Hybrid Analysis of Micropolar Ethylene-glycol Nanofluid on Stretching Surface Mounted Triangular, Rectangular and Chamfer Fins by FEM Strategy and Optimization with RSM Method

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Abstract
This paper analysis heat transfer and angular velocity of micropolar ethylene-glycol nanofluid over the triangular, rectangular and chamfer fins on the stretching sheet. The innovation of this paper is to investigate parameters of nanofluid flow passing from the different fins on the stretching surface. The finite Element Method is selected for solving governing equations. The nanofluid temperature in the space of fins is warm and equal to the surface temperature. The temperature value is 30 degrees. The maximum values of nanofluid temperature exist in the last fin of surfaces. By passing the nanofluid flow from the first fins of the surface, the temperature of flow comes from 25℃ to 31℃ and at the ends of the surface, the temperature is high value. The maximum of ethylene glycol angular velocity occurs at x=0.9 for chamfer and rectangular modes and the minimum of temperature occurs at x=0.8 for 3 different fins. The angular velocity for nanofluid on the triangular and chamfer modes is 6.5% bigger than other baffles.

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NOMENCLATURE

| Symbol | Description |
|--------|-------------|
| H | Distance the plates (m) |
| C | Nanofluid concentration |
| K | Dimensionless temperature |
| x, y | Coordinates (m) |
| u, v | Velocity components (m/s) |
| Tc | Temperature of the cold wall (K) |
| ΔT | Temperature difference |
| Nb | Brownian motion |
| T | Temperature |
| ρ | Density (kg/m³) |
| μ | Dynamic viscosity (kg/m. s) |
| β | Thermal expansion (1/K) |
| α | Thermal diffusivity (m²/s) |
| Cp | Specific heat at constant pressure (J/kg.k) |
| V | Kinematic viscosity (m²/s) |
| k | Thermal conductivity (W/m.k) |
| P | Modified fluid pressure |
| ∅ | Dimensionless concentration |
| g | Gravitational acceleration (m/s²) |
| φ | Electrical conductivity (s/m) |
| Pr | Prandtl number (υ/α) |
| B0 | Magnetic field intensity |
| Nt | Thermo-phoretic parameter |
| σnf | Ferrofluid electric conductivity |

1. INTRODUCTION

Thread stretching sheet with different fins at steady-state two-dimensional flow of a micropolar/classical ferro-fluid was investigated. A ferrofluid is a form of fluid that exists in which micro particles of iron, magnetite, or cobalt. Ferrofluids are made-up of magnetic iron pieces suspended in oil, commonly kerosene, with a surfactant...
to prevent oleic acid. Ferrofluids and nanofluids are used in rotary seals in computer hard drives and other rotating shaft motors [1–9]. 

Ţălu et al. [10] investigated the fractal geometry of internal thread surfaces manufactured by cutting tap and rolling tap. The application of fractal geometry in internal threads surface characterization to disclose fault fine structures of the internal thread geometry caused by the manufacturing process is briefly presented in this work. Zheng and Dai [11] studied a new finite element method for computing structural stochastic responses of linear problems. The method decouples the stochastic response into a sequence of deterministic responses with random variable coefficients and gives a new expansion of stochastic response. Pasha et al. [12] investigated the analytical solution of non-Newtonian second-grade fluid flow by VIM and ADM methods on a stretching sheet. This study aimed at investigating the variation of heat transfer and velocity changes of the fluid flow along the vertical line on a surface drawn from both sides. Coggon [13] have reviewed electromagnetic and electrical modeling by the finite element method. The finite element approach is based on energy minimization in the solution of physical problems; in this case, electromagnetic energy is minimized. Numerical and analytical comparison of the stability and instability of angular motion of a bar drawn by a spring by AGM method reviewed by Pasha et al. [14]. Krishna et al. [15] have researched Hall and ion slip effects on unsteady MHD free convective rotating flow through a saturated porous medium. The present study has an immediate application in understanding the drag experienced at the heated and inclined surfaces. Tripathy et al. [16] investigated the chemical reaction effect on MHD free convective surface over a moving vertical plate. In this research, the nonlinear partial differential equations were transformed into a two-point limit value problem with the help of similarity and t variables. Sarkar and Sahoo [17] studied the unsteady MHD flow on a stretchable rotating disk with heat transfer. Turner and Weidman [18] investigated Homann stagnation-point flow impinging on a biaxially stretching surface. The normal impact of the axial flow of the Homann stagnation point on a surface running perpendicularly, planar, biaxial is investigated. Application of numerical methods in micropolar fluid flow and heat transfer in permeable reviewed by Pasha et al. [19]. Thread stretching sheet with different fins at steady-state two-dimensional flow of a micropolar/classical ferrofluid was investigated [20–32]. This paper analysis heat transfer and angular velocity of micropolar ethylene-glycol nanofluid over the triangular, rectangular, and chamfer fins on the stretching sheet and investigated the magnetism effect around the different fins. The innovation of this paper is to investigate parameters of nanofluid flow passing from different positions of the fins (rectangular, triangular and chamfer fins) on the stretching surface. The structure of this paper is a study on the differential equations of ethylene glycol nanofluid by finite element strategy. By this strategy, the magnetic parameter, velocity, and temperature of the nanofluid were studied in separate contours. The problem of grid study is shown in Figure 1 as flowsheet.

