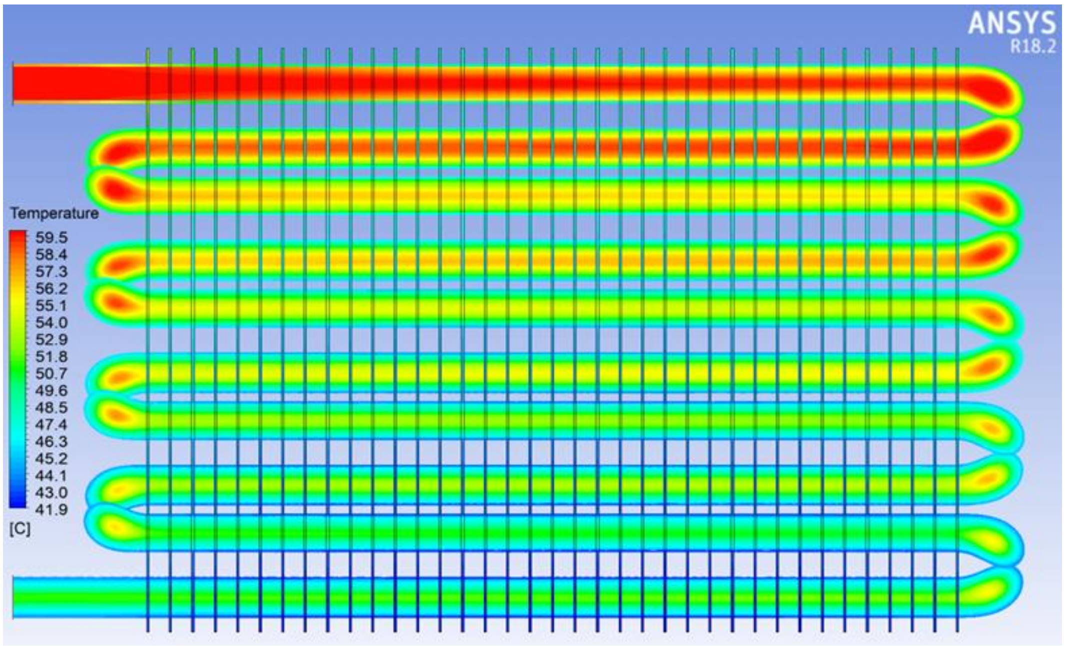


Figure 3. Temperature contours of water at different fluid velocities.

V1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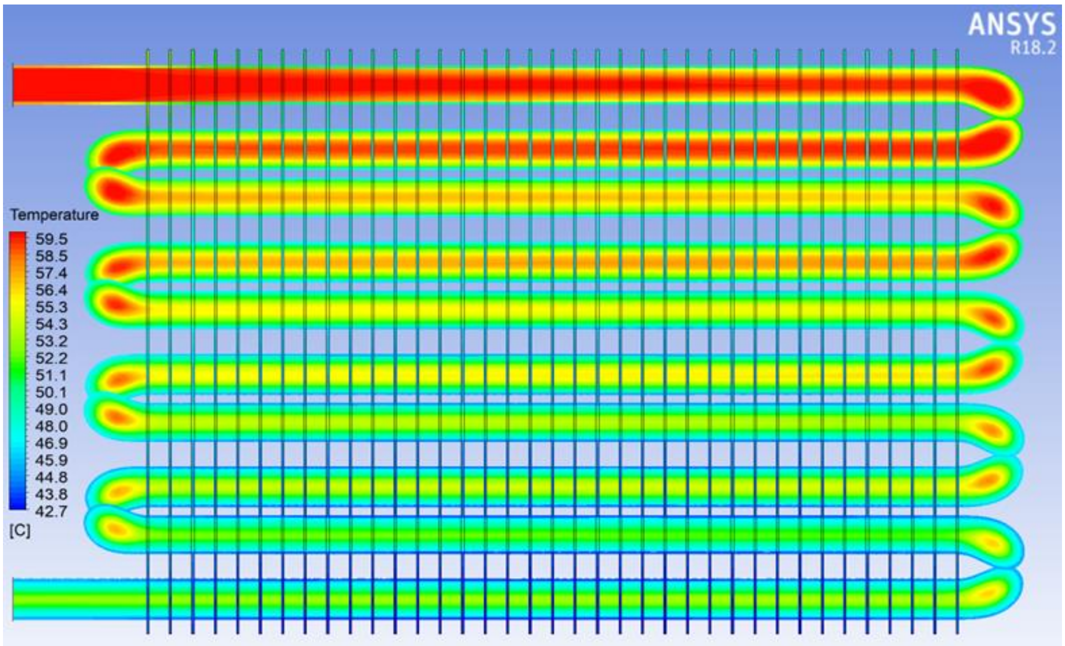
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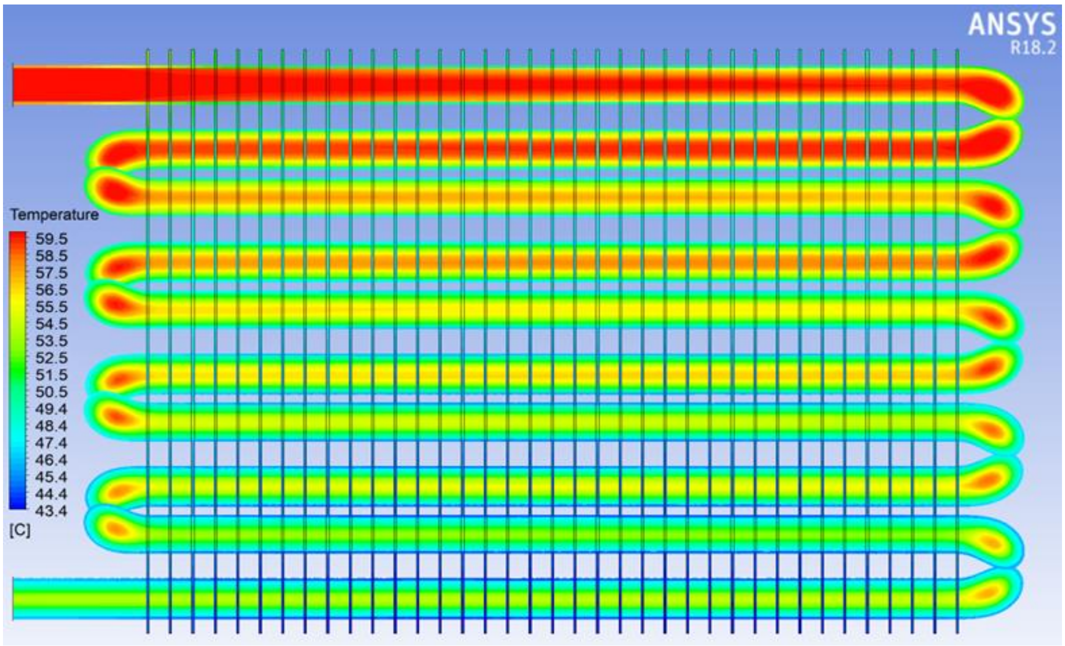

