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Investigated Numerically the Impact of Magnetic Field on Heat Transfer and Nano-Ferrofluid Flow in a Straight Pipe

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ABSTRACT

Abstract: The research examines velocity, Nusselt number, Y plus, magnetism effectiveness, and flow of Fe_3O_4-distilled water in a magnetic field tube in order to investigate heat transfer and flow. Magnetic fields modify flow patterns by generating vortexes and changing thermal boundary layers. The surface of a model with a 210 mm tube length and a 25.4 mm inner diameter exhibits equal magnet shed spots. The entry of the nanomaterial at a temperature of 300 K is shown by the three different entrance velocities of 0.05, 0.1, and 0.5 m/s that were recorded at the entry region. These limitations were used. Three instances of the first magnets were taken when the middle magnet was switched on, followed by the first and third, and finally all three of them. In the exit region, an exit pressure of 0 pa was given to the surfaces of heat at a constant temperature of 350 K. Three magnetic flux forces one, two, and three Tesla were calculated. The temperature value at the three magnets is 349 K, which is the biggest temperature value compared to the other examples, demonstrating that the temperature value rises with the number of magnetization stages.

1. Introduction

Heat transfer is a significant issue in various industries, including construction and transportation. To improve efficiency, heat exchangers must be designed with high heat transfer rates. There are three methods: active, passive, and compound. Corrugated surfaces, a passive method, increase surface area and heat transfer rate [1, 2]. Nanoparticle production techniques can be categorized into physical, biological, and chemical methods. Mechanical ball milling is a common physical method for producing dry powder nanoparticles. Thermal conductivity is crucial for creating energy-

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efficient thermal transfer fluids. Traditional fluids with low thermal conductivities, such as water, oils, and ethylene glycol, restrict cooling capacity despite development in this area. At normal temperature, the thermal conductivity of water is 700 times greater than that of copper [3, 4]. When there is an electric current passing through the commercial electromechanical holder in TEM, Lorentz force is applied. The punch deflects vertically toward the loading axis of the holder due to this force, which is vertical to both the magnetic field and the electric current. Friction tests are possible with this configuration, in which a magnetic field is applied to the cantilever and a portion of the punch. Since the Lorentz force on the cantilever is three orders of magnitude less, it is ignored [5,6,7]. [8] The study investigated the use of Fe_2O_3/Kerosene nanofluid in a copper oscillating heat pipe exposed to field magnetism. Results showed that Fe_2O_3 nanoparticles significantly improved the pipe's thermal performance and heat transfer coefficient, especially under field magnetism conditions. The evaporator's surface temperature was higher than the vapor temperature but lower in the condenser. [9] The study investigated the impact of field magnetism on the flow of nanofluid inside a sinusoidal 2-tube heat exchanger. The base fluid is water containing 4% nanoparticles (Fe_3O_4). The study found that the sinusoidal construction of the interior tube enhances the Nusselt number within the heat exchanger. Field magnetism also promotes the diffusion of the cold border layer into the inner tube, increasing the Nusselt number and heat transmission. This effect is more pronounced at high Reynolds numbers. [10] A one-dimensional multiphase flow model with heat transfer for thermomagnetic-pumped ferrofluid was proposed, combining the basic fluid's thermodynamic equations with a simplified particle model. The implemented model provides accurate predictions, but heat transfer coefficient forecasts have high sensitivity to errors. [11] A study on steady-state laminar ferro flow across a partially filled porous tube showed a significant increase in heat transmission due to the presence of both porous material and field magnetism. The combined presence of these factors may enhance heat transmission by up to 2.41-fold, with porous media contributing more than field magnetisms. [12] In a heated circular tube, the convective heat transfer coefficients of Al2O3 nanofluids are investigated and compared to distilled water in this work. The convective heat transfer coefficient increased by 8%, according to the results, which is more than the rise in thermal conductivity [13] The study explored heat transport between nanoparticle suspensions in turbulent pipe flow, evaluating pumping power, heat transfer rate, and operating conditions. It found an ideal particle loading for maximizing heat transfer and minimizing costs, with a relationship between concentration and temperature. [14] The study explores the theoretical improvement of nanofluids in convective heat transfer over a circular pipe, focusing on the impact of nanoparticle concentration, Reynolds and Prandtl coefficients, and volume concentration. Results show that increasing particle concentration increases heat transfer rate and pressure decreases. Researchers are working on fabrication to improve nanofluids' applicability in electronics, building, and chemical industries.

2. Aim of the investigations

This research aims to investigate the horizontal heat transmission of Fe_3O_4-distilled water in a tube with a magnetic field, as well as its enhanced characteristics. The efficacy of the volume fraction, field magnetism, Reynolds number are all examined in this research.

3. Theoretical analysis

This chapter will cover all of the basic equations that were used to get the results from the numerical component, along with the setups and programs required to provide reliable and accurate results. Research in Computational Fluid Dynamics (CFD) is carried out to get more profound understanding of the field. The two-component condition configuration is included in the disturbance model, which is represented by the (k-ε) model, the turbulent model used because it is the most suitable method to show vortex in the fluid, which causes increasing in heat transfer rate. Thus, the mathematical organization approaches will deal with these Cartesian direction coordinates (x, y, and z). A three-dimensional geometry computation is created. The cases were solved using the simulation program ANSYS (20.1).

3.1 Assumptions

In the current experiment, the running nanofluid is supposed to consist of Fe_3O_4 and water, with certain flow parameters (three-dimensional, steady flow, Newtonian, incompressible, turbulent).

3.2 Regulatory formulas

Since there are no other equations that can be used to solve the problem, all of the equations were obtained from the primary source of the Ansys Workbench software, which is used in situations like this.