2. PROBLEM DEFINITION

On a stretching sheet with ten numbers of different fins in the y > 0 direction, a steady-state two-dimensional flow of a micropolar/classical ferrofluid was assumed as shown in Figure 2. In the geometry of this paper, we discussed the effect of using fins with different shapes on nanofluid heat transfer and nanofluid flow velocity. In the industry, heat transfer can be optimized and increased by using fans with different positions and at the same distance from each other. Triangular and rectangular and chamfer fins are used on the surfaces. Nanofluid flow is entered with 25 °C and angular velocity is entered from 1 direction and passes through the fins and surface. The surface temperature is 30°C and the surface have been stretched by velocity in the X direction (UW(x) =ax, a>0). The velocity in the x-direction is 2m/s and the velocity in the y-direction is 0.2m/s. In this paper, the effect of the magnetic force (B) on the surface is investigated. The finite element method is used for solving this case. The governing equation for ferrofluid was simulated as follows. The physical properties of water and Ethylene-glycol nanofluid at 25 °C are summarized in Table 1.

![Figure 1. Grid study of the problem](image-url)
The finite element method is used to solve this case. In the below, the governing equation for ferrofluid is [27]:

\[
\frac{d}{dx}(\rho_{nf} u') = \nabla \cdot (\rho_{nf} \nu')
\]

(1)

\[
\rho_{nf} \left( \frac{dv}{dx} + (2 \mu_{nf} + \kappa) \nabla v) - (\mu_{nf} + \kappa) \nabla \cdot v + (\mu_{nf} + \kappa) \nabla \cdot (\nabla \nu) + j_B + \rho_{nf} \mathbf{g} \right)
\]

(2)

\[
\rho_{nf} \left( \frac{dv}{dx} + (\varphi + \lambda + Y_{nf}) \nabla (\rho_{nf} \cdot N) - Y_{nf} \nabla \cdot (\nabla \nu) + (\mu_{nf} + \kappa) \nabla \cdot (\nabla \nu) - 2 \kappa N + \rho_{nf} \right)
\]

(3)

where effective density, effective dynamic viscosity, and spin gradient viscosity are presented by Brinkman [21], Bourantas and Loukopoulos [22], respectively:

\[
\rho_{nf} = (1 - \varphi) \rho_f + \varphi \rho_s
\]

(4)

\[
\mu_{nf} = \frac{\mu_f}{(1 - \varphi)^2}
\]

(5)

\[
Y_{nf} = (\mu_{nf} + \kappa / 2)
\]

(6)

In addition, flow is incompressible in the absence of external forces. Therefore, equations will be difficult to solve.

\[
\rho_{nf} \left( \frac{dv}{dx} + (\mu_{nf} + \kappa) \nabla v + \kappa (\nabla \nabla v) + j_B \right)
\]

(7)

\[
\rho_{nf} \left( \frac{dv}{dx} + (\mu_{nf} + \kappa) \nabla v + \kappa (\nabla \nabla v) - 2 \kappa N + \rho_{nf} \right)
\]