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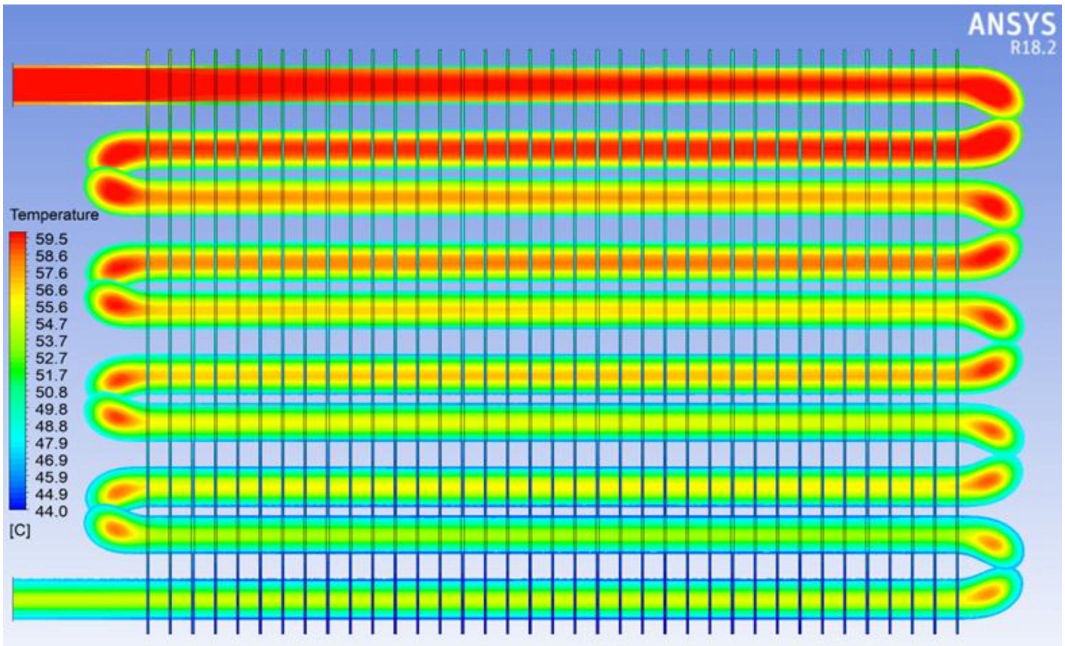
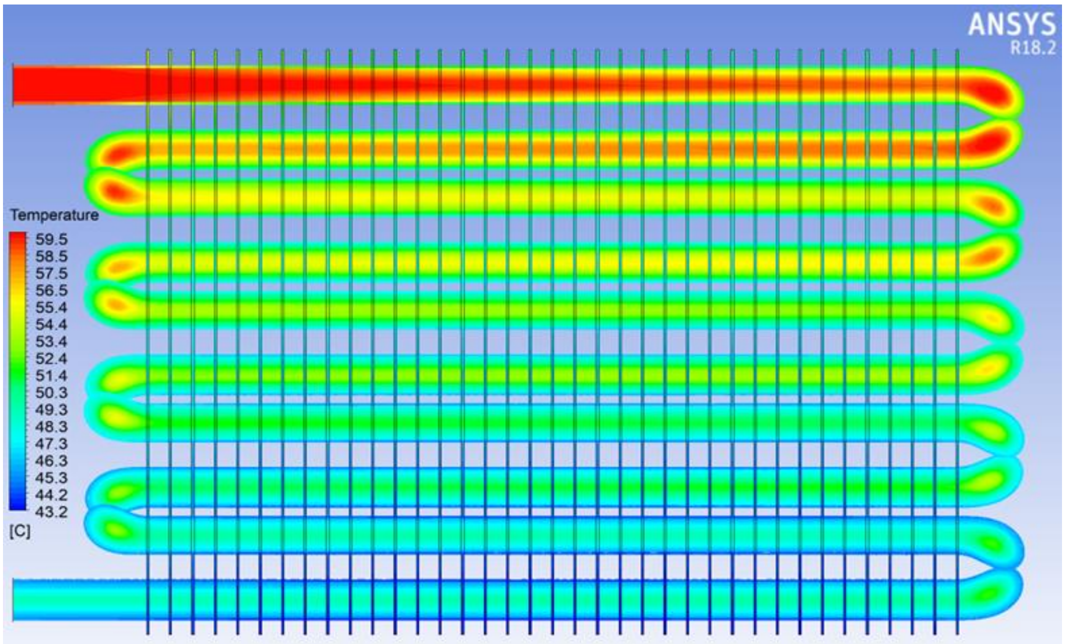


Figure 4. Temperature contours of PGW at different fluid velocities.

