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Analytical Approach of Fe_3O_4-Ethylene Glycol Radiative Magnetohydrodynamic Nanofluid on Entropy Generation in a Shrinking Wall with Porous Medium

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ABSTRACT

This research mainly focuses on the effects of heat absorption/generation and radiation on the hydromagnetic flow of Fe_3O_4-ethylene glycol nanofluid through a shrinking wall with porous medium and the computation of the entropy generation. We considered basic governing ordinary differential equations into partial differential equations by using appropriate similarity solutions. Moreover, hyper geometric function is employing to determine the formulated problem. We analyze the effects of appropriate physical parameters on the Bejan number, Entropy generation, Nussult number, skin friction, fluid temperature and velocity profiles. In addition, the derived result of the present study is compared with those in the existing literature. We noted that the presence of heat absorption and suction parameters reduces the Bejan number and increases the entropy generation, and the heat source, porous medium, radiation parameters minimize the entropy production. The presence of porosity parameter reduced the fluid velocity, improved fluid temperature and minimized the entopy production. Nanosolid volume fraction parameter reduced both Nussult number and skin friction coefficient.

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NOMENCLATURE

.	magnetic field strength	T_w	wall temperature
Br	Brinkman number	T_∞	temperature far away from the sheet
C_p	specific heat at constant temperature	k_{nf}	thermal conductivity of the nanofluid
M_3	Hartmann number	k_f	thermal conductivity of the base fluid
M	Kummer's function	k_s	thermal conductivity of the nanoparticles
Nr	radiation parameter	k^*	The absorption coefficient of the fluid
Ns	entropy generation number	σ	electric conductivity
Pr	Prandtl number	σ^*	Stephan-Boltzman constant
T	local temperature of the fluid	S_{G0}	characteristic entropy generation rate
Q	Temperature dependent volumetric rate of heat source	ΔT	temperature difference
Qr	radiative heat flux	Ω	dimensionless temperature difference
Re_x	Reynolds number	θ	dimensionless temperature
S	Suction parameter	ϕ	the solid volume fraction
S_G	local volumetric Entropy generation rate	β	uniform heat generation/absorption

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1. INTRODUCTION

There are several systematic challenges pertaining to efficient heat transfer of heat in different processes, example, in batteries, drug formulation, chemical reactions, fuel cells, solar cells, and others. This phenomenon has been studied through the field of nanotechnology. The most important performance of nanotechnology is nanofluids. Many scientific and technological fields utilize nanofluid models. Choi [1] introduced the notion of increase in the thermal conductivity of nanofluid. Ibrahim et al. [2] analyzed the nanofluid heat transfer effects with hydromagnetic and stagnation point flow numerically. Various types of nanoparticle, including Cu, Ag, Al_2O_3 and TiO_2, used in the base fluid towards a porous stretching surface has been examined by Hayat et al. [3]. Al_2O_3-water with hydromagnetic flow towards a vertical microtubefor enhancement of the heat transfer rate has been researched by Malvandi and Ganji [4]. The effects of flow towards a shrinking sheet using nanofluid with slip conditions have been developed by Rahman et al. [5]. The phenomenon of flow through a shrinking porous sheet, along with analytical result of Fe_3O_4-water hydrodynamic nanofluid flow was researched by shaha et al. [6].

Over the most recent few decades, incredible interest has been shown by scientists on the subject of stretching surfaces with magnetic field because of its colossal applications in various mechanical and engineering procedures. Some of these fascinating and amazing applications are glass plastic expulsion, fiber drawing, crystal developing, petroleum industries, paper creation, plasma studies, etc. Heat transfer effects in CuO–water nanofluid flow with magnetic field were analyzed by Sheikholeslami et al. [7]. Jamaludin et al. [8] researched the effects of shrinking surface flow of heat generation or absorption and hydromagnetic Cu and Al_2O_3 based hybrid nanofluid flow numerically. Heat conduction effects on shrinking porous surface with Cu and Ag - $C_6H_9NaO_7$ Corrosion based nanofluids flow has been studied by Dero et al. [9]. It is clear that copper and silverbased volume fraction nanoparticle improves the thermal conduction and reduces the fluid velocity. Heat conduction effects of shrinking porous surface with thermal radiation and copper based nanofluid flow were studied by Haq et al. [10]. Heat conduction of various types of nanofluid flow towards shrinking surface was reported in literature [11-14].