(8)

and the body force proposed by hussanan et al. [23] is:

\[
j_B = -\sigma_{nf} B_{nf}^2 v
\]

(9)

The ferrofluid electric conductivity represents [24]:

\[
\sigma_{nf} = \left[ 1 + \frac{2(\varphi - 1)G}{(\varphi + 2) - (\varphi - 1)G} \right] \rho_f
\]

(10)

and the governing equations would be:

\[
\rho_{nf} \left( \frac{du}{dx} + v \frac{dv}{dy} \right) = \left( \mu_{nf} + \kappa \right) \frac{dx^2}{dx} + \kappa \frac{dN}{dy} - \sigma_{nf} B_{nf}^2 u
\]

(11)

\[
\rho_{nf} \left( \frac{dv}{dx} + v \frac{dv}{dy} \right) = Y_{nf} \frac{dx^2}{dx} - \kappa \left( 2N + \frac{dx}{dy} \right)
\]

(12)

The specific heat capacity and the effective thermal conductivities were defined by Mohyud-Din et al. [25].

\[
C_p,\rho_{nf} = \frac{c_p,\rho(1 + \varphi \rho_p \nabla v)}{\rho_{nf}}
\]

(13)

\[
\frac{k_{nf}}{\kappa_f} = \frac{k_{nf} + 2k_f - 2 \kappa (\nu - \kappa)}{k_{nf} + 2k_f - \varphi \rho_p \nabla v}
\]

(14)

The energy equation represented as follows:

\[
u \frac{dv}{dx} + \nu \frac{dv}{dy} = \frac{\kappa_{nf} + \kappa_{nf}^2 \nu}{\kappa_{nf} + 2 \kappa_{nf} \nu} \frac{dx^2}{dy^2}
\]

(15)

It is stated as according to Rosland’s approximation as follows:

\[
u \frac{dv}{dx} + \nu \frac{dv}{dy} = \frac{\kappa_{nf} + 16 \kappa_{nf}^2 \nu}{\kappa_{nf} + 3 \kappa_{nf} \nu} \frac{dx^2}{dy^2}
\]

(16)

The boundary conditions are:

\[
u = \nu w(x), \quad \nu = \nu w, \quad \text{at } y = 0, \quad u \rightarrow 0, \quad y \rightarrow \infty
\]

(17)

\[
u = \nu w(x), \quad \nu = \nu w, \quad \text{at } y = 0, \quad N \rightarrow 0, \quad y \rightarrow \infty
\]

(18)

\[
u = \nu w(x), \quad \nu = \nu w, \quad \text{at } y = 0, \quad T \rightarrow T_w, \quad y \rightarrow \infty
\]

(19)

In order to familiarize ourselves with these calculations, we have defined the velocity components in the x and y directions u and v, respectively. The suction and injection are represented by the positive and negative values of the surface mass transfer velocity, \( \nu_w \). The angular velocity is denoted by N. \( \mu \) is dynamic viscosity, and \( \rho \) is a constant in the 0-1 range. When set to 0, the microelement is specified. If \( \delta = 1 \), the concentration of microelements was shown to be weak. Furthermore, when the turbulent boundary layer flow is required, \( \delta = 1 \). microelement is specified. If

\[
\eta = \frac{\nu}{\sqrt{\nu_i}} \quad \text{u} = \text{axF(\eta)}, \quad \nu = -\sqrt{\nu_i}F(\eta), \quad N = \text{ax F(\eta)}, \quad \text{\theta(\eta)} = \frac{\tau - \tau_{w}}{\tau_{w} - \tau_{w}}
\]

(20)

By substituting the variables in relations (20) in to the Equations (11), (12), (16), we have:

\[
\begin{align*}
\frac{1}{(1 - \varphi)^2} \left( 1 - \varphi \right) F(\eta) + \left( 1 - \varphi \right) \frac{\rho_f}{\rho_i} F'\eta(\eta) - \left( 1 - \varphi \right) \frac{\rho_f}{\rho_i} F''(\eta) \\
M \left( 1 + \frac{2(\varphi - 1)\rho_f}{(\varphi + 2) - (\varphi - 1)\rho_f} \right) F(\eta) + k G(\eta) = 0
\end{align*}
\]