V1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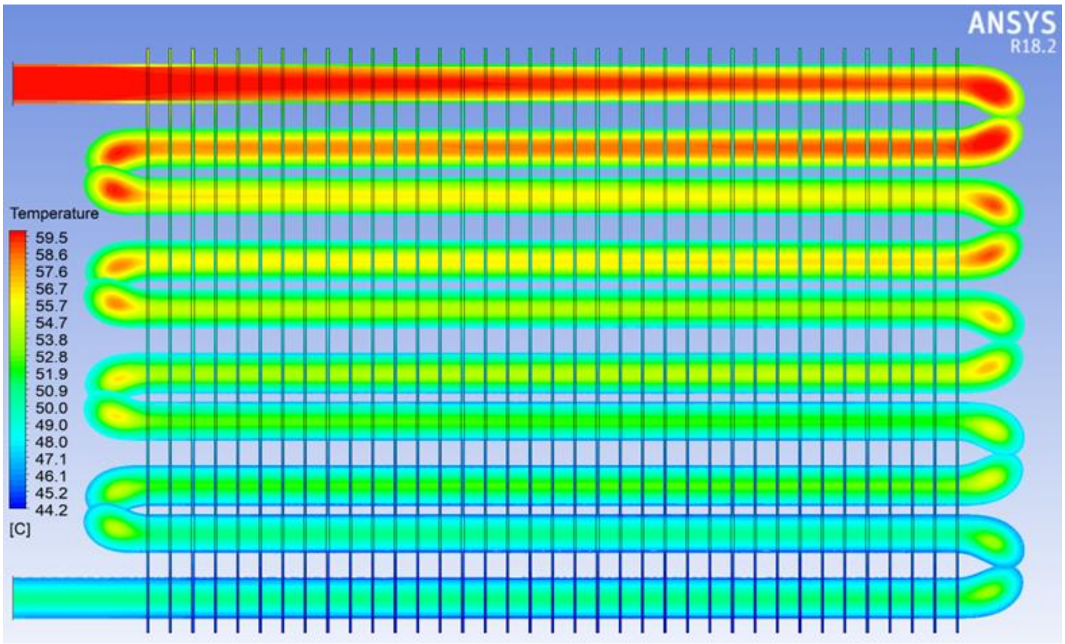
V2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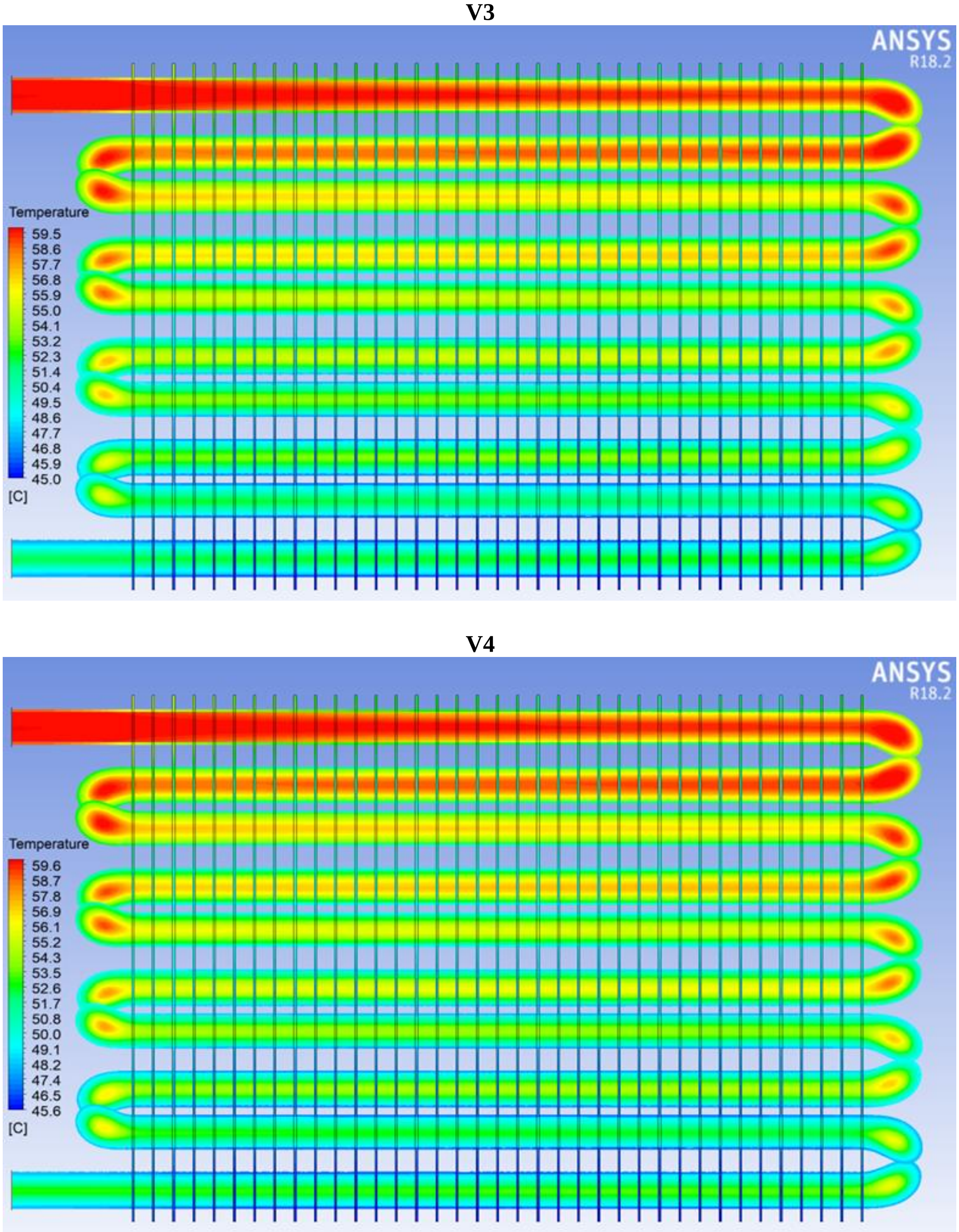
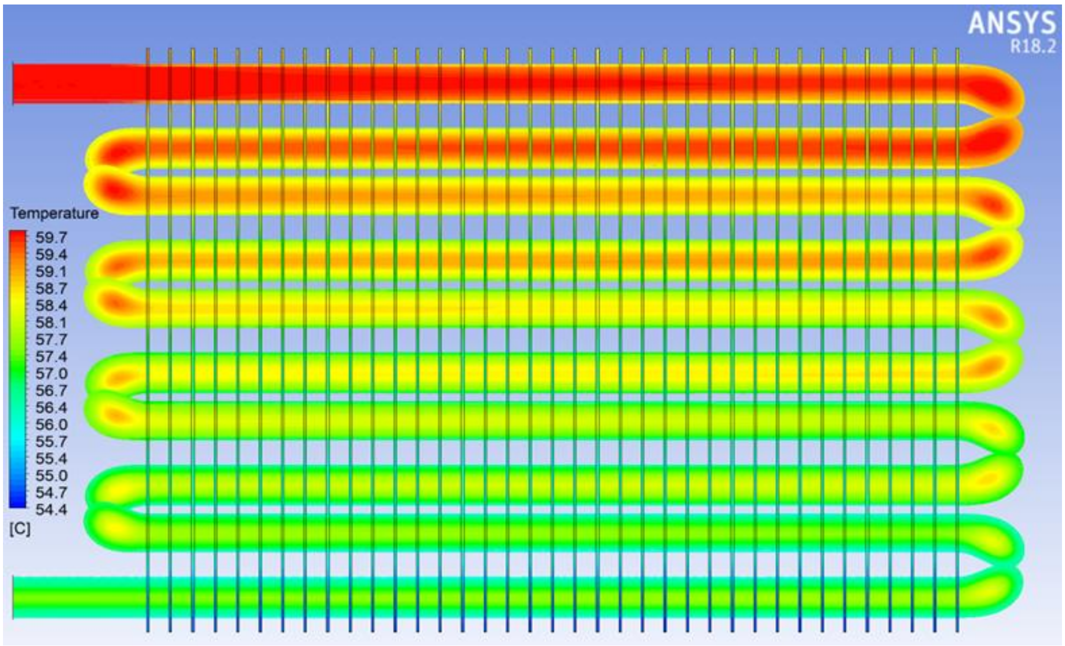