On the other hand, entropy represents an irreversibility process and it is utilized to enhance the capacity of machine. The entropy models can be related to manufacturing and engineering processes pertaining to nanofluids. This has been an active research area recently. Hayat et al. [15] investigated thermal irreversibility analysis for energy activation and non-linear thermal radiation of Jeffrey nanofluid flow towards stretchable sheet. Hosseinzadeh et al. [16] studied thermal irreversibility analysis for Fe_3O_4-Ethylene glycol nanofluid with nonlinear thermal radiation and Lorentz force effects. Shahsavar at al. [17] presented an analysis of heat and irreversibility study of Fe_3O_4nanofluid flow through a concentric annulus. Mehrali at al. [18] researched the impacts of Fe_3O_4 nanofluid flow and conducted an analysis of entropy on magnetic. Very recently, López et al. [19] investigated the effects of Al_2O_3nanofluid flow and analyzed the entropy on hydromagnetic, nonlinear radiation and slip conditions. Shukla et al. [20] have studied a homotopy method for irreversibility analysis of vertical cylinder flow of viscous dissipation and magnetohydrodynamic (MHD) nanofluid flow. Hayat et al. [21], investigated on MHD nonlinear thermal radiation and joule heating effects with respect to nanofluid flow with entropy analysis has been conducted. Rana and Shukla [22] provided an analytical solution for an irreversibility study of aligned MHD nanofluid flow towards a plate with Ohmic dissipation and viscous dissipation effects.

The study of boundary layer MHD nanofluid flow and heat transfer due shrinking wall with porous medium is very significant because of its several applications in engineering and industrial processes, such as extrusion of polymer sheets from a die, drawing of plastic films, polyester thin wall heat shrink tubing, shrink film, wire drawing, glass fiber, and paper production. Govindaraju et al. [23] researched the irreversibility mechanism of Ag-water MHD nanofluid fluid flow with heat source or sink and radiation effects. Abdul Hakeem et al. [24] presented the non-uniform heat source or sink and radiation effects on Ag-water MHD nanofluid flow, along with the analysis of entropy. Ganga et al. [25] researched the effects of the irreversibility and Ag-water inclined MHD nanofluid flow towards a stretching sheet. Recently, the irreversibility phenomenon of various types of nanofluid flow was investigated by many researchers [26-32]. Some researchers reported data by demonstration of experimental work [33-38]. To the best of author's knowledge, upto now, no theoretical results are given for the effects of heat transfer and irreversibility of hydromagnetic Fe_3O_4-ethylene glycol nanofluid flow in a shrinking wall with porous medium, heat sink or source and thermal radiation. This is the main motivation of our present study.

Motivated by the above discussions, we designed analytically the heat sink or source, MHD and thermal radiation effects on Fe_3O_4-ethylene glycol nanofluid flow in a shrinking wall with porous medium. The fluid velocity, heat transfer process, Bejan number and the irreversibility phenomenon, skin friction co-efficient and temperature transfer rate are examined with the graphs, in which our solutions are in good agreement with earlier published results.

The contents of this paper are divided up as follows:

The description of physical model is clearly prescribed in section 2. In this section, the mathematical model for the 2-Dimentional incompressible flow of Fe_3O_4-ethylene glycol based nanofluid has been presented. Section 3 is devoted to the solution of these models equations by hyper geometric function method. The Entropy generation and Bejan number has been computed in section 4. The results and discussion has been presented in section 5. Finally, the main findings of the current study have been given in section 6.

2. MATHEMATICAL ANALYSIS

In this investigation, consider the incompressible 2-dimentional flow of Fe_3O_4-Ethylene glycol based nanofluid towards a shrinking wall with porous medium. The fluid flow is along the *x*-axis (horizontal) and the *y*-axis is the vertical dimension, then *y>0* is the occupied volume of the fluid. Suppose normal to the flow of an applied magnetic field is *B(x)* with velocity *u=ax* (Figure 1). The two-dimensional thermal radiation with magnetohydrodynamic flow of governing equations are given, as follows [26, 39-41] (Figure 2):

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\frac{\mu_{nf}}{\rho_{nf}}\frac{\partial^2 u}{\partial y^2}-\frac{\upsilon_{nf}}{K_p}u-\frac{\sigma_{nf}B(x)^2}{\rho_{nf}}u \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha_{nf}\frac{\partial^2 T}{\partial y^2}-\frac{1}{(\rho C_p)_{nf}}\frac{\partial q_r}{\partial y}+\frac{Q(T-T_\infty)}{(\rho C_p)_{nf}} \tag{3}$$

Here *u* and *v* denote the velocity components along the *x*-axis and the *y*-axis, respectively; *B(x)* represents the magnetic parameter; ν_{nf}, μ_{nf}, ρ_{nf}, α_{nf} denote the kinematic viscosity, dynamic viscosity, density, thermal diffusivity, respectively. The subscript *nf* indicates the nanofluid; *T* denoted as fluid temperature, while *Q* represents the volumetric heat sink or source rate.The heat flux q_r [26, 41] through the Rosseland approximation is defined as:

$$q_r=-\frac{\sigma^*}{3k^*}\frac{\partial T^4}{\partial y}. \tag{4}$$

Here k* is the absorption coefficient of the fluid, from Equations (3) and (4), we have