(21)
\[
\frac{1}{(1-\eta^2)^{\frac{a}{2}}} G''(\eta) + \left(1 - \eta^2 + \frac{b}{\rho I} \right) F'(\eta) G'(\eta) - k \left(2 G(\eta) + F'(\eta) \right) = 0
\]

\[
\left( \frac{h_1 + 2h_2 + 2(h_1 - h_2) + 2h_1 + \phi}{h_1 + 2h_2 + 2(h_1 - h_2)} \right) \theta''(\eta) + \left(1 - \eta^2 + \frac{c}{\rho I} \right) F(\eta) \theta'(\eta) = 0
\]

and here the new boundary conditions are:

\[
F(\eta) = S, F'(\eta) = \alpha, G(\eta) = -\delta E''(\eta), \theta(\eta) = 1, \text{ at } \eta = 0
\]

\[
F'(\eta) \leftrightarrow 0, G(\eta) \leftrightarrow 0, \theta(\eta) \rightarrow 0 \text{ at } \eta \rightarrow \infty
\]

3. SIMULATION METHODOLOGY

3.1 Finite Element Method (FEM)  Finite Element Method is an important numerical method that one of the practical applications for this method is Flexpde software. That is solved the nonlinear partial differential equations and ordinary differential equations. The output of the results FlexPDE is also a ‘problem-solving environment’ that executes the full range of functions required to resolve partial differential equation systems. The finite element method is a numerical method for solving partial differential equations defined based on one or two spatial variables. In this method, to solve the problem, a large system is divided into smaller and simpler parts called finite elements. This spatial discretization requires defining the object or environment of the problem as a network, or mesh.

According to Figure 3, the largest grid of mesh is around the edges, because around the baffles the fluid properties such as temperature and velocity of nanofluid flow changed.

3.2 Validation for Methods  In this section, for validation, we compared our work with Jalili et al. [20]. The computational error in our work is very low compared to others. The maximum number of errors happened when \( \eta = 1.5 \) and minimum number of errors happened when \( \eta = 1 \). Figure 4 shows comparison of data presentations for present study and Jalili et al. [20]. The Comparison of velocity for present work and Jalili’s work at \( K = 10, \delta = 0.5, \phi = 0.03 \) are summarized in Table 2.

4. RESULTS AND DISCUSSION

Figure 5 shows the nanofluid velocity is low around the space of the surface and fins. The maximum nanofluid velocity is attached to the surface of fins. The value of the maximum velocity is 2 m/s. By increasing the
distance of nanofluid from the surface, the velocity is reduced but by decreasing the distance from the surface, the velocity is increased. By comparing modes a-5 and b-5 we find that if we use a triangular blade instead of a chamfer blade, we create a larger velocity gradient.

Figure 6 shows the angular velocity of nanofluid flow passing the stretching surface. On the surface, many fins exist, such as rectangular fins, triangular and chamfer fins. Under the surface, the angular velocity of nanofluid is very low but on the surface and near the fins, the angular velocity increases. In general, the angular velocities near the rectangular and chamfer fins (b-6) have an additional value than the triangular fins, because the surface of their side is larger than the triangular side. With an increase in variety of the fins (d-6) on the surface, the angular velocity of nanofluid has a maximum value.

Figure 7 shows the changes of nanofluid temperature passing the stretching surface. The nanofluid temperature in the space of fins is warm and equal to the surface temperature. The value of temperature is 30°C. The maximum values of nanofluid temperature exist in the last fin of surfaces. By passing the nanofluid flow from the first fins of the surface, the flow temperature increased from 25 to 31°C and at the ends of the surface, the temperature is high. Due to the different positions of the fin at the top of the page, we find that if we use a triangular blade at the top of the page, we create a larger temperature gradient than other modes.

The vectors of angular velocity for nanofluid flow are shown in Figure 8. The most dispersion of velocity (N) is shown in Figure 8d. As in the middle of the surface near the third and eighth fins, the value of angular velocity is low and at the beginning and the end, the value of velocity is high.

Figure 9 shows the changes of nanofluid flow near the rectangular and triangular and chamfer fins in the chart. The lowest value of velocity in the x-direction of nanofluid flow is in the x=0 to x=0.1 with u=0.3m/s. The maximum velocity in the x-direction is 2m/s. The variations in velocity all over the different fins are very high.

In the state of triangular and chamfer fins (b-10) on the surface, the maximum angular velocity exists at x=0.2 near the first fins. The value of the velocity at x=0.2 is 400. In the position of different fins shapes next to each other (triangular and rectangular and chamfer), most changes of angular velocity are created in the x=0 to x=1.
In the same case, the velocity has a variation in the modes. In the $x=0$, the value of angular velocity is 30 and in $x=0.4$, the value of velocity is $N=150$.

Figure 11 shows the changes of nanofluid temperature passing the stretching surfaces. The value of temperature begins from 28 to 31°C all over the different fins. The temperature of nanofluid in the $x=0.2$ to $x=0.8$ have a constant value ($T=30^\circ$C) and no changes around the fins.

According to Table 3, the maximum ethylene glycol temperature occurs in the $x=0.1$ for three different fins, and the minimum temperature occurs in the $x=0$ for 3 different fins. The maximum nanofluid temperature is $T=30.36^\circ$C and minimum temperature is $T=28.13^\circ$C. The maximum temperature change exists around the 3 different (rectangular, triangular and chamfer) baffles, and the thermal boundary layer in this position is larger than in other cases. The nanofluid temperature on the 3 different fins is 4.5% bigger than chamfer and rectangular fins and 5.34% bigger than chamfer and triangular modes. Due to the different positions of the fin at the top of the page, we find that if we use a chamfer blade at the top of the page, we create a larger temperature gradient than other modes.
a) Triangular and rectangular fins

b) Triangular and chamfer fins
c) Rectangular and chamfer fins
d) Rectangular, triangular and chamfer fins

Figure 9. Comparison of velocity (u) changes in rectangular and triangular fins for threatened stretching surface

Figure 10. Comparison of angular velocity changes in rectangular and triangular fins for threatened stretching surface
TABLE 3. Numerical comparison of temperature between different modes of fins

| η  | $T_3$ different fins | $T_{chamfer and rectangular}$ | $T_{chamfer and triangular}$ | $T_{rectangular and triangular}$ |
|----|----------------------|-------------------------------|-------------------------------|-------------------------------|
| 0  | 28.13                | 28.33                         | 28.34                         | 28.33                         |
| 0.1| 30.36                | 29.94                         | 29.96                         | 29.89                         |
| 0.2| 30.00                | 30.00                         | 29.99                         | 29.97                         |
| 0.5| 30.00                | 30.00                         | 29.99                         | 29.97                         |
| 0.8| 29.99                | 30.00                         | 30.00                         | 29.99                         |
| 0.9| 30.09                | 30.08                         | 30.34                         | 29.83                         |
| 1  | 29.09                | 29.09                         | 29.09                         | 29.11                         |

According to Table 4, the maximum of ethylene glycol velocity occurs in the $x=0.3$ with $T=399.98$ for chamfer and triangular modes and the minimum of temperature occurs in the $x=0.8$ with $T=33.34 \degree C$ for 3 different fins. The angular velocity for nanofluid on the triangular and chamfer modes is 34.5% bigger than 3 different baffles and 58.54% bigger than chamfer and rectangular baffles. The most boundary condition for angular velocity shown around the initial baffles of the stretching sheet.

TABLE 4. Numerical comparison of angular velocity between different modes of fins

| η  | $N_3$ different fins | $N_{chamfer and rectangular}$ | $N_{chamfer and triangular}$ | $N_{rectangular and triangular}$ |
|----|----------------------|-------------------------------|-------------------------------|-------------------------------|
| 0  | 37.85                | 49.97                         | 49.95                         | 49.95                         |
| 0.1| 100.99               | 48.87                         | 48.01                         | 47.76                         |
| 0.2| 43.33                | 45.25                         | 399.98                        | 46.06                         |
| 0.5| 57.87                | 47.89                         | 69.33                         | 76.55                         |
| 0.8| 33.34                | 46.76                         | 70.90                         | 77.89                         |
| 0.9| 89.08                | 120.43                        | 89.05                         | 55.48                         |
| 1  | 34.04                | 47.56                         | 48.02                         | 48.76                         |

5. CONCLUSION

In this paper, variation of temperature and velocity in the $x$-direction and the angular velocity of the nanofluid flow through triangular and rectangular fins are investigated in the existence of a uniform magnetic field. The innovation of this paper is to investigate parameters of nanofluid flow passing from the different fins on the stretching surface. The finite element method is selected for solving governing equations.

- The effect of velocity changes in the $x$-direction around the baffles has more value than the surrounding space. The amount of flow velocity is reduced by increasing the distance from the surface in the $y$-

Figure 11. Comparison of temperature changes in in rectangular and triangular fins for threatened stretching surface
direction. General, the angular velocities near the rectangular fins and chamfer fins have an additional value than the triangular fins, because the surface of their side is larger than the triangular side. With the increasing, variation of the fins on the surface, the angular velocity of nanofluid has a maximum value.

- The temperature of nanofluid in the space of fins is warm and equal to the temperature of a surface. The value of temperature is 30°C. The maximum values of nanofluid temperature exist in the last fin of surfaces. By passing the nanofluid flow from the first fins of the surface, the temperature of flow comes from 25 to 31°C and at the ends of the surface, the temperature is high.

- The lowest value of velocity in the x-direction of nanofluid flow is in the x=0 to x=0.1 by u=0.3m/s. The maximum velocity in the x direction is 2m/s. Changes in velocity all over the different fins are very high.

- In the state of triangular and chamfer fins together on the surface, the maximum angular velocity exists at x=0.2 near the first fins. The value of velocity at x=0.2 is 400. In the position of different fins shapes next to each other (triangular and rectangular and chamfer), most changes of angular velocity are created in the x=0 to x=1. In the same case, the velocity has a variation the modes. In the x=0, the value of angular velocity is 30 and in x=0.4, the value of velocity is N=150. The angular velocity for nanofluid on the triangular and chamfer modes is 6.5% more than other baffles.

- The value of temperature begins from 28 to 31°C in all over the different fins. The temperature of nanofluid in the x=0.2 to x=0.8 have a constant value (T=30°C) and no changes around the fins.

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Persian Abstract

چکیده

این مقاله انتقال حرارت و سرعت راپیدر نانوسیال اپن گلیکول میکروویژیلا را بر روی بالهای مثلثی، مستطیلی و بخشی ورق کشی تحلیل می‌کند. نوآوری این مقاله بررسی پنوس بازارهای جریان نانوسیال، محدودیت باله‌های گازی و محدودیت باله‌های غیر ریزی داده است. مدل نانوسیال در ارتفاع باله‌های گازی و در دامنه سطح می‌باشد. مدل نانوسیال در اولین باله‌های سطح، باله‌های دو دانه 30 درجه سانتی‌گراد ایجاد می‌شود و در انتهای سطح، دامنه از ارتفاع بالایی بیرون می‌رود. مدل نانوسیال در کل رابطه با pancakes به تعداد 80 درجه سانتی‌گراد با دانه 30 درجه سانتی‌گراد ایجاد می‌شود. مدل نانوسیال در انتهای باله‌های سطح، باله‌های دو دانه 30 درجه سانتی‌گراد می‌شود و در انتهای سطح، دامنه از ارتفاع بالایی بیرون می‌رود. مدل نانوسیال در کل رابطه با pancakes به تعداد 80 درجه سانتی‌گراد با دانه 30 درجه سانتی‌گراد ایجاد می‌شود. تحقیق در این مقاله با بذرک گزینه‌های بی‌گردا انتقال حرارت و سرعت راپیدر نانوسیال اپن گلیکول در 9 = خ. برای باله‌های مثلثی و مستطیلی و حداقل دما در 0.8 = خ. برای 3 باله‌های مختلف خ. می‌دهد. سرعت راپیدر برای نانوسیال در حالت‌های مثلثی و بخشی ورق کشی بزرگ‌تر از باله‌های گردا است.