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Study the Forced Convection of a Hybrid Nanofluid in a Square Channel Partially Filled with a Porous Media Using the K-epsilon Turbulence Model

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Abstract

The use of joint technologies to improve the heat transfer process in engineering and industrial applications enhances the heat transfer coefficient and Nusselt number, thus increasing its thermal efficiency and performance for these applications for example (air conditioning systems, solar energy systems, storage tanks, and heat exchangers). This paper presents a numerical simulation using (the k-epsilon turbulence) model to investigate the influence of forced convection heat transfer and fluid flow for a channel (square cross-section) of a length (50 cm), width of (12 cm), and height (12 cm) partially filled with height layer (8 cm) of the porous medium (Glass Spheres of diameter 5mm) with the addition of hybrid nanofluids (HNF) to the base fluid (Engine Oil) as a combined technique to obtain the best improvement, where the three- dimensional (3D) test model was designed using the commercial code COMSOL Multiphysics 6.0 program in two cases, the first does not contain any addition to the improvement, and the second contains the joint techniques (porous media and HNF), the governing equations for the turbulent flow of the fluid (mass conservation equation, momentum conservation equation, energy conservation equation) were solved. The results showed that the temperature, velocity, and pressure distribution of the base fluid in a test section increases significantly using these techniques and enhances the heat transfer coefficient compared to the results for the test section without these additions. In addition, the temperature distribution increases with the increase in the axial length of the fluid flow in the test section of the channel. The results of this study also showed that the porous material leads to obstruction of the fluid flow, and thus the thickness of the boundary layer decreases, and the shape of the temperature and velocity distribution changes along the test section.

Keywords: Forced Convection, Partially Filled, Hybrid Nanofluid, Porous Media, Square Channel, k-epsilon turbulence model.

1. Introduction

Porous medium technology has been used in many different industrial and engineering applications such as fluid flow in channels, pipes, heat exchangers, solar energy systems, electronic devices, etc. to improve efficiency and performance by improving the heat transfer coefficient and thus increasing the Nusselt number**.** However, in recent years combined techniques have been used to obtain high thermal performance for systems and devices used in various engineering fields. One of these technologies is the use of a hybrid nanofluid with a porous medium. Several researchers have addressed in their previous investigations the use of these combined techniques in different channels and applications. Iskandar Waini et al. [1] This research dealt with a theoretical study of mixed convection in a horizontal surface immersed in a porous medium. Hybrid nanoparticles consisting of alumina (Al_2O_3) and copper (Cu) were added in certain proportions to improve the properties of the base fluid (water) to obtain high thermal performance for the application used. The study showed that the addition of hybrid nanoparticles to the base fluid leads to a delay in the separation of the adjacent layer. Kaouther Ghachem et al. [2] This research paper includes a theoretical study by adding hybrid nanofluids to counterflow in a small three-dimensional heat exchanger with wavy rectangular channels numbering ten at the top five and at the bottom five. All surfaces of the heat exchanger are insulated by a thermal insulator. The hot nanofluid passes through the upper channels while the cold passes through the lower channels. The results showed the highest thermal efficiency achieved at (Number of wave N=8, volume fraction $\varnothing = 5\%$, inlet fluid velocity u=50 mm/s). Mohammad Ghazvini, and Hossein Shokouhmand [3] This research focuses on conducting a numerical study of heat transfer by forced convection in a micro-channel. Nanofluids, which are copper oxide (CuO), were added to the basic fluid (water) as a technique to improve the heat transfer process. Two methods were used, the first is the presence of fins, and the other is the use of a porous medium to compare them. The parameters that have been studied for this research paper and their effect on the temperature distribution and the heat transfer coefficient are both (Reynold number, porosities, particle of volume fraction, and different channel aspect ratio). Mohsen Izadi et al. [4] This research presents a numerical study of heat transfer by free convection within a square-shaped space that is thermally insulated from the top and bottom. Where the hybrid nanofluids were used by mixing it with the base fluid and in the presence of the porous medium as a dual technique to improve the heat transfer process and thus increase the heat transfer coefficient and the Nusselt number. This study focused on the impact of each of the following (Darcy number, Raylieigh number, porosity, and ratio of thermal conductivity) on thermal patterns of fluid flow. Kamel Milani Shirvan et al. [5] This research conducted a numerical study of two-dimensional flow on turbulent heat transfer and improved the efficiency of the heat exchanger of the double pipe type filled with porous medium with the addition of nanofluids as another means of improvement. The research results showed that the Nusselt number increases with the increase in the Reynolds number and decreases with the study number and the thickness of the porous material. P. R. Mashaei et al. [6] This research studies the effect of fluid flow properties and forced convection heat transfer in a cylindrical heat pipe by adding hybrid nanoparticles ($Al_2 O_3$), which is a mixture with the porous material, to the base fluid to improve the thermal properties of the pipe. Huijin Xu [7] Conceptually examined the flow and heat transfer in microchannels with micro-/Nano porous media, and by taking into account the LTNE effect and the slip boundary, analytical solutions for velocity and temperature were produced. It examined how heat moved inside multi-layered porous-medium microchannel heat exchangers. For parallel-flow/counter-flow configurations, the two fluids' local temperature distributions were found. D.A. Nield [8] Analytical research is done on the initiation of convection in a horizontal layer of a porous material saturated with a nanofluid. The effects of Brownian motion and thermophoresis are taken into account in the nanofluid model. According to the research, a typical nanofluid's (high Lewis number) primary influence is through a buoyancy effect paired with nanoparticle conservation, with nanoparticles' contribution to the thermal energy equation being a second-order effect. It is discovered that depending on whether the fundamental nanoparticle distribution is top-heavy or bottom-heavy, the presence of the nanoparticles can significantly lower or raise the critical thermal Rayleigh number. If the distribution of nanoparticles is bottom-heavy, oscillatory instability may occur. Sabah R. Mahdi, and Suhad A. Rasheed [9] This research deals with a practical study of heat transfer by internal forced convection of a channel with a triangular cross-section filled with porous medium to enhance the heat transfer process and improve the transfer coefficient and Nusselt number. The temperature increases gradually along the axis of fluid flow, and the Nusselt number increases gradually with an increase in the Reynolds number. These results were compared to the same channel without the presence of the porous material. The current research focuses on studying the heat transfer of the internal flow of a channel with a square cross-section that is partially filled with a porous medium consisting of homogeneous glass balls. A hybrid nanofluid was added as a secondary addition to improve the heat transfer process of this channel.