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha_{nf}\frac{\partial^2 T}{\partial y^2}-\frac{16\sigma^* T_\infty^3}{3k^*(\rho C_p)_{nf}}\frac{\partial^2 T}{\partial y^2}+\frac{Q(T-T_\infty)}{(\rho C_p)_{nf}} \tag{5}$$

The heat conductivity can be expressed as follows:

$$\begin{gathered}\mu_{nf}=\frac{\mu_f}{(1-\varphi)^{2.5}},\qquad \rho_{nf}=(1-\varphi)\rho_f+\varphi\rho_s\\ (\rho C_p)_{nf}=(1-\varphi)(\rho C_p)_f+\varphi(\rho C_p)_s,\\ k_{nf}=\frac{k_s+2k_f-2\varphi(k_f-k_s)}{k_s+2k_f-\varphi(k_f-k_s)},\qquad \alpha_{nf}=\frac{k_{nf}}{(\rho C_p)_{nf}},\\ \frac{\sigma_{nf}}{\sigma_f}=1+\frac{3\left(\frac{\sigma_{nf}}{\sigma_f}-1\right)\phi}{\left(\frac{\sigma_{nf}}{\sigma_f}+2\right)-\left(\frac{\sigma_{nf}}{\sigma_f}-1\right)\phi}\end{gathered} \tag{6}$$

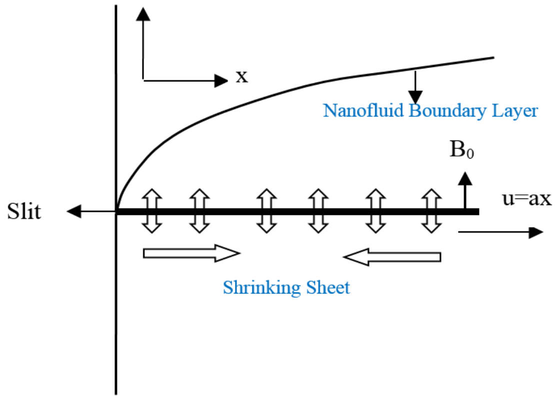

Figure 1. Schematic representation of the flow diagram

where the physical problem of the surface conditions is

$$\begin{gathered}u=-U_x, v=-v_x, T=T_w=T_\infty+T_0(x)^n, \text{at } y=0,\\ u\to u=0,\qquad T\to T_\infty, \text{as } y\to\infty.\end{gathered} \tag{7}$$

Here, v_x noted as wall mass transfer velocity; in which $v_x<0$and $v_x>0$ are the injection and suction parameters. The non-dimensional and similarity variables are [26, 42, 43].

$$\begin{gathered}u=axf'(\eta), v=-(\nu a)^{\frac{1}{2}}f(\eta), \theta(\eta)=\frac{T-T_\infty}{T_w-T_\infty}\\ \eta=y\left(\frac{a}{\nu}\right)^{1/2}\end{gathered} \tag{8}$$

After applying the similarity transformation of Equations (2) and (3), we have

$$f'''+B_1B_2ff''-B_1B_2f'^2-B_2(M_3-B_1k)f'=0 \tag{9}$$

$$\omega\theta''+Pr\,f\,\theta'-nPrf'\theta+\beta\,Pr\,\theta=0. \tag{10}$$

With

$$f(\eta)=S, f'(\eta)=-1, \theta(\eta)=1 \text{ at } \eta=0\ \ f'(0)\to 0, \theta(\eta)\to 0 \text{ as } \eta\to\infty \tag{11}$$

Based on Equations (9), (10) and (11), Prandtl number $Pr=\frac{\upsilon_f}{\alpha_f}$, porosity parameter $k=\frac{\upsilon_f}{aK_p}$, $\beta=\frac{Q}{a(\rho C_p)_f}$ noted heat sink or source parameter, $M_3=\frac{2L\sigma B_0^2}{\rho}$ noted as Hartmann number. In addition,

$$B_1=\left(1-\varphi\left(1-\frac{\rho_s}{\rho_f}\right)\right), B_2=(1-\varphi)^{5/2}, B_3=\frac{k_{nf}}{k_f},$$

$$B_4=1-\varphi+\varphi\frac{(\rho Cp)_s}{(\rho Cp)_f}, \omega=\frac{B_3}{B_4}\frac{3NrB_3+4}{3NrB_3}, Nr=\frac{k^*k_f}{4\sigma^* T_\infty^3}.$$