V3

V4

Figure 5. Temperature contours of ZnO/PGW at different fluid velocities.

V1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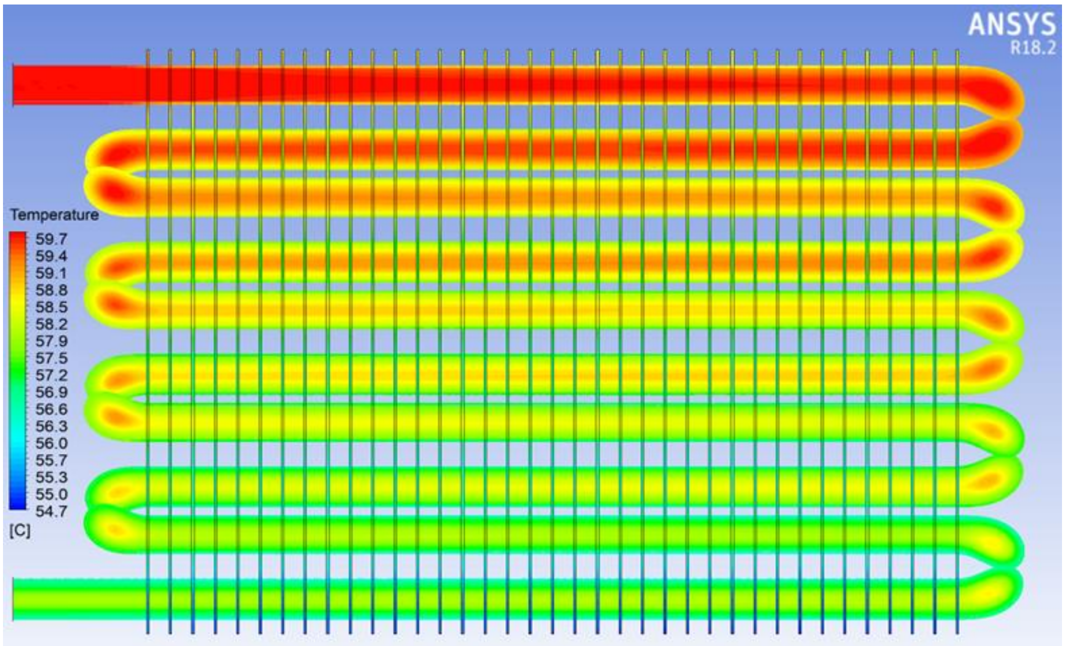