2. Description of the Problem

The heat transfer through the square channel is forced convection, where the three-dimensional test section was designed with a length of (0.5 m), a width of (0.12 m), a height of (0.12 m), and a hydraulic diameter of (0.12 m). The uniform heat flux was exposed at the bottom of the test section of (3000 W / m^2), and the fluid (Engine Oil) flow through the test section of (0.08 m/s). The test section was designed in two cases. The first was without the porous medium and the second was with the presence of a layer of porous medium with a height of (0.08m) and the addition of hybrid nanoparticles to compare the two cases as shown in Figures (1, and 2) below.

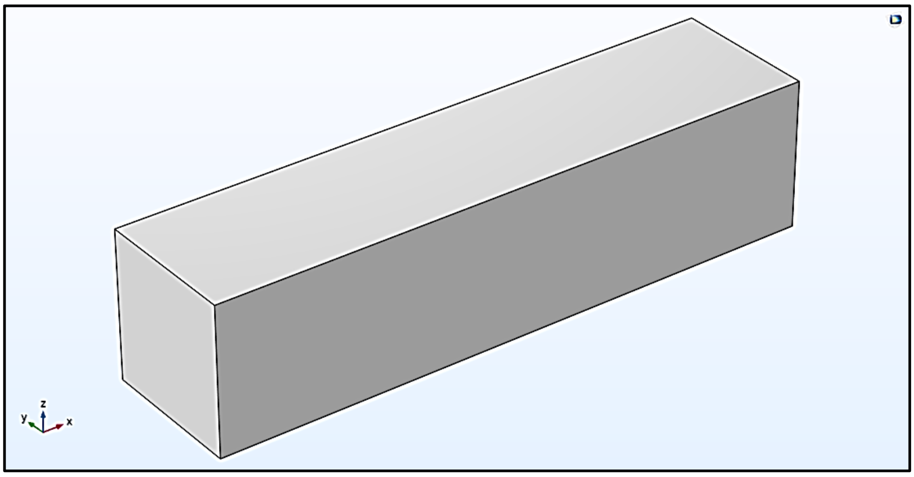

Figure 1 3D model of a test section without porous media and HNF.

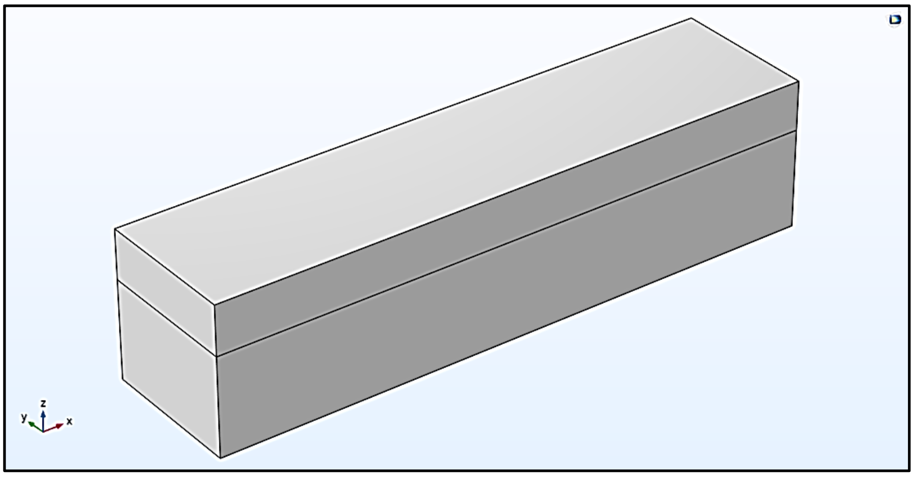

Figure 2 3D model of a test section with a layer (0.08 m) of porous media.

3. Properties of HNF

The (MoS_2+ZnO) nanoparticle additives in a base fluid (Engine Oil) under realization were regarded as a Newtonian fluid, single-phase flow and an isotropic flow. The effective thermal properties of a base fluid specific heat capacity (Cpnf), density (ρ_{nf}), dynamic viscosity (μ_{nf}), and thermal conductivity (k_{nf}) of a hybrid nonfluid were calculated using the following Equations [10,11]:

The volume fraction of an HNF:

$$\varnothing_{hybrid-nanofluid}=\varnothing_{nanoparticle1}+\varnothing_{nanoparticle2} \tag{1}$$

The density of an HNF:

$$\rho_{hnf}=\rho_{np1}\varnothing_{np1}+\rho_{np2}\varnothing_{np2}+(1-\varnothing_{hnf})\rho_{bf} \tag{2}$$

The specific heat of an HNF:

$$Cp_{hnf}=\frac{\varnothing_{np1}\rho_{np1}Cp_{np1}+\varnothing_{np2}\rho_{np2}Cp_{np2}+(1-\varnothing_{hnf})\rho_{bf}Cp_{bf}}{\rho_{hnf}} \tag{3}$$

The viscosity of an HNF:

$$\mu_{hnf}=\frac{\mu_{bf}}{(1-\varnothing_{np1}-\varnothing_{np2})^{2.5}} \tag{4}$$