3. ANALYTICAL SOLUTION OF FLOW FIELD AND THERMAL ANALYSIS

The shrinking sheet fluid flow solution of (9) with (11) is obtained as follows [26, 41]:

$$f(\eta) = S - \frac{1-e^{-\alpha\eta}}{\alpha},$$
$$\text{with } \alpha = \frac{SB_1B_2+\sqrt{(SB_1B_2)^2-4B_1B_2+4B_2M_3-4kB_1B_2}}{2} \tag{12}$$

Substituting Equation (12) into Equation (10), we have

$$\omega\theta'' + Pr\left(S - \left(\frac{1-e^{-\alpha\eta}}{\alpha}\right)\right)\theta' - nPre^{-\alpha\eta}\theta + \beta\, Pr\,\theta = 0. \tag{13}$$

Here, we introduce a new variable

$$\xi = \frac{Pre^{-\alpha\eta}}{\omega\alpha^2} \tag{14}$$

Substituting Equation (14) into Equation (13) , we have

$$\xi\theta_{\xi\xi} + (1 - a_0 + \xi)\theta_\xi + \left(n + \frac{\beta Pr}{\omega\alpha^2\xi}\right)\theta = 0. \tag{15}$$

From Equation (11), it becomes

$$\theta(\xi) = 1, \theta(0) = 0\,. \tag{16}$$

Using Kummer's function [26,43], we obtain the solution of Equations (14), (15), and (16), in terms of η

$$\theta(\eta) = e^{-\alpha\left(\frac{a_0+b_0}{2}\right)\eta}\frac{M\left[\frac{a_0+b_0}{2} - n; 1+b_0; \frac{\Pr e^{-\alpha\eta}}{\omega\alpha^2}\right]}{M\left[\frac{a_0+b_0}{2} - n; 1+b_0; \frac{\Pr}{\omega\alpha^2}\right]} \tag{17}$$

where $a_0 = \frac{Pr}{\omega\alpha}\left(S - \frac{1}{\alpha}\right)$, $b_0 = \sqrt{a_0{}^2 - 4\frac{\beta Pr}{\omega\alpha^2}}$.

The dimensionless wall temperature gradient is

$$\theta'(0) = -\alpha\left(\frac{a_0+b_0}{2}\right) + \alpha\frac{\frac{a_0+b_0}{2}-n}{1+b_0}\frac{M\left[\frac{a_0+b_0+2}{2}-n;\ 2+b_{0;}\ \frac{Pr}{\omega\alpha^2}\right]}{M\left[\frac{a_0+b_0}{2}-n;\ 1+b_{0;}\ \frac{Pr}{\omega\alpha^2}\right]}. \tag{18}$$

We denote the skin friction and Nusselt number as

$$C_f = \frac{\tau_w}{\rho u_w^2} = \frac{\operatorname{Re}_x^{-1/2}}{B_1}f''(0), B_1C_f\operatorname{Re}_x^{-1/2} = -f''(0)$$
$$Nu = \frac{-k_{nf}x\left(\frac{\partial T}{\partial y}\right)_{y=0}}{k_f(T_w - T_\infty)} = -\frac{k_{nf}}{k_f}\operatorname{Re}_x^{-1/2}\theta'(0), \tag{19}$$
$$\frac{k_f}{k_{nf}}Nu_xRe_x^{-\frac{1}{2}} = -\theta'(0)$$

4. ANALYSIS OF ENTROPY AND BEJAN NUMBER

Now, using the second law of thermodynamics, the analysis of entropy generation expression of magnetohydrodynamic nanofluid flow with thermal radiation is given by

$$S_G = \frac{k_{nf}}{T_\infty^2}\left[\left(\frac{\partial T}{\partial x}\right)^2 + \left(1 + \frac{16\sigma^*T_\infty^3}{3k_{nf}^*k_{nf}}\right)\left(\frac{\partial T}{\partial y}\right)\right] + \frac{\mu_{nf}}{T_\infty}\left(\frac{\partial u}{\partial y}\right)^2 + \frac{\sigma B_0^2}{T_\infty}u^2 + \frac{\nu_{nf}}{k_{nf}}u^2 \tag{20}$$