3.3 Magnetic induction method

The Maxwell condition and Ohm regulation provide the appealing acceptance condition in the main method. The connection between the attractive field and the stream field is provided by the condition. Generally speaking, this thickness is described by the Ohm regulation given by [15]:

$$\vec{j} = \sigma\vec{E} \qquad (1)$$

Where σ is the electrical conductivity of the media. For liquid speed field $\vec{U}$ in an attractive field $\vec{B}$, Ohm regulation takes the structure:

$$\vec{j} = \sigma(\vec{E} + \vec{U} \times \vec{B}) \qquad (2)$$

The enlisting condition may be deduced as follows from Maxwell condition and Ohm regulation:

$$\frac{\partial\vec{B}}{\partial t} + (\vec{U} \cdot \nabla)\vec{B} = \frac{1}{\mu\sigma}\nabla^2\vec{B} + (\vec{B} \cdot \nabla)\vec{U} \qquad (3)$$

From the tackled attractive field $\vec{B}$, the present thickness $\vec{j}$ can be determined involving Ampere’s connection as:

$$\vec{j} = \frac{1}{\mu}\nabla \times \vec{B} \qquad (4)$$

The attractive field $\vec{B}$ in a MHD issue can be deteriorated into the remotely forced field $\vec{B}_0$ and the prompted field $\vec{B}$ because of smooth movement. Just the actuated field $\vec{B}$ should be addressed. From Maxwell situations, the forced field $\vec{B}_0$ fulfills the accompanying condition:

$$\nabla^2\vec{B}_0 - \mu\sigma'\frac{\partial\vec{B}_0}{\partial t} = 0 \qquad (6)$$

Where σ' is the electrical conductivity of the media wherein field $\vec{B}_0$ is produced.

3.4 Ansys package

Using ANSYS's User Defied Function to mimic the magnetic field, the research examines a uniform magnetic field produced by permanent magnets and magnetite ferrofluid in a magnetic vortex generator.

3.5 System geometry and mesh generation

The system geometry was created with a 210 mm total tube length and an inner diameter of 25.4 mm for the flow, as shown in Figure 1. On the tube's surface, the magnets' shed locations are evenly spaced, measuring 10 mm in width and 45 mm apart, where the heat sources that are exposed to the wall are represented by its outer layer.

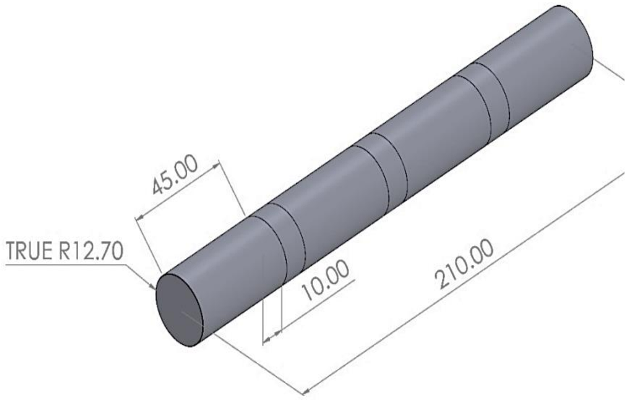


Figure 1. Geometry shape.

For complicated geometries, the research employed unstructured tetrahedron grids, and ANSYS made it possible to generate meshes and three-dimensional models with little assistance from the user. The study involved 1451380 cells, requiring mesh independence to ensure accurate results with a stable output size.

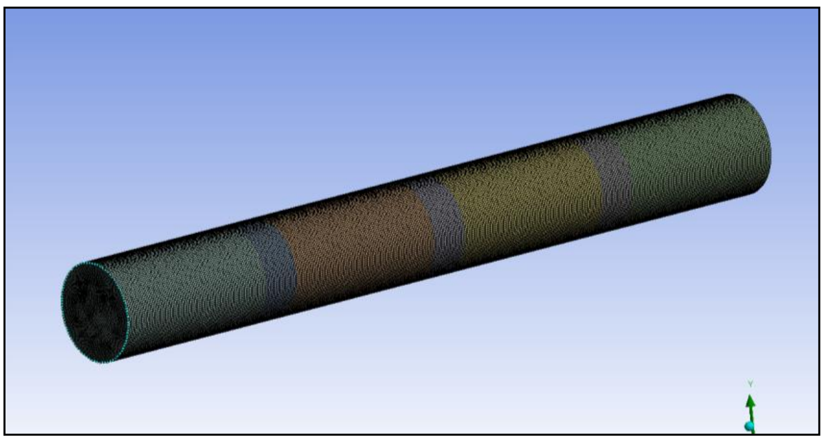


Figure 2. Mesh generated

Table 1. Mesh independency

case	node	element	Temp. max (k)	Temp. outlet (k)	Pre. difference (pa)
1	634212	523421	335.812	346.31	0.0455
2	1063643	974323	331.493	343.99	0.0394
3	1304363	1243667	329.081	343.81	0.0379
4	1505772	1451380	329.074	343.79	0.0378

3.6 Boundary conditions

The study recorded three entry velocities of nanomaterial at 300 K, and measured three magnetic flux forces at a constant temperature of 350 K. The exit region experienced a 0 Pa pressure, indicating nanomaterial penetration.

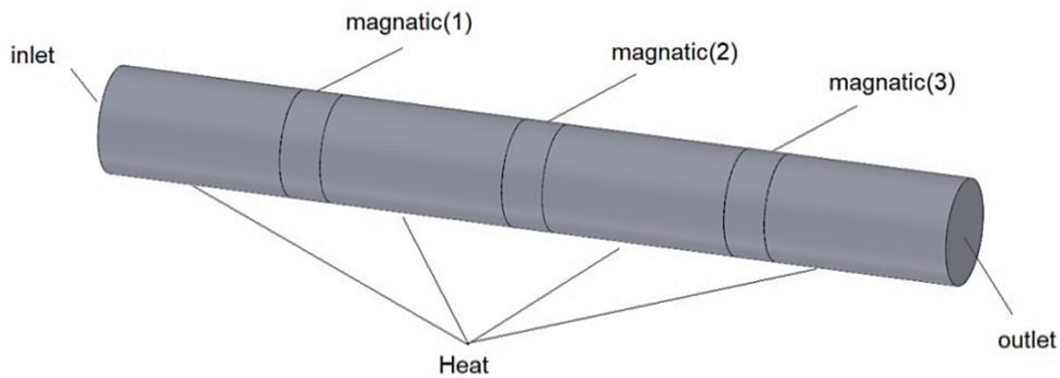
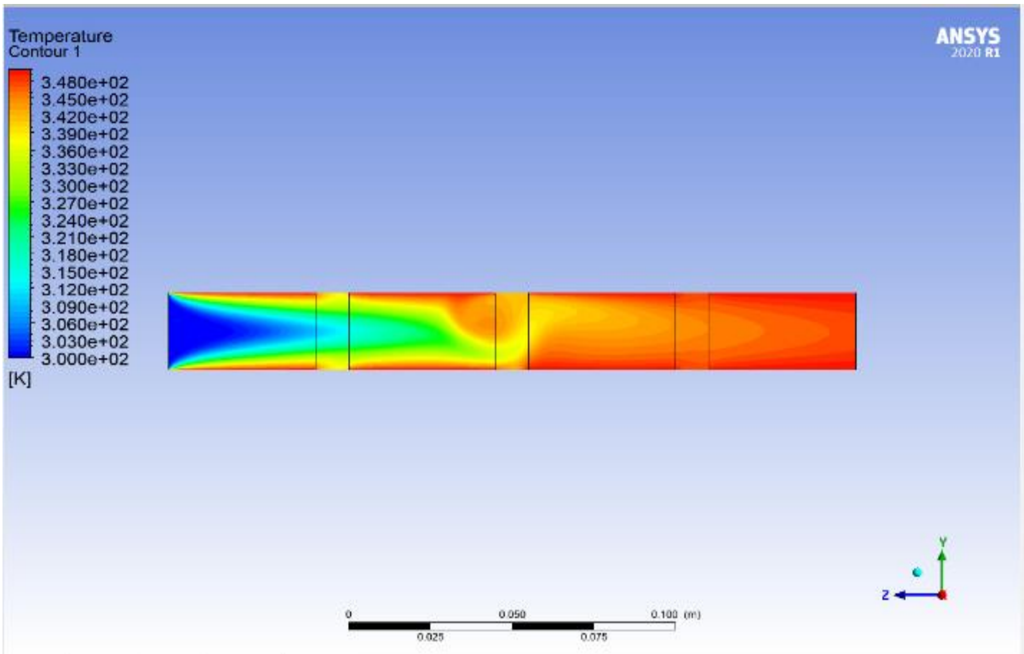


Figure 3. Boundary conditions

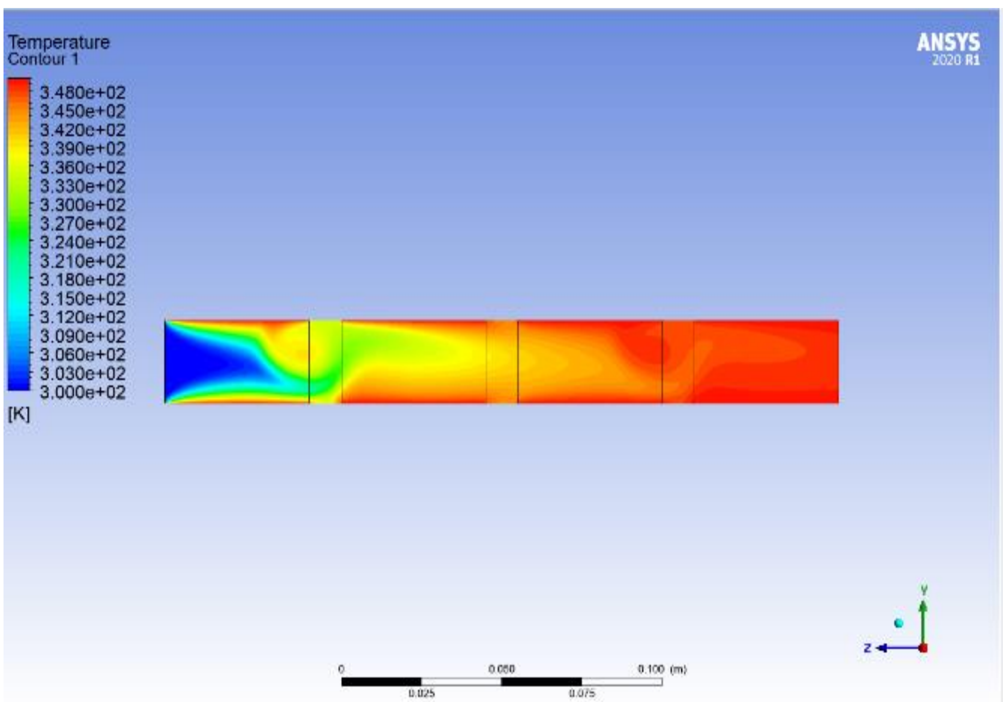
4. Results and discussion

4.1 The number of magnets effects on the vortex flow and exit temperature

The magnetized fluid is moved in the direction of the magnetic flux lines by the increase in magnet count (between every two vertical lines). As a result, the fluid turbulence value rises dramatically, and the channel's turbulence stages rise with the number of magnets. The temperature value at the three magnets is 349.324 K, which is the biggest temperature value compared to the other examples, as Figure 4 shows that the temperature value rises with the number of magnetization stages.


Temperature
Contour 1
3.480e+02
3.450e+02
3.420e+02
3.390e+02
3.360e+02
3.330e+02
3.300e+02
3.270e+02
3.240e+02
3.210e+02
3.180e+02
3.150e+02
3.120e+02
3.090e+02
3.060e+02
3.030e+02
3.000e+02
[K]
ANSYS
2020 R1
0
0.050
0.100 (m)
0.025
0.075

(a)


Temperature
Contour 1
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3.420e+02
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3.330e+02
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3.270e+02
3.240e+02
3.210e+02
3.180e+02
3.150e+02
3.120e+02
3.090e+02
3.060e+02
3.030e+02
3.000e+02
[K]
ANSYS
2020 R1
0
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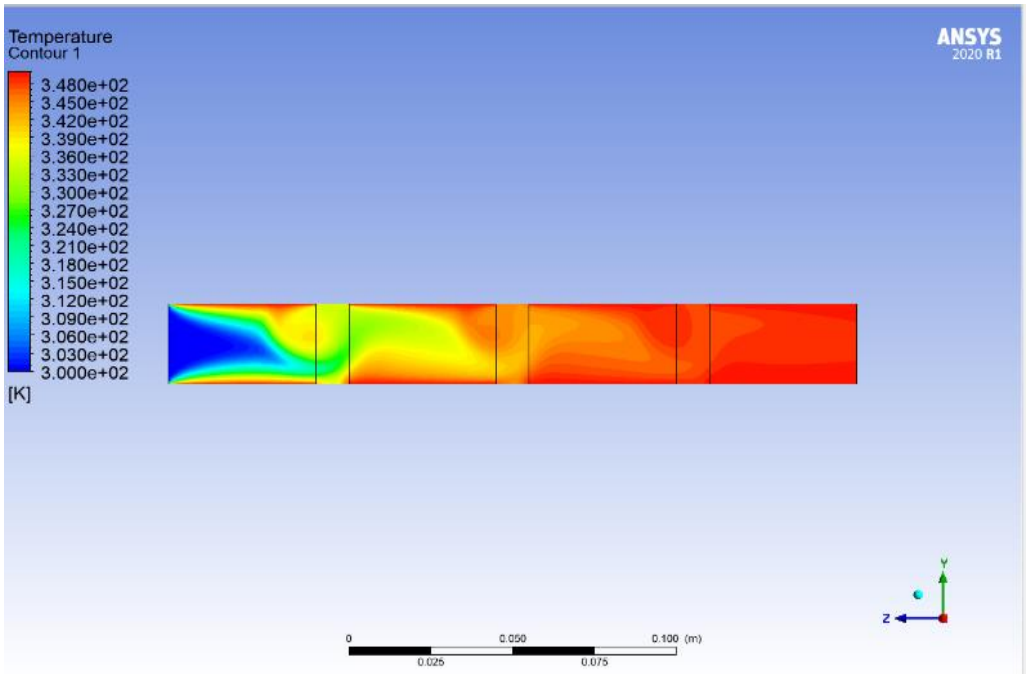
0.100 (m)
0.025
0.075

(b)



(c)

Figure 4. Temperature contour at inlet velocity 0.05 m/s and magnetic field 3 tesla. (a) 1 magnet, (b) 2magnet, (c) 3 magnets.

The accompanying picture makes it evident that the exit temperature is inversely related to the fluid entrance velocity and rises as the number of magnetic coils and magnetic flux increase. This idea is inverted in Figure 5, where the velocity decreases by 0.5 m/s due to an increase in the magnetic field and the number of magnets. This is because, since the forces of movement's velocity are more than those that draw the fluid's metal particles to it, the high flow velocity acts to block the magnetic field and keep it from being impacted by heat.

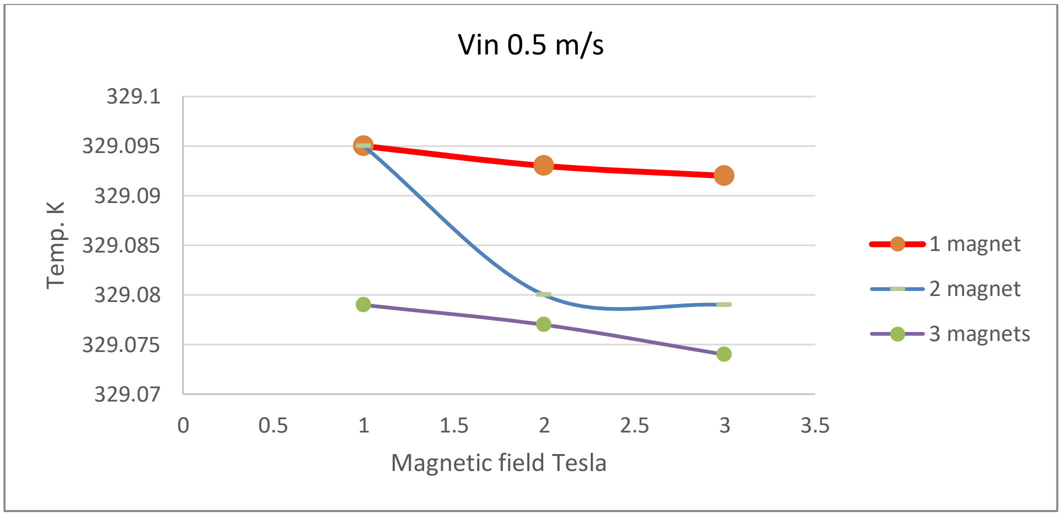
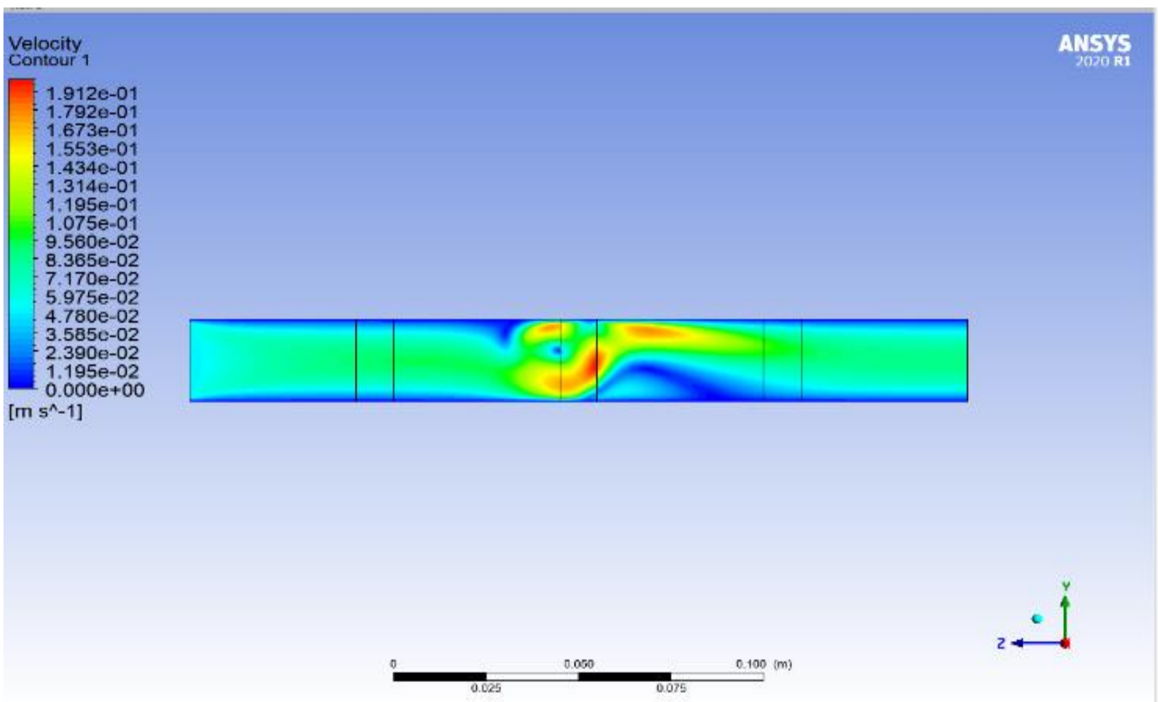
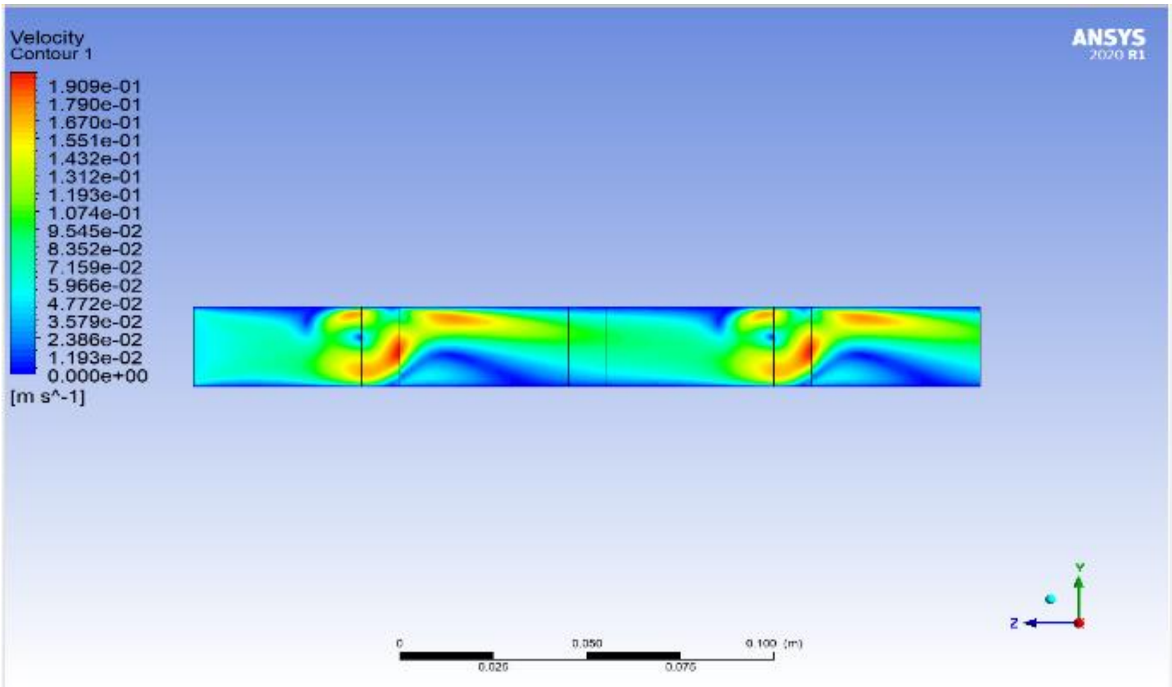


Figure 5. Temperature with magnetic field at inlet velocity 0.5 m/s.

Regarding the flow velocity vortices, it is undeniable that the temperature ratio rises as the number of vortices increases, disrupting the fluid and raising the exit temperature in the process. Figure 6 illustrates this well, showing how the number of magnets greatly influences the vortices that form during the flow.



(a)



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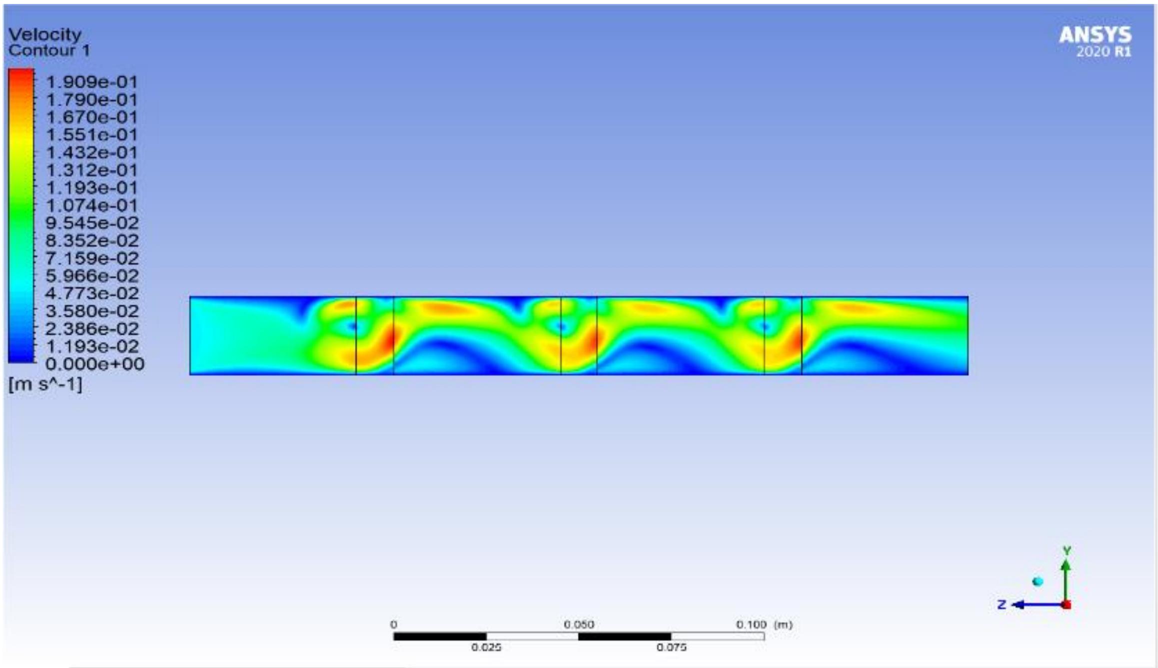
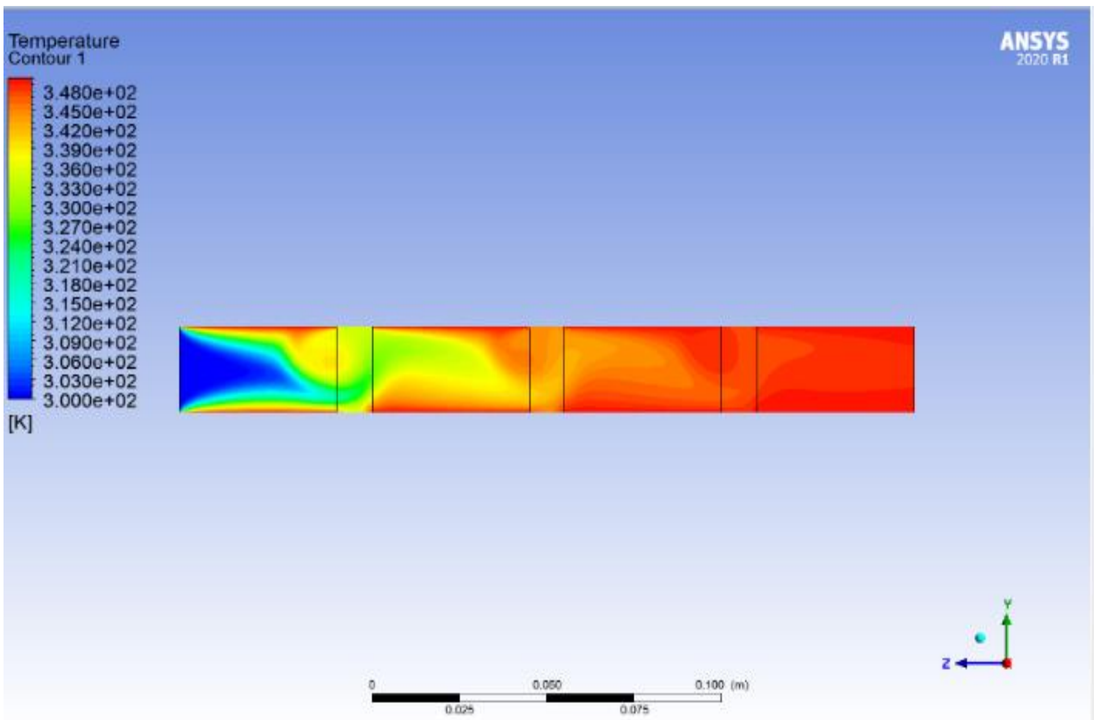


(c)

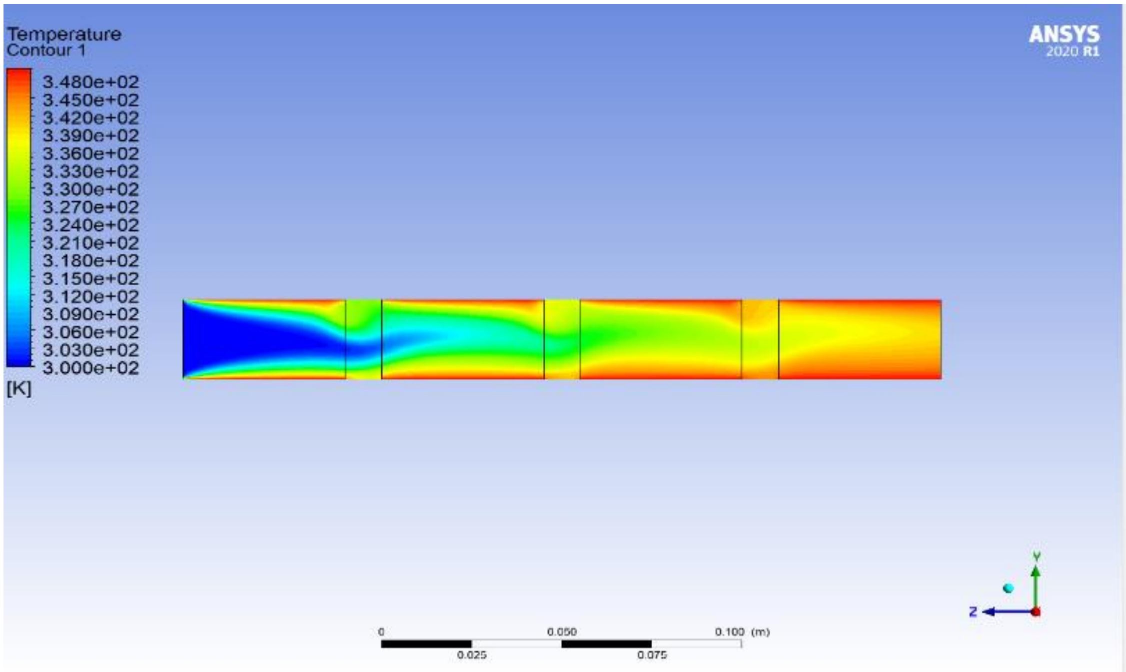
Figure 6. Velocity contour at inlet velocity 0.05 m/s and magnetic field 3 tesla. (a) 1 magnet, (b) 2magnet, (c) 3 magnets.

4.2 The impact of the entrance velocity on the vortex flow and temperature at exit

The entrance velocity is one of the major variables influencing the heat transfer values because, an increase in the fluid's flow velocity does not provide the fluid with enough time to heat up sufficiently, and there are magnets present to impede this movement and raise the turbulence level as illustrates in figure 7. In comparison to the other situations, the temperature at which the largest entrance temperatures occurred was 349.324 K, or the entry velocity of 0.05 m/s.



(a)



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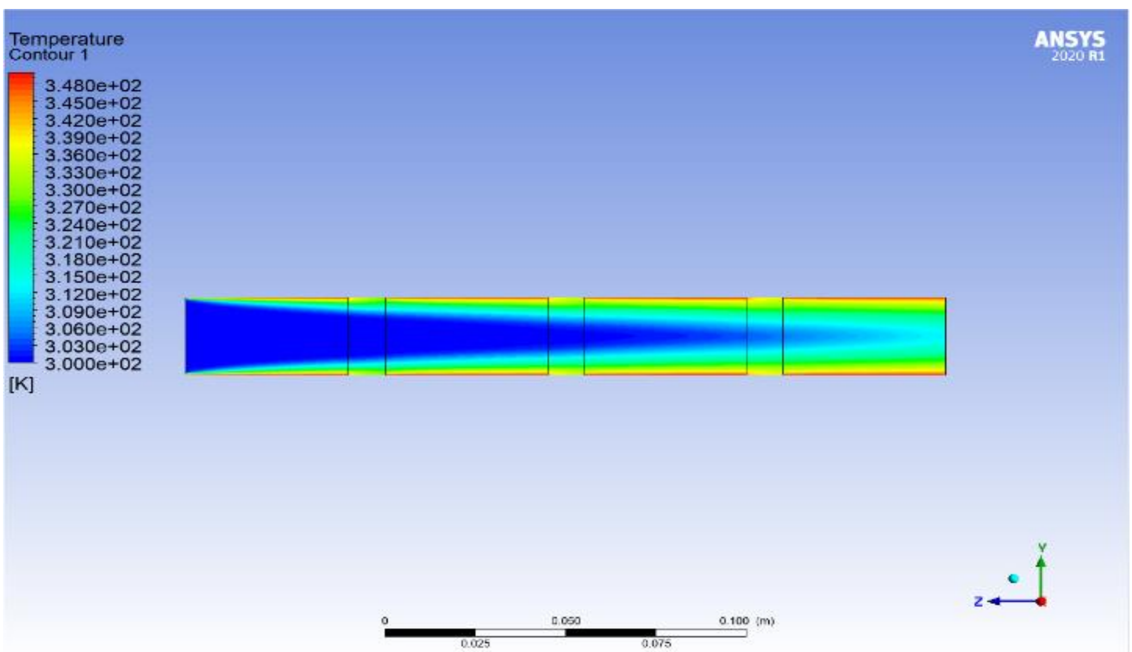
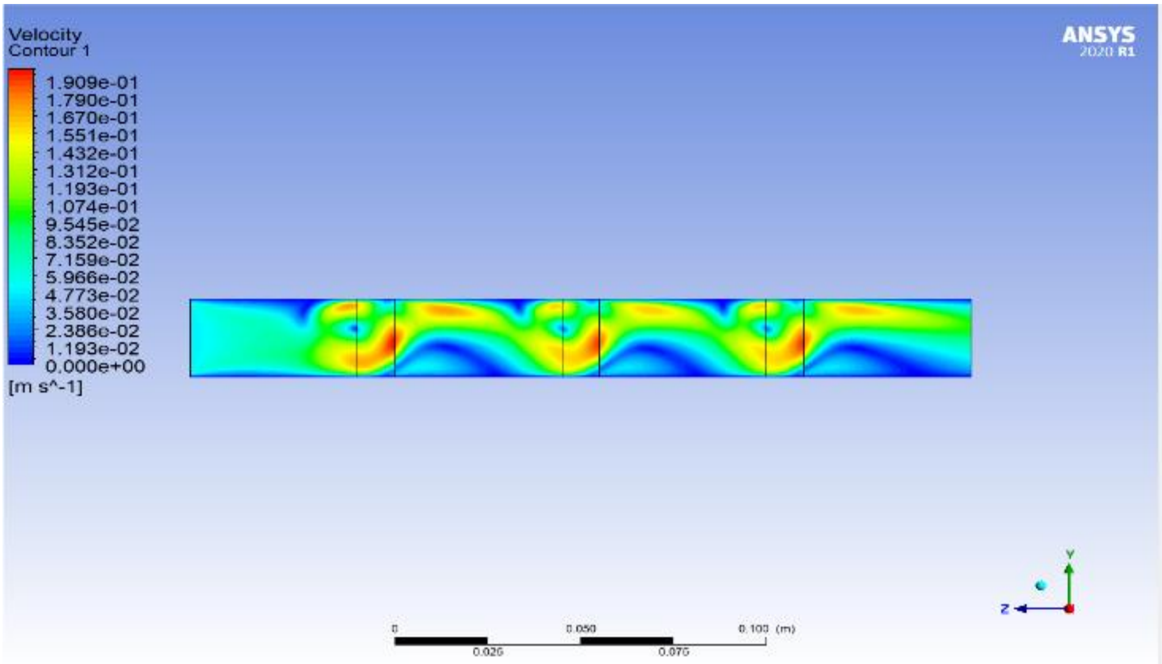


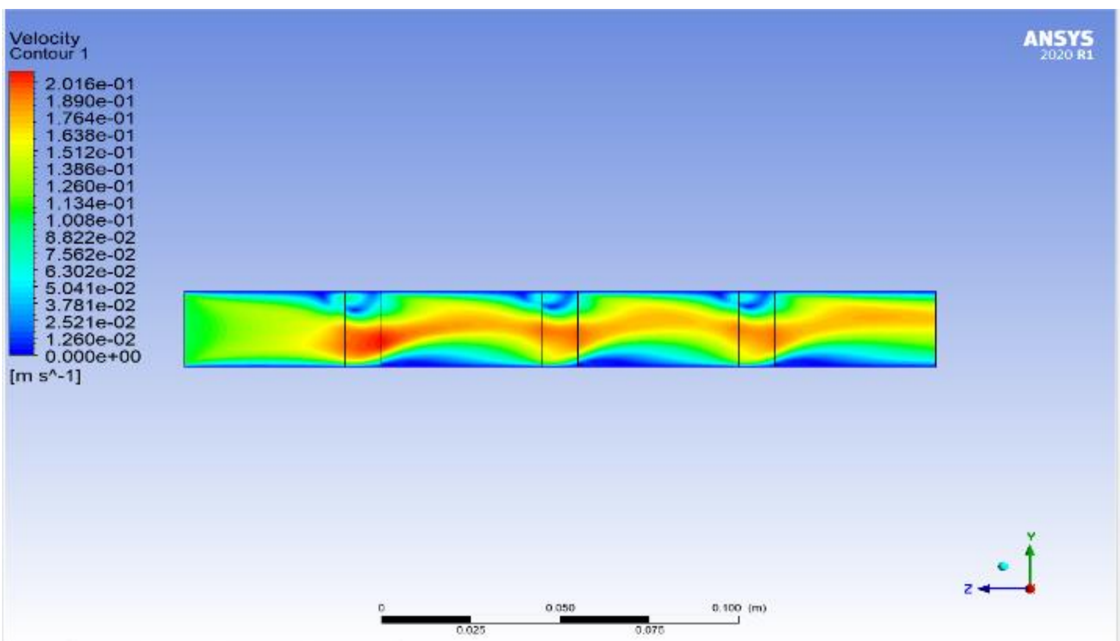
(c)

Figure 7. Temperature contour at magnetic field 3 Tesla and 3 magnets. (a) 0.05 m/s, (b) 0.1 m/s, (c) 0.5 m/s.

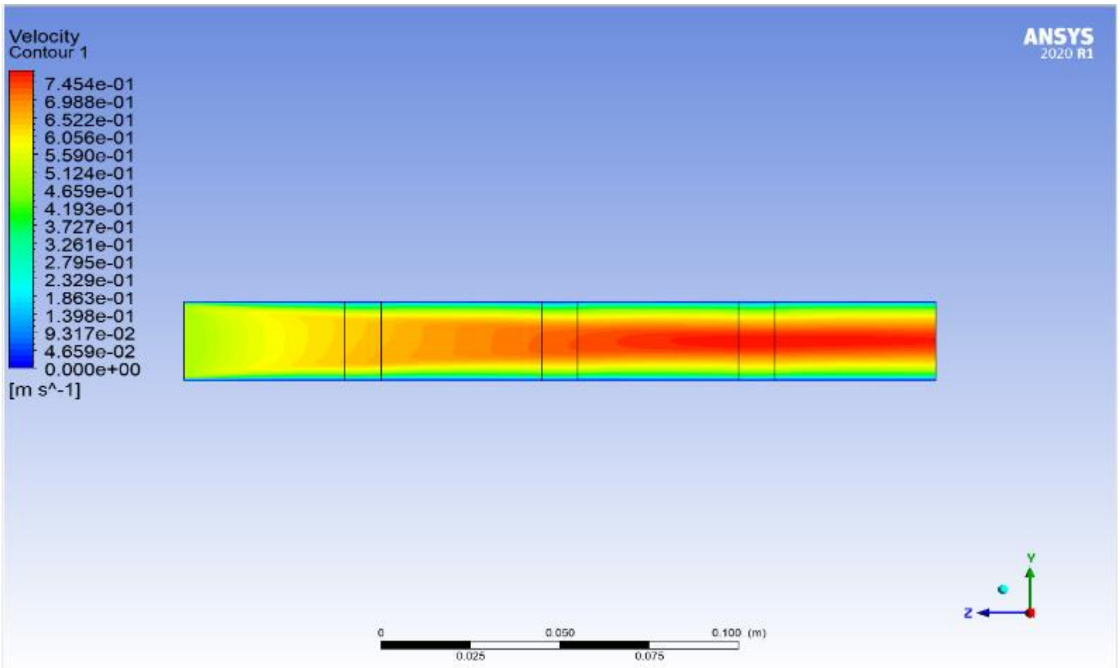
Regarding the velocity vortices, it is well known that an increase in the magnetic flux value can either attract or repel the fluid's magnetic material particles, depending on the flux's direction. This will impede the flow and cause the channel vortices to rise, as seen in figure 8.



(a)



(b)



(c)

Figure 8. Velocity contour at magnetic field 3 Tesla and 3 magnets. (a) 0.05 m/s, (b) 0.1 m/s, (c) 0.5 m/s.

5. Compare with earlier studies

The geometry used in this study was compared to other studies that used ferromagnetic materials to verify that the simulation software operated correctly. The channels at the entrance and outflow are 2 mm wide and 500 μm deep. The circular chamber measures D = 6 mm in diameter and H = 500 μm in depth. Using a laser engraving device to create the channel through a transparent double-sided adhesive tape that was 500 μm thick (the tape's brand and source). Studying the impact of the magnetic field, a 3.2 mm3 neodymium–iron–boron (NdFeB) permanent magnet cube of grade N42 was positioned adjacent to the chamber. A paramagnetic fluid, diluted water-based ferrofluid (EMG707, Ferrotec), was introduced into the apparatus. A prior measurement and report were made on the permanent magnet's magnetic field magnitude as a function of distance from the magnet. The range of the flow rate is 50–400 μL/min [16].

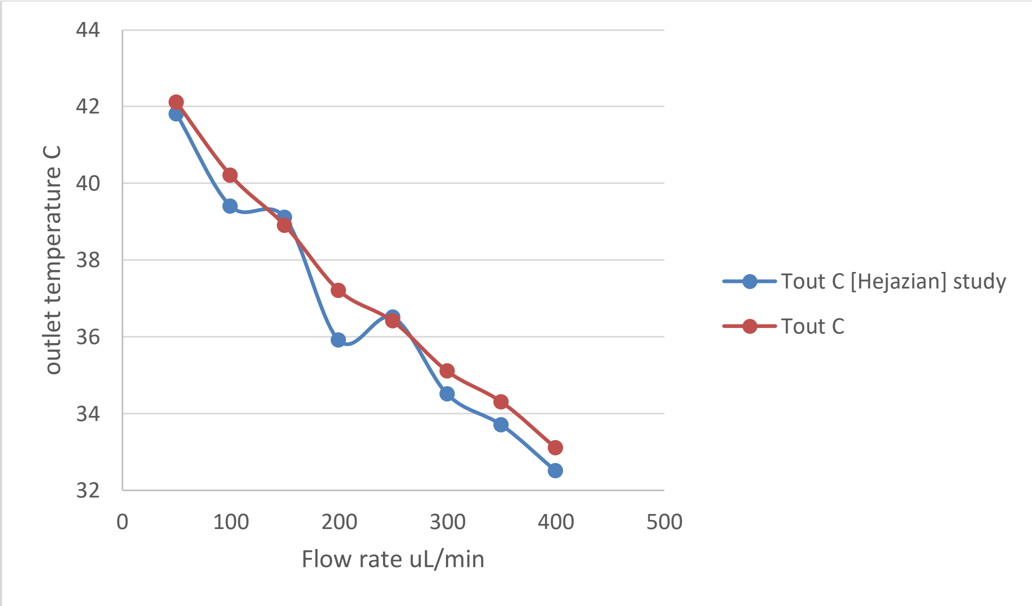


Figure 9. Outlet temperature at C with range of flow rate.

The findings of the exit temperatures were compared with the change in flow rate following the model design and configuration necessary for the comparison procedure. The findings demonstrated that there is very little, up to a 10% error rate, in the difference between the outcomes of the prior research and the simulation that was run.

6. Conclusions

From the current study, the following conclusions may be made:

1) As the number of magnets rises, the fluid turbulence value increases dramatically. The greater the number of magnets in the channel, the higher the turbulence stages, and the higher the exit temperature value.

2) The temperature ratio rises as the number of vortices that perturb the fluid increases, raising the temperature at the exit.

3) The velocity of entry is one of the primary variables in H.T values because an increase in the fluid's flow velocity does not give the fluid enough time to acquire a sufficient amount of heat for heating and because magnets are present to obstruct this movement and increase the turbulence values.

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