The thermal conductivity of an HNF:

$$k_{hnf}=k_{bf}\,\frac{(\frac{\varnothing_{np1}k_{np1}+\varnothing_{np2}k_{np2}}{\varnothing_{total}})+2k_{bf}+2(\varnothing_{np1}k_{np1}+\varnothing_{np2}k_{np2})-2(\varnothing_{total}k_{bf})}{(\frac{\varnothing_{np1}k_{np1}+\varnothing_{np2}k_{np2}}{\varnothing_{total}})+2k_{bf}-(\varnothing_{np1}k_{np1}+\varnothing_{np2}k_{np2})+(\varnothing_{total}k_{bf})} \tag{5}$$

Table 1 Physical and thermal properties of a based fluid (Engine Oil) and nanofluids [12].

Physical properties	**Nanoparicle1 (MoS_2)**	**Nanoparicle2 (ZnO)**	**Based on Fluid (Engine Oil)**
	Volume fraction = 3%	**Volume fraction = 1%**	
Density (kg/m^3)	5060	5600	884
Heat Capacity (J/kg. K)	397.21	495.2	1910
Thermal Conductivity (W/m^2. K)	904.4	13	0.144
Dynamic Viscosity (Pa. s)	----------------	----------------	0.7994

Table 2 Physical and thermal properties of an HNF.

Property	HNF (MoS_2 + ZnO)
	Volume fraction (0.03+0.01) = 0.04
Density (kg/m^3)	1056.44
Heat Capacity (J/kg. K)	1617.6309
Thermal Conductivity (W/m^2. K)	0.162
Dynamic Viscosity (Pa.s)	0.8848

4. Creating Mesh of Problem Statement

The type of mesh used in this problem is (Normal) for two cases, as shown in Figures (3, and 4) below. The mesh number increased when the porous material layer was placed due to the increase in the number of edges without the presence of this layer.

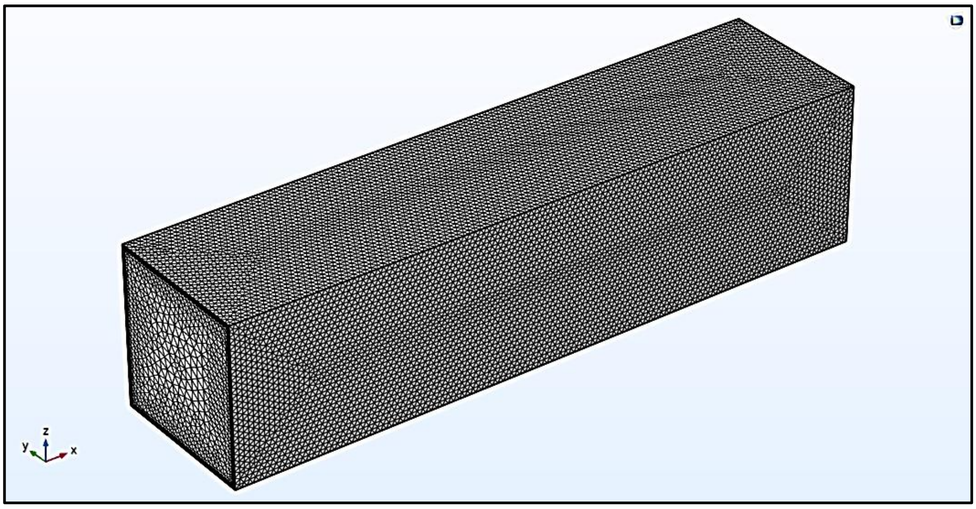

Figure 3 Mesh of a 3D model for a test section without porous media.

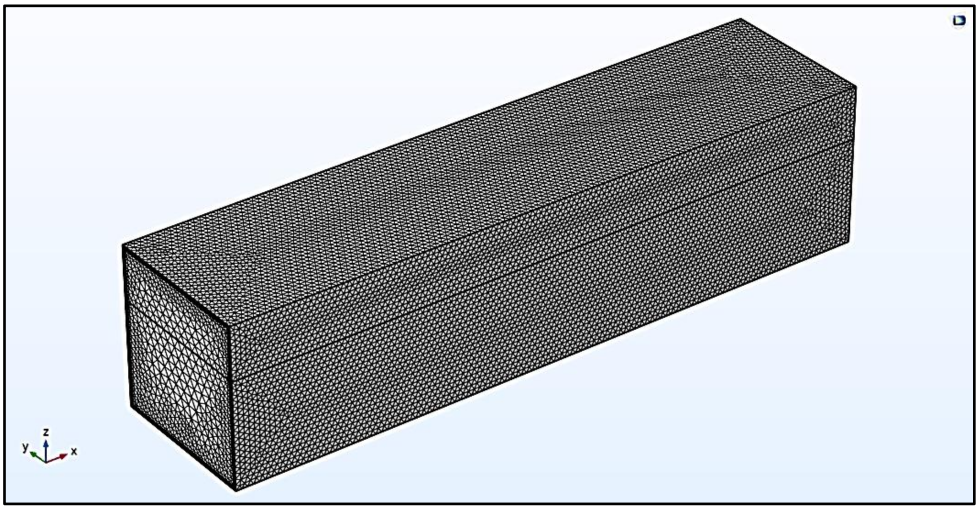

Figure 4 Mesh of a 3D model for a test section with a layer (0.08 m) of porous media.

5. Converging of Problem Statement in COMSOL Multiphysics

Figures (5, and 6) below represent the convergence of the error rate with the number of trials for the numerical solution using the COMSOL Multiphysics program for each of the temperatures, pressure, and speed for the two cases studied, the first is an empty channel and the second is partially filled with porous medium with a hybrid nanofluid.