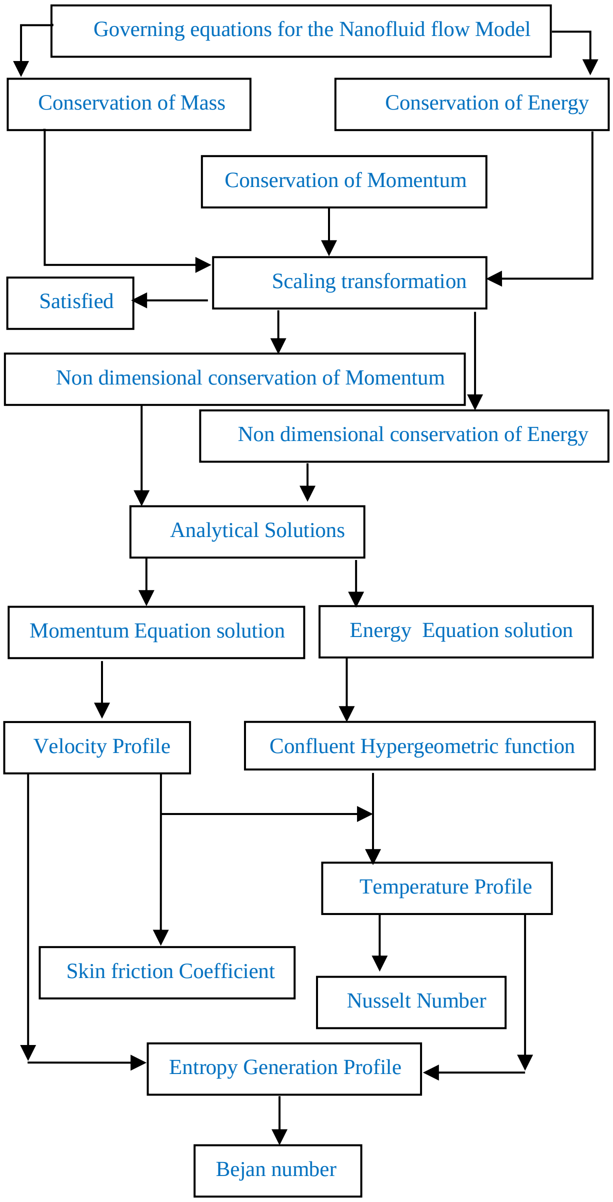

Figure 2. Flowchart of the study

The rate of entropy generation characteristic is given by

$$(S_G)_0 = \frac{k_{nf}(\Delta T)^2}{x^2T_\infty^2}. \tag{21}$$

Using Equations (20) and (21), we obtain the entropy generation number

$$N_s = \frac{S_G}{(S_G)_0}. \tag{22}$$

From Equations (17), (20), (21) and (22), we can specify the entropy generation number as

$$N_s = \left(\frac{3+4Nr}{3}\right)\theta'^2(\eta)Re_x + \frac{Br}{\Omega}f''^2(\eta)Re_x + \frac{Br}{\Omega}(M_3 + k)f'^2(\eta), \tag{23}$$

where *Br* is the Brinkman number and Hartmann number denoted as M_3.

$$Br = \frac{\mu_{nf} u_w^2}{k_{nf} \Delta T}, \quad \Omega = \frac{\Delta T}{T_\infty}, \tag{24}$$

The Bejan number (Be) was proposed by Bejan with respect to the energy optimization problem utilized by the solution of thermal irreversibility. Thermal irreversibility pertaining to the sum of all entropy in the model is given as:

$$Be = \frac{Eh}{Eh+Em} \tag{25}$$

5. RESULTS AND DISCUSSION

In this study, the analytical solutions are established for Fe_3O_4-ethylene glycol nanofluid through a shrinking wall with porous medium and the computation of entropy generation is analyzed. Figures 3 to 21 depict the effects of various important physical parameters, including the Bejan number, velocity of the fluid, Nusselt number, heat profile, entropy generation and skin friction co-efficient. The important physical parameters, nanosolid volume fraction (ϕ), heat sink or source (β), porosity parameter (*k*), radiation parameter (Nr), Hartmann number (M_3), suction parameter (S) effects are analyzed based on the trends in the respective figures. The current results have been discussed to the solutions achieved by Muhaimin et al. [39] and Bhattacharyya [40] (see Table 2). The presented results showed a good agreement with data reported in literature [39, 40].

5. 1. Fluid Flow and Heat Transfer

The profiles of fluid velocity along with various settings of the

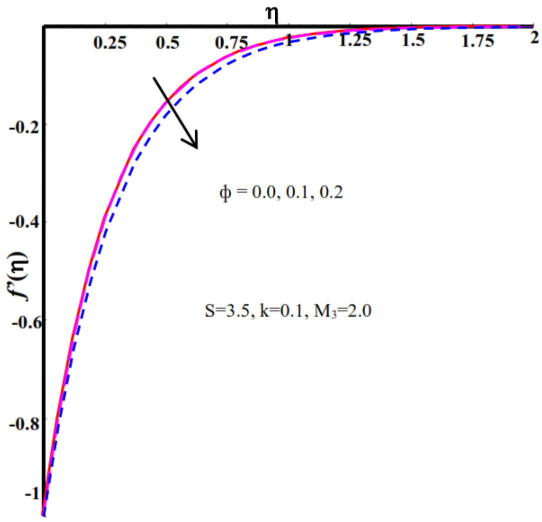

Figure 3. Impact of nanoparticles volume fraction parameter on f'(η)