V2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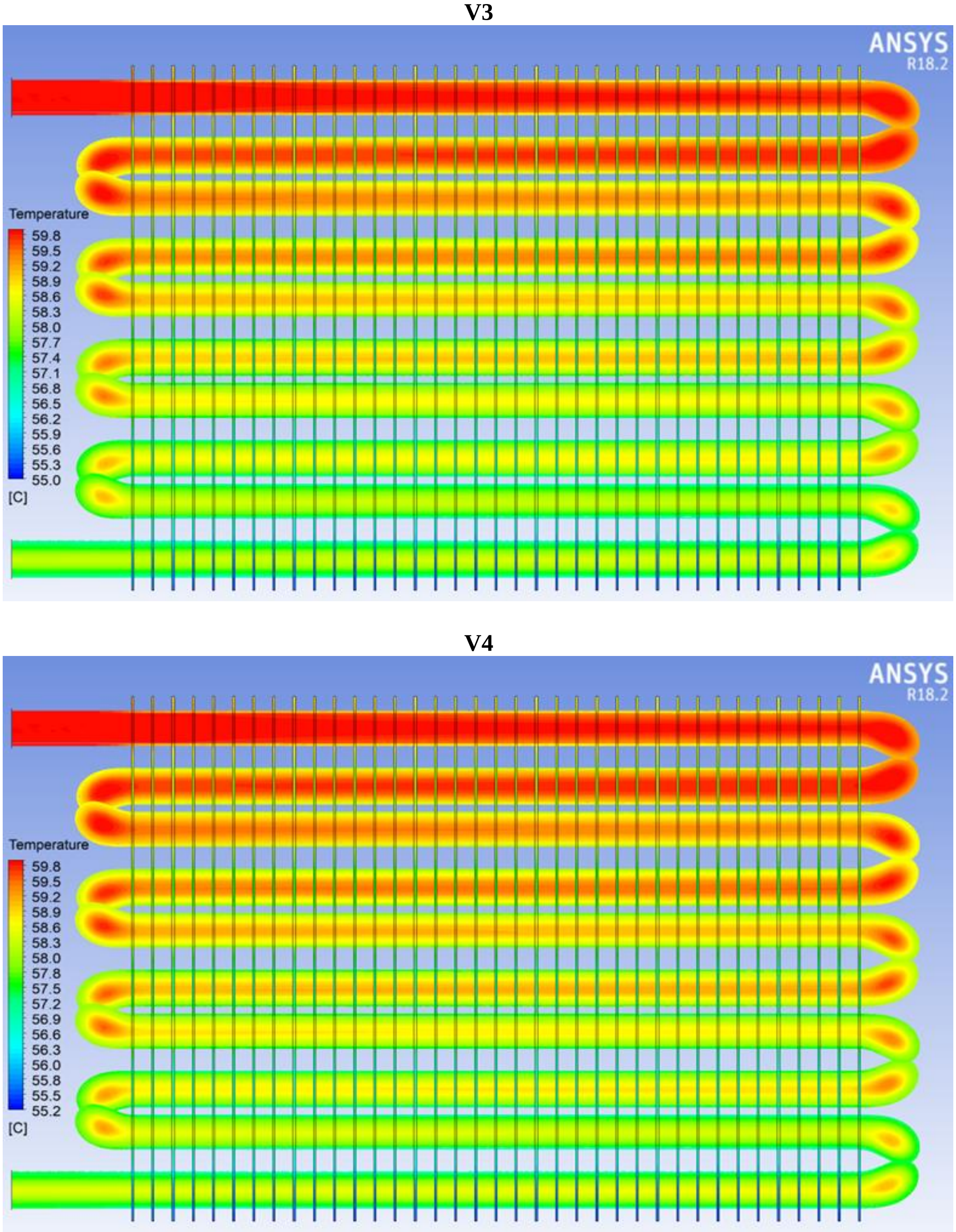
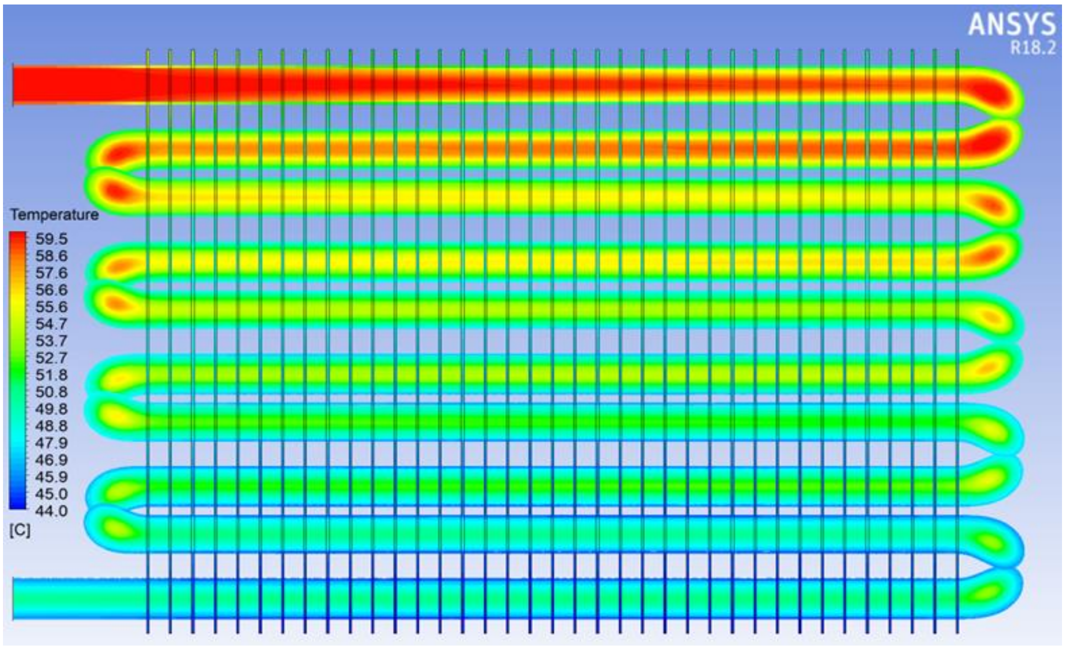


Figure 6. Temperature contours of MgO-TiO_2 at different fluid velocities.

V1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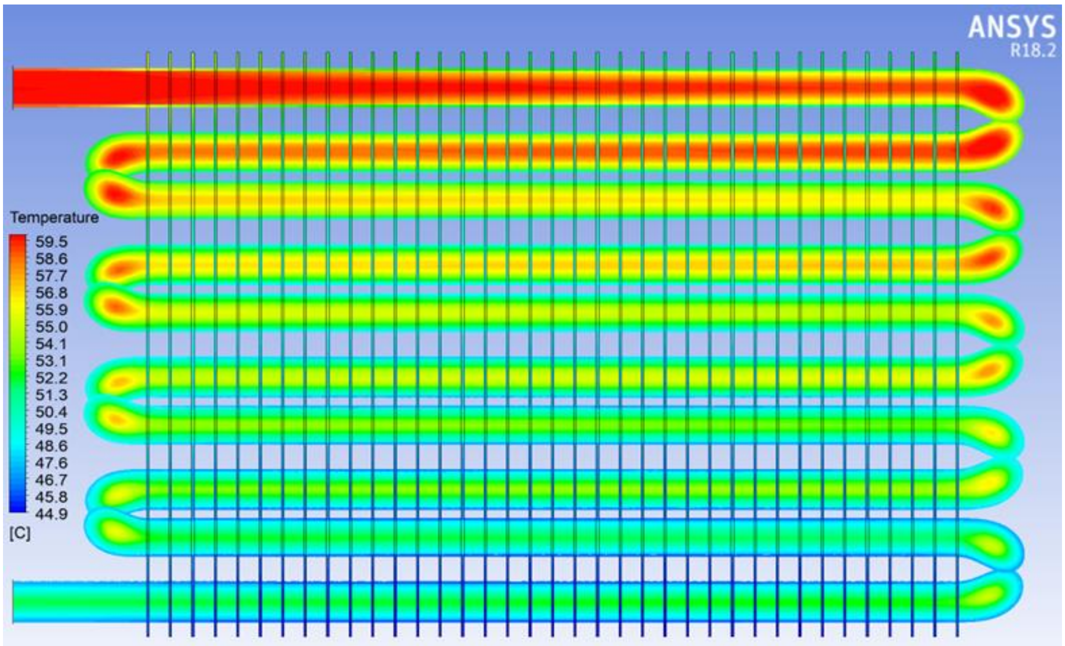
V2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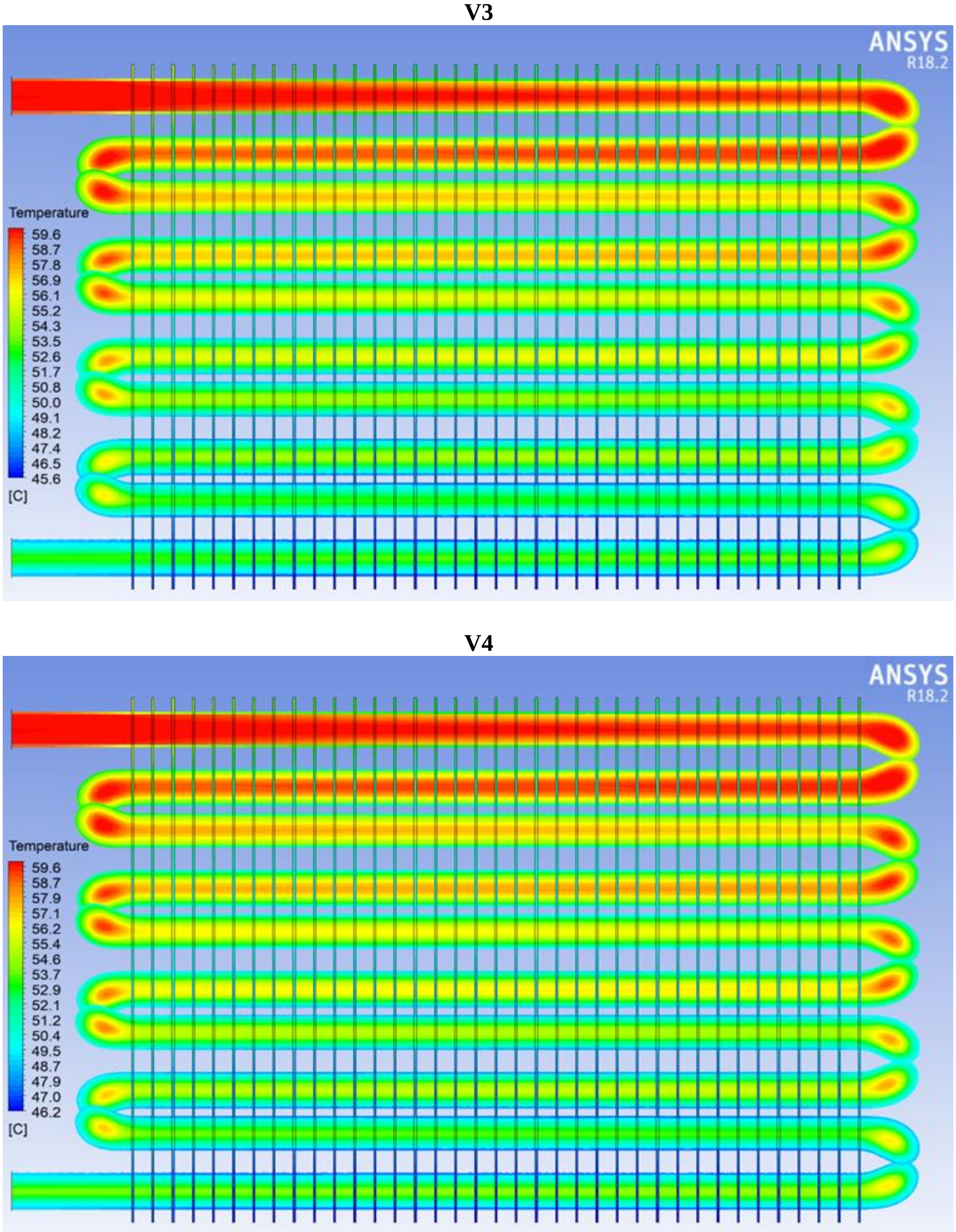

Figure 7. Temperature contours of MWCNT-Fe_3O_4 at different fluid velocities.

According to the results obtained, the heat transfer rates of all fluids were given at different fluid velocities in Figure 8. It was observed that the heat transfer rate increased for all fluids with increasing fluid velocity. The highest and lowest heat transfer rates were calculated with 202.73 W for MgO-TiO_2 nanofluid and 121.59 W for PGW fluid, respectively. Compared to water, the highest heat transfer increase was obtained in MgO-TiO_2 nanofluid with 33.4% at 0.05 m/s. When this value is compared with PGW, the increase rate was calculated as 63.6%. The second highest heat transfer coefficient values were obtained in water fluid. This situation can be explained by thermal conductivity and heat capacity values.

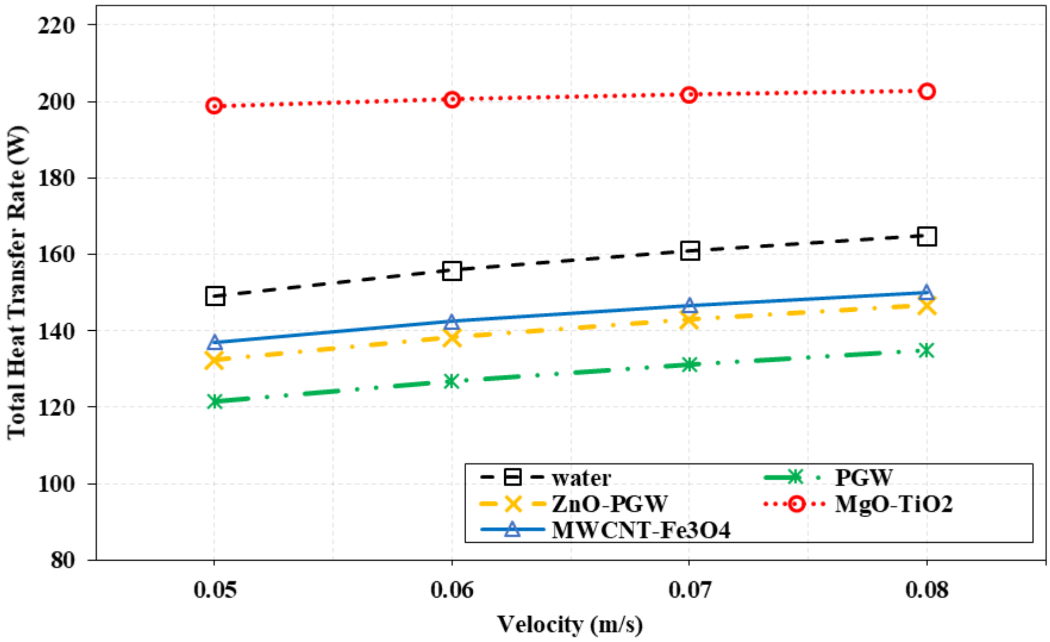

Figure 8. Total heat transfer rates of all fluids at different fluid velocities.

In figure 9, pressure difference values of all fluids are given. It has been calculated that the differences between the inlet/outlet pressure values of all fluids except water are very high. It is also seen that the increase in fluid velocity causes the pressure difference values to increase. The highest pressure difference value was calculated in ZnO/PGW nanofluid. This can be explained by the fluid viscosity. Higher viscosity causes more pressure loss.

The values of the outlet temperatures of all fluids for different fluid velocities are given in Figure 10. It was calculated that when the fluid velocity increased, the temperature values also increased. When the fluids were compared, it was calculated that the most significant temperature values were in MgO-TiO_2 nanofluid. It is seen that other fluids have close values. The highest outlet temperature was obtained at 58.07 ^{o}C in MgO-TiO_2 nanofluid and the lowest at 57.48 ^{o}C in ZnO/PGW nanofluid.

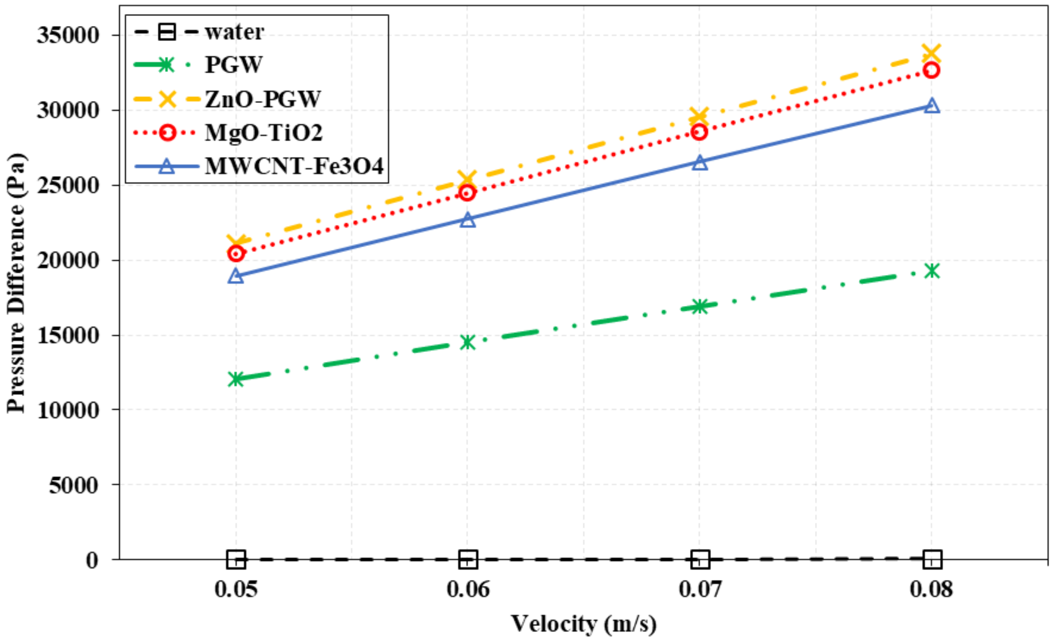

Figure 9. Pressure difference values of all fluids at different fluid velocities.

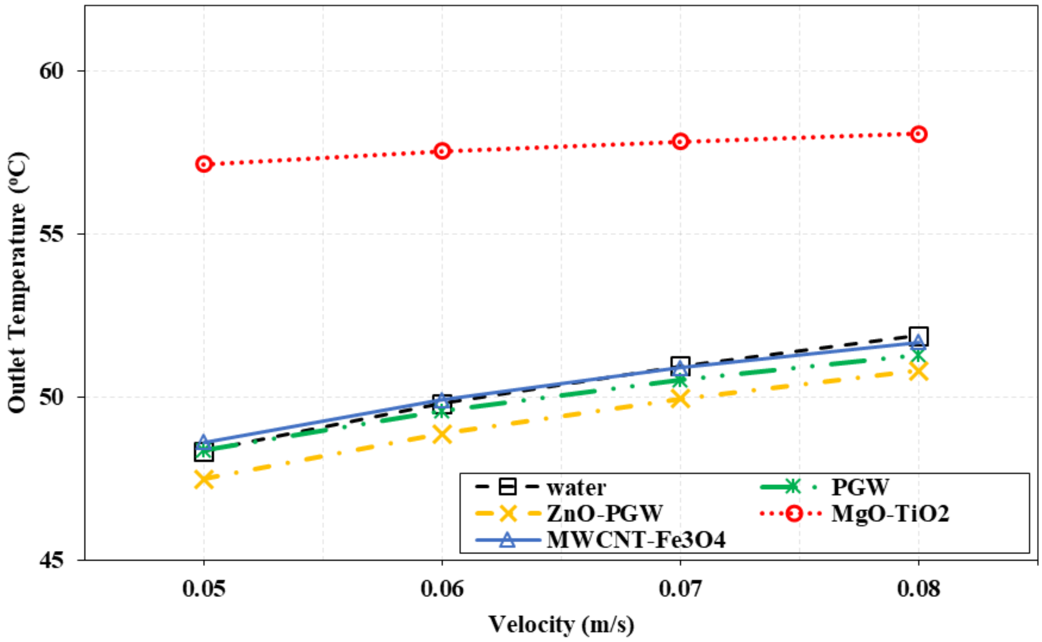

Figure 10. Outlet temperature values of all fluids at different fluid velocities.

4. CONCLUSION

In this study, the effect of using different nanofluids on the heat transfer performance of a heat exchanger was numerically investigated. A 3D heat exchanger model was created and the thermal performance of the system was analyzed by using different types of fluids at different fluid velocities. The following results were obtained as a result of the analysis:

It was observed that the heat transfer rate increased for all fluids with increasing fluid velocity. The highest heat transfer increase was obtained in MgO-TiO_2 nanofluid with 33.4% (202.73 W) at 0.05 m/s fluid velocity compared to water. The most important parameter causing this is the thermal conductivity value. When this value is compared with PGW, the increase rate was calculated as 63.6%. The highest pressure difference value was calculated in ZnO/PGW nanofluid. This can be explained by the fluid viscosity. Higher viscosity causes more pressure loss.

In the numerical analysis, it was seen that the thermal properties of the fluids affect the results very much due to the single-phase assumption. When the results were examined, it was seen that the single-phase analysis is not sufficient, especially compared to the experimental results.

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