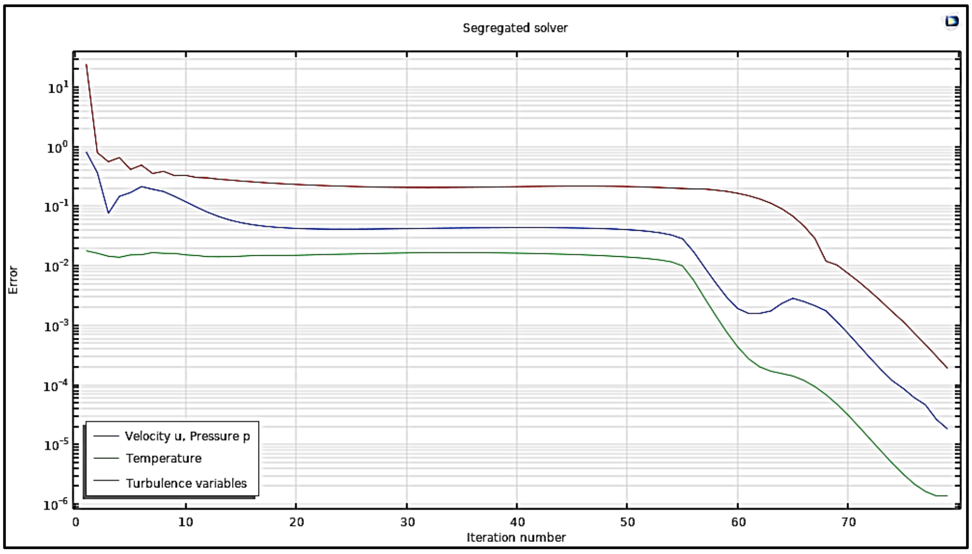

Figure 5 Converging plot of a channel (test section) without any additives.

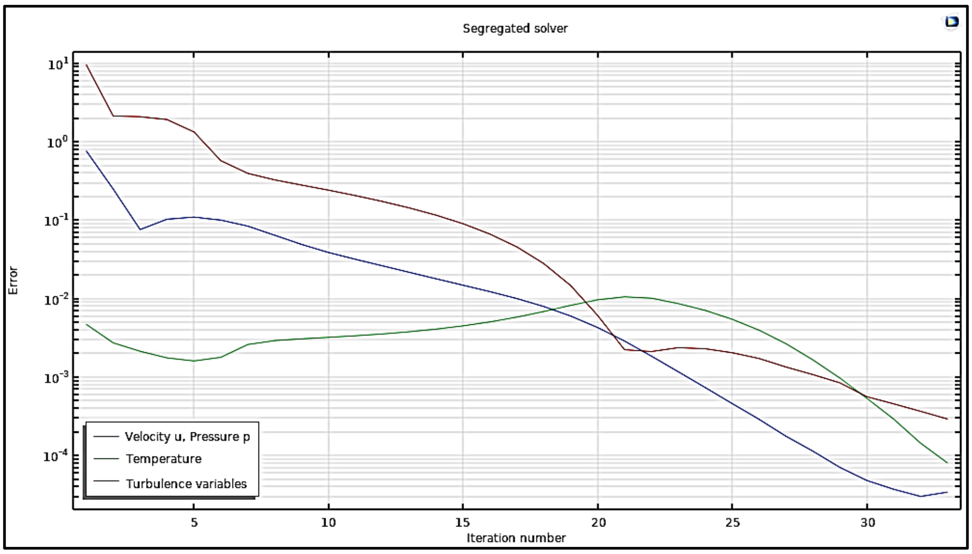

Figure 6 Converging plot of a channel (test section) with porous media and HNF.

6. Results and Discussion

6.1 Temperature, Velocity, and Pressure Distribution of a Fluid Flow

The Figures (7 to 12) below represent the temperatures, velocity, and pressure distribution of the fluid flow in the channel (test section) for two different cases. The first is without the porous medium and the addition of nanoparticles. The second is the presence of a porous medium layer at a height of (0.08 m) with the addition of hybrid nanofluids in certain proportions with the base fluid (Engine Oil). We note that the temperatures, velocity, and pressure distribution increase by adding these improvements to the base fluid.

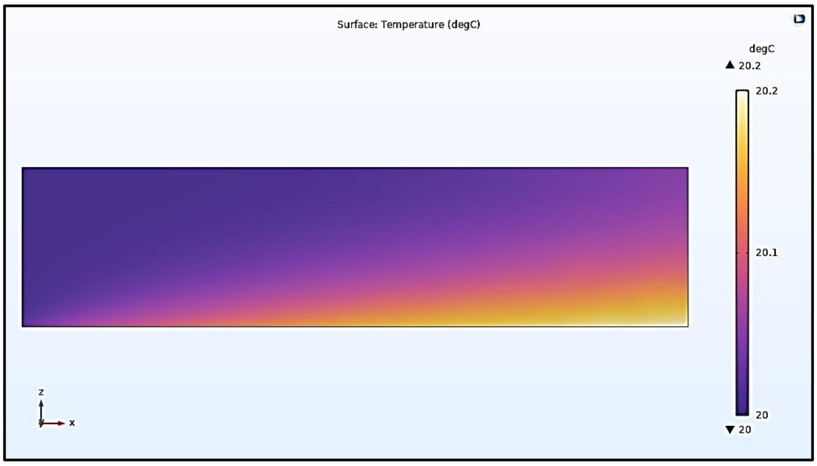

Figure 7 2D of surface temperatures for a test section without porous media and HNF.

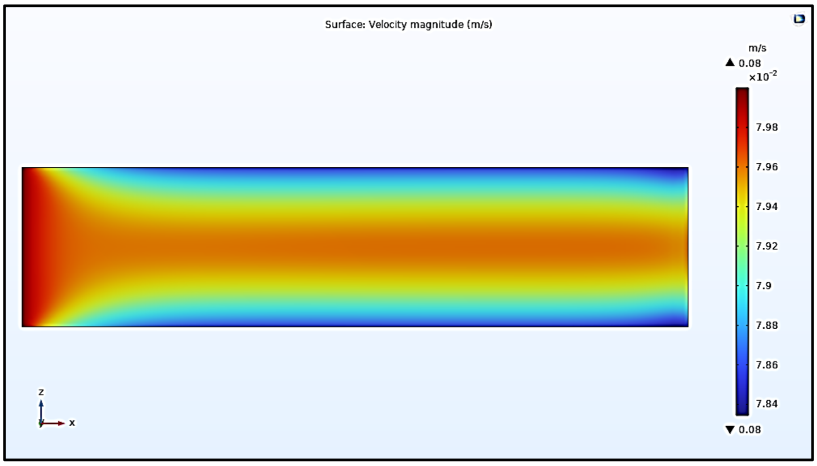

Figure 8 2D of surface velocity for a test section without porous media and HNF.

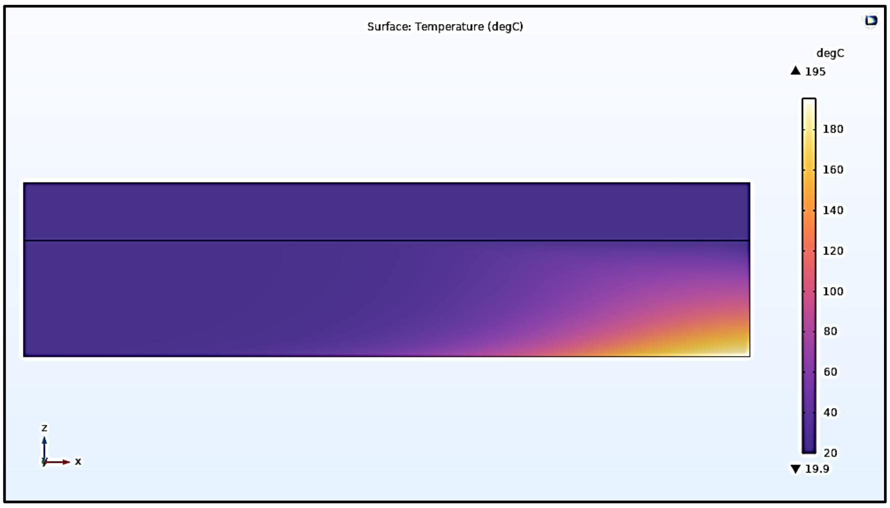

Figure 9 2D of surface temperatures for a test section with layer (0.08 m) of porous media and HNF (MoS_2 +ZnO).

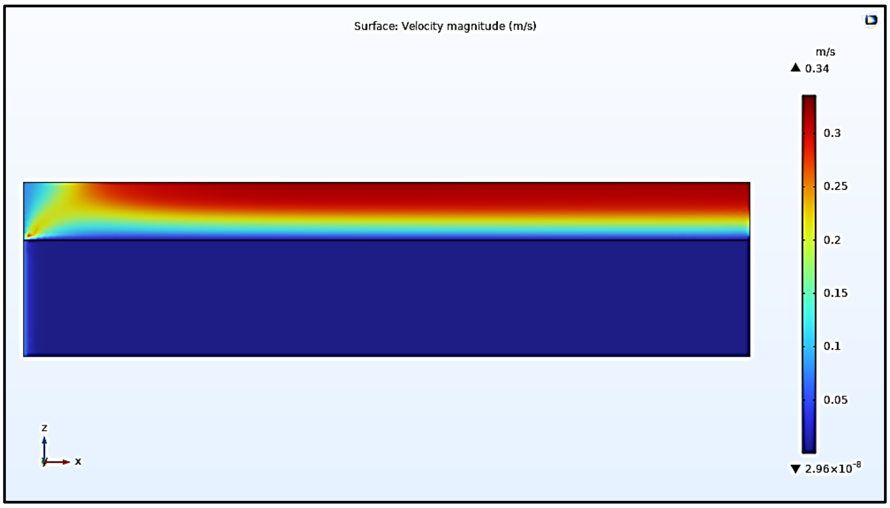

Figure 10 2D of surface velocity for a test section with layer (0.08 m) of porous media and HNF (MoS_2 +ZnO).

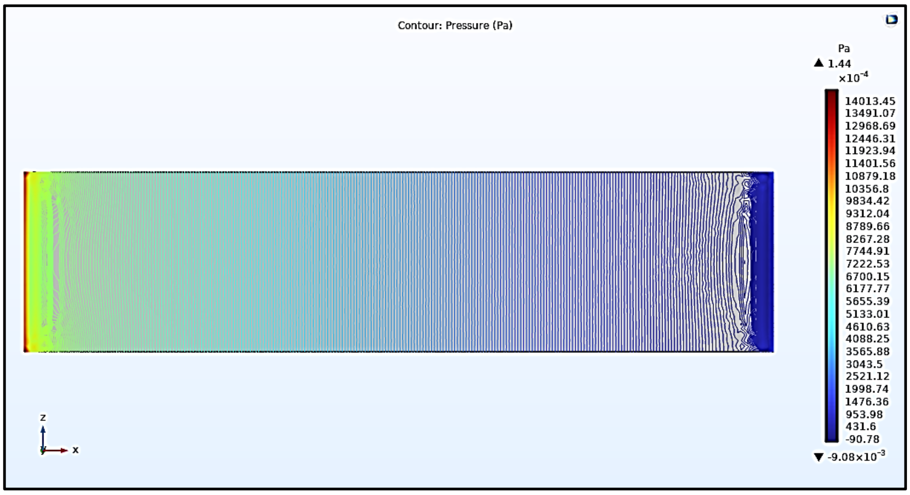

Figure 11 2D of surface pressure for a test section without porous media and HNF.

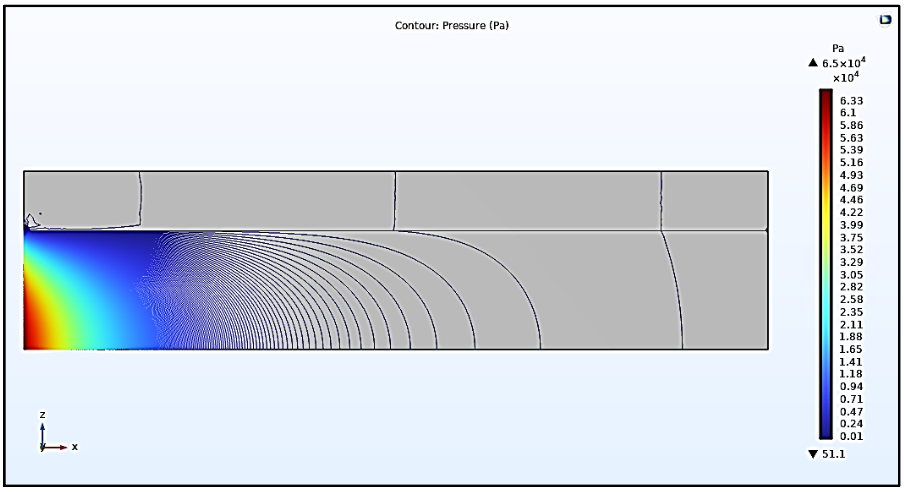

Figure 12 2D of surface pressure for a test section with layer (0.08 m) of porous media and HNF (MoS_2 +ZnO).

6.2 Comparison of Present Work with Previous Studies

Figure (13) represents the distribution of temperatures along the test section of a channel at a distance (0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45 m) respectively. We notice an increase in temperatures with the length of the test section. In addition, the temperatures increased when the porous material and hybrid nanomaterials were present. The temperature distribution was compared in the case of not using the porous material and in the case of using it with previous studies [9] of the same phenomenon, and the results showed that it exhibits the same behavior in terms of increase, as shown in the Figure (14) below. Details of the comparison of the current study with the previous study are shown in the attached Table (3) below.

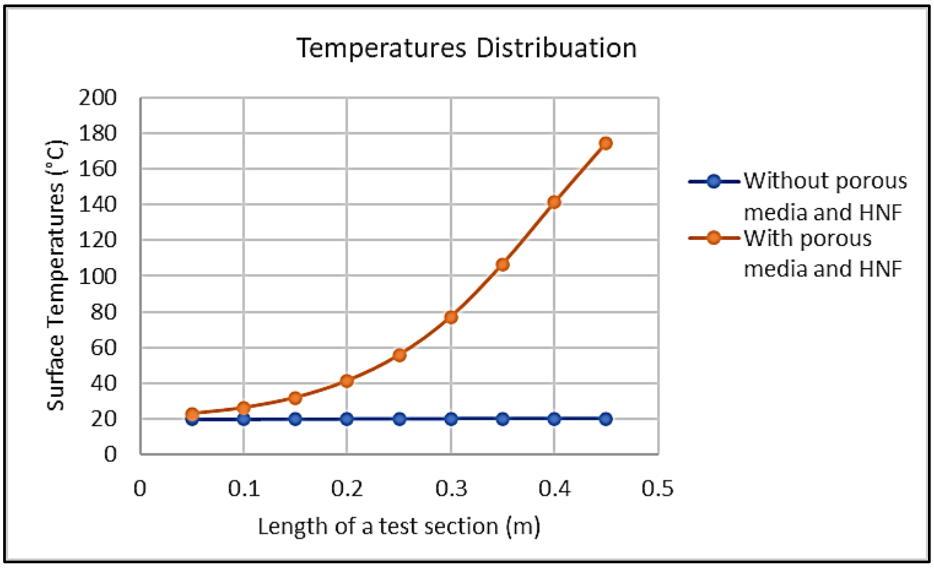

Figure 13 Surface temperatures with the length of a channel for nine points at the lower test section.

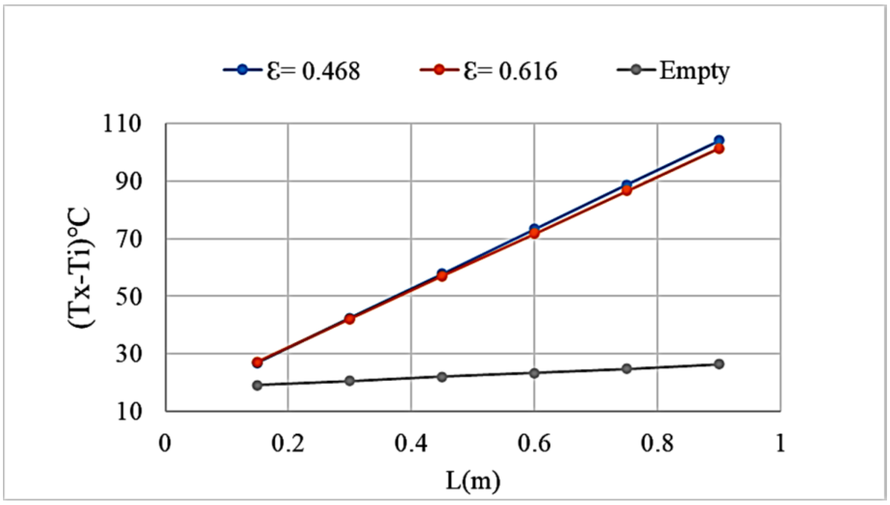

Figure 14 Temperatures distributions against the length of the test section for previous work [9].

Table 3 Some details of the compassion process in the current study with privies work.

Authors	**Working Fluid**	**Type of Porous Media**	**Type of Study**	**Cross-section of a Channel**
Present Work	Engine oil	Glass spheres	Numerical	Triangular
Sabah R. Mahdi, and Suhad A. Rasheed [9]	Air	Glass spheres	Experimental	Square

6.3 Effect of Porous Media on Boundary layer

Figures (15 to 18) below represent the temperature and velocity distribution diagram of the fluid flow through the test section of the square channel. We notice that the porous material obstructs the flow of the fluid, which leads to deformation of the velocity and temperature diagram, so the thickness of the boundary layer decreases, and the friction coefficient increases.

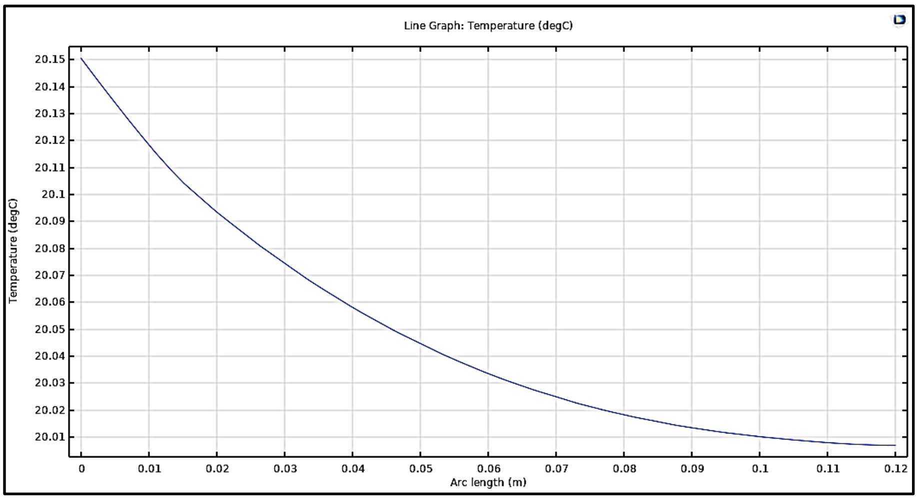

Figure 15 Temperature distribution against the height of a test section without any additives.

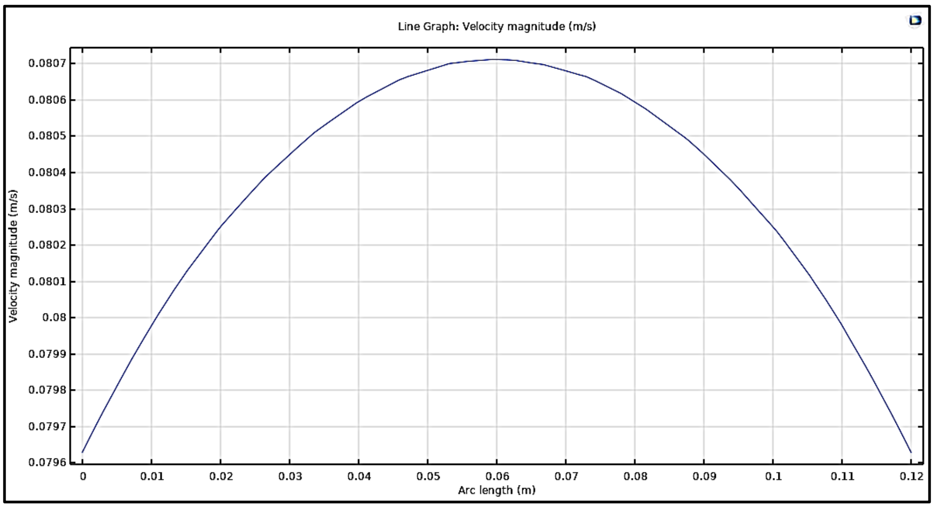

Figure 16 Velocity distribution against the height of a test section without any additives.

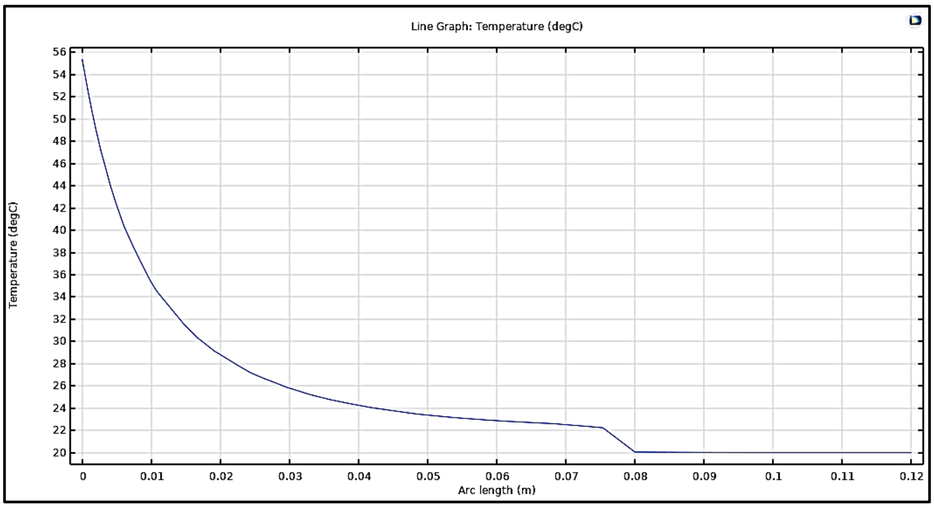

Figure 17 Temperature distribution against the height of a test section with porous media and HNF.

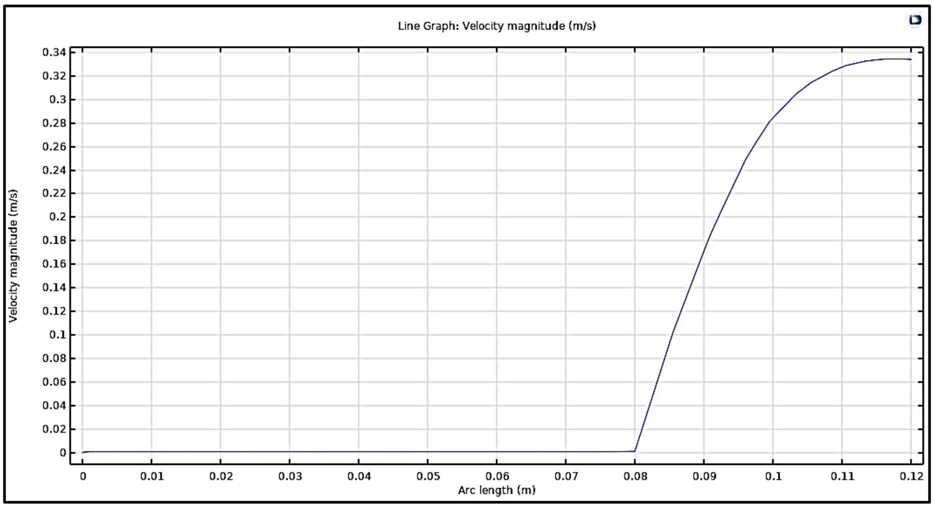

Figure 18 Velocity distribution against the height of a test section with porous media and HNF.

7. Conclusions

The following points were recorded and concluded from the current research**:**

1. The temperature and velocity distribution of the test section increased (89.64 %) with the presence of the porous material and the addition of the hybrid nanofluids.
2. The pressure distribution of the base fluid increases (98.82 %) with the addition of hybrid nanofluids.
3. The addition of hybrid nanofluids to the base fluid improved its physical and thermal properties, and thus increased the temperature distribution and velocity of the fluid flow inside the channel (Test Section).
4. The temperature distribution increases gradually and significantly in the presence of the porous material and the hybrid nanofluids with the length of the test section.
5. When conducting a comparison of the current study with previous studies of the locational temperature distribution along the test section, it showed that it follows the same behavior in terms of increase.

8. Recommendations

The points below are some suggestions for current work for its development**:**

1. Study the effect of changing the type of porous material on the temperature and velocity distribution of the fluid.
2. Studying the effect of changing the type of hybrid nanofluids on the temperature and velocity distribution of the base fluid, for example using aluminum oxide with copper oxide (Al_2O_3+CuO).
3. Studying the effect of changing the shapes of the channel on the temperature distribution to compare which one gives the best temperature distribution, for example, the triangle, rectangle, or circular shape.

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دراسة الحمل الحراري القسري لسائل نانوي هجين في قناة مربعة مملوءة جزئيًا بوسائط مسامية باستخدام (k- epsilon turbulence model)

الخلاصة: *استخدام التقنيات المشتركة لتحسين عملية انتقال الحرارة في التطبيقات الهندسية والصناعية يعزز من معامل انتقال الحرارة وعدد نسلت وبالتالي تزداد كفائتها الحرارية وادائها مثال عن هذه التطبيقات (المبادلات الحرارة , انظمة الطاقة الشمسية, انظمة تكييف الهواء, خزانات الماء وغيرها). يقدم هذا البحث دراسة عددية باستخدام نموذج (**k-epsilon turbulence**) للتحقق من تأثير انتقال الحرارة بالحمل القسري وجريان المائع لقناة ذات مقطع عرضي مربع الشكل مسلط عليها اسفل مقطع الاختبار فيض حراري منتظم مقدارة (3000 واط / م^2) و مملوءة جزئيا بطبقة ارتفاع (8 سم) بالوسط المسامي (كرات زجاجية بقطر 5 ملم) مع اضافة السوائل النانوية الهجينة (**MoS_2+ZnO**) للمائع الاساسي (زيت) كتقنية مشتركة للحصول على افضل تحسين للاداء. حيث تم تصميم نموذج ثلاثي الابعاد (**x, y, and z**) لمقطع الاختبارالخاص بالقناة باستخدام برنامج (**Commercial Code COMSOL Multiphysics 6.0**) بحالتين الاولى لايحتوي على اي اضافة للتحسين والثانية يحتوي على التقنيات المشتركة (الوسط المسامي واضافة السوائل النانوية الهجينة) وتم حل المعادلات الحاكمة الخاصة بالجريان المضطرب للمائع (معادلة حفظ الكتلة ,معادلة حفظ الزخم, معادلة حفظ الطاقة). اظهرت نتائج هذه الدراسة ان توزيع درجات الحرارة والسرعة والضغط لجريان المائع (زيت) عبرمقطع الاختبار للقناة يزداد بشكل ملحوظ باستخدام هذه التقنيات ويعزز من معامل انتقال الحرارة مقارنة بالنتائج التي تم الحصول عليها لنفس مقطع الاختبار بدون هذه التحسينات, اضافة لذلك ان توزيع درجات الحرارة يزداد بزيادة الطول المحوري لسريان المائع في مقطع الاختبار للقناة. وبينت نتائج هذه الدراسة ايضا ان المادة المسامية تؤدي الى عرقلة جريان المائع وبالتالي يقل سمك الطبقة الحدودية ويتغيير شكل توزيع درجات الحرارة والسرع على طول مقطع الاختبار مع ملاحظة زيادة معامل الاحتكاك.*