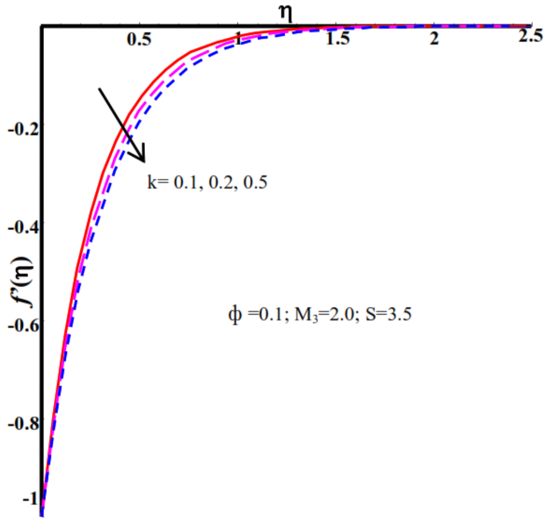

Figure 4. Impact of porosity parameter on f'(η)

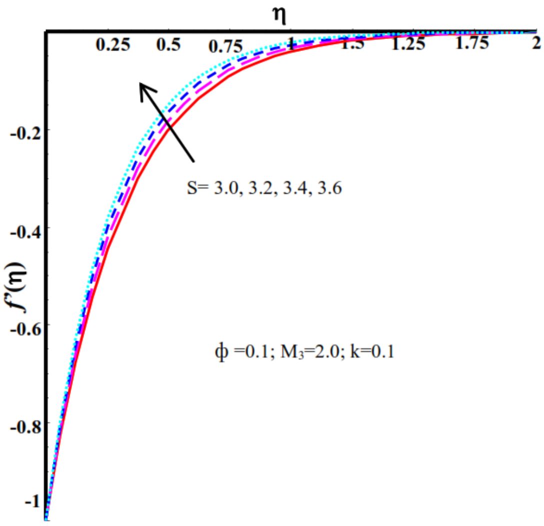

Figure 5. Impact of suction parameter on f'(η)

nanosolid volume fraction, suction and porosity parameters are presented in Figures 3-5, respectively. From these figures, increasing the porosity and nanosolid volume fraction parameters result in a reduction of the fluid flow, while increasing the suction parameters causes enhancing the fluid flow. The presence of both porosity and nanosolid volume fraction slows down the fluid velocity. The impact of ϕ variation on $f'(\eta)$ is presented in Figure 3, while the variation of porosity parameter on$f'(\eta)$ is represented in Figure 4. Figure 5 demonstrates the evolution of suction parameter on $f'(\eta)$. It is noted that the enhancing of ϕ and k reduces$f'(\eta)$, while increasing S leads to a reduction in $f'(\eta)$.

The thermal profile for various settings of the nanosolid volume fraction, porosity, suction, radiation, heat sink or source parameters are presented in Figures 6-10, respectively. Increasing the value of Fe_3O_4

nanoparticle leads to a development of heat conduction in Ethylene glycol based nanofluid. The porosity parameter also increases heat conduction in Ethylene glycol based nanofluid. But, the presence of radiation and suction parameters reduces heat conduction in Ethylene glycol based nanofluid. The effect of ϕ on θ(η)is exhibited in Figure 6, while that of the porosity parameter on θ(η) is shown in Figure 7. Both parameters enhance the thermal transfer in nanofluid flow, but the opposite result is given by the radiation and suction parameters, as shown in Figures 8 and 9, respectively. Further, the presence of Fe_3O_4 nanoparticle enhances with the temperature profile. This is because Fe_3O_4 particles have high thermal conductivity, so the thermal boundary layerthickness increases. The porosity parameter also develops the thermal boundary layer thickness. However, the presence of thermal radiation and suction parameters are reduces the thermal boundary layer thickness.

The impacts of the heat sink or source parameter with respect to the heat profile are presented in Figure 10. It generates energy in the boundary layer, which is caused by the heat source (β>0) on the heat profile. Energy is absorbed in the boundary layer, which arises from the heat sink (β<0) on the heat profile.

5. 2. Nusselt Number and Skin Friction

Figure 11 represent the effect of skin friction coefficient $-f''(0)$ for various values of Hartmann number and nanosolid volume fraction parameters against suction parameter. The skin friction coefficient $-f''(0)$ diminish for higher values ofϕ while the overturn trend is checked for large value of Hartmann number. Against Hartmann number, the different values of radiation, suction, nanosolid volume fraction parameters on Nusselt number has been depicted in Figure 12. The heat transfer rate improved with large value of radiation and suction parameters and reduced value of nanosolid volume fraction.

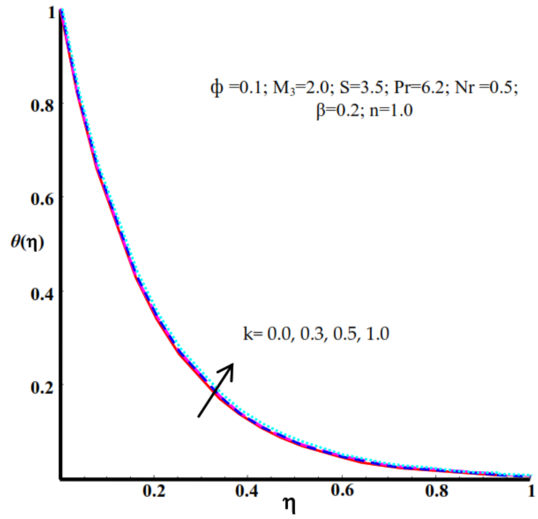

Figure 7. Impact of porosity parameter on θ(η)

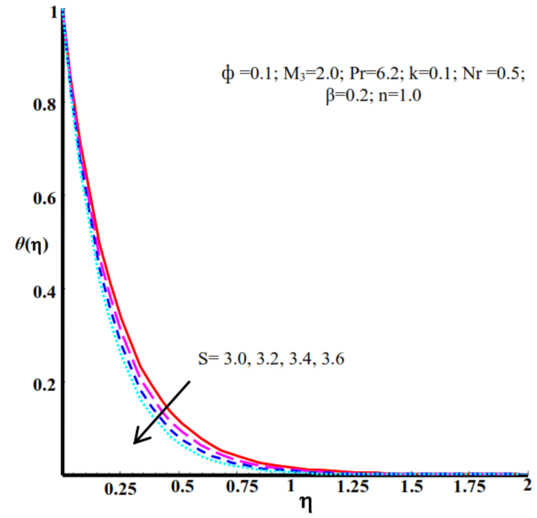

Figure 8. Impact ofsuction parameter on θ(η)

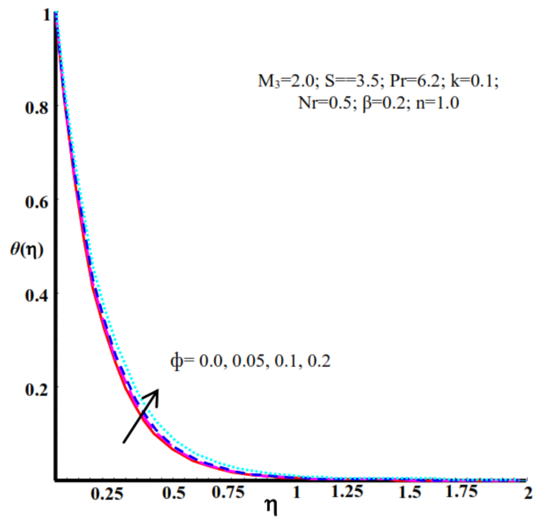

Figure 6. Impact of nanoparticles volume fraction parameter on θ(η)

5. 3. Bejan Number and Entropy Generation

The effects of the porosity, heat sink or source, nanosolid volume fraction, radiation, suction parameters pertaining to the entropy generation profile are presented in Figures 13-17. In Fe_3O_4-ethylene glycol nanofluid, the entropy generation increases with the increase in the suction and heat sink (β<0) parameters. Furthermore, the presence of heat source (β>0), radiation, porosity, nanosolid volume fraction parameters diminishes the production of entropy. The characteristics of entropy generation with respect to φ are shown in Figure 13. Figure 14 indicates the results ofentropy generation for different porosity parameters. The effects of the suction parameter on Ns are shown in

Figure 15. Figures 16 and 17 depict the characteristics of radiation and heat sink or source parameters, respectively. It is clear that the presence of Fe_3O_4 nanofluid volume fraction, porosity parameter, thermal radiation, uniform heat source parameters are control the more entropy production. But the suction parameter develop the entropy production.

The influence of Bejan number with respect to various physical parameters like Brinkman number, nanosolid volume fraction, heat sink or source, suction parameters have been depicted in Figures 18-21. From the figures, the Bejan number is improved with the heat source (β>0) and nanosolid volume fraction parameters, but is reduced with the heat sink (β<0), suction and Brinkman number. Figure 18 shows the variation of φ on Be. Figure 19. depicts the impact of *S* onBe. Figures 20 and 21 indicate the results of Be with respect to different values of Brinkman number and heat sink or source parameters, respectively.

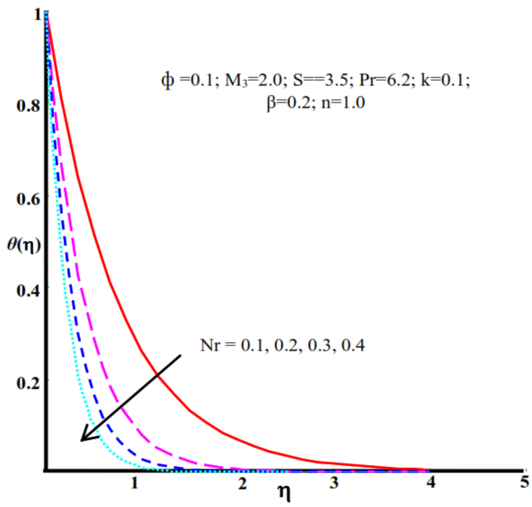

Figure 9. Impact of radiation parameter on θ(η)

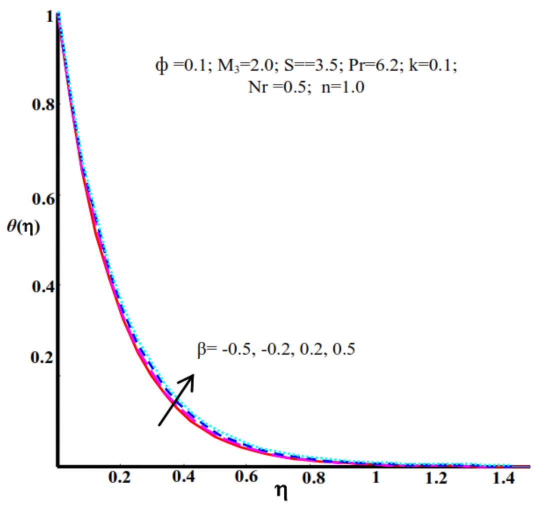

Figure 10. Impact of β on θ(η)

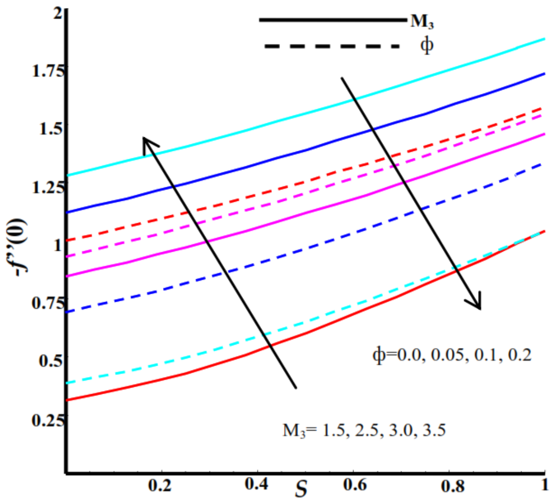

Figure 11. Impact of ϕ and M3on -f''(0)

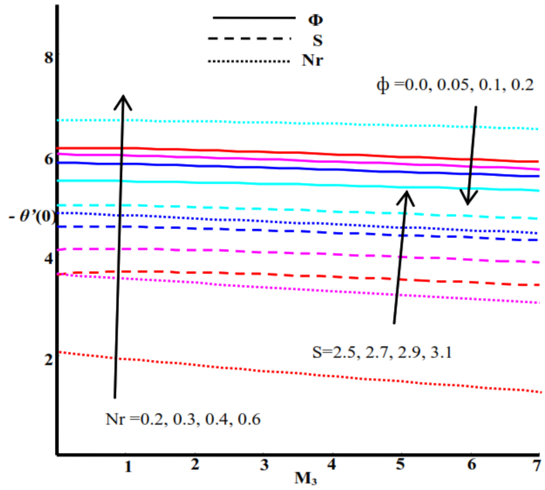

Figure 12. Impactof ϕ, S and Nr on –θ'(0)

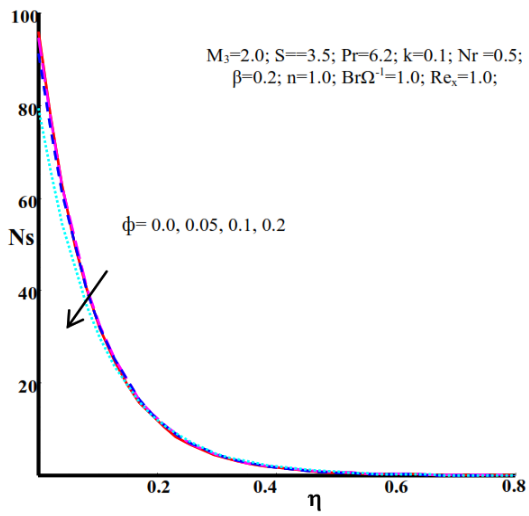

Figure 13. Impact of nanoparticles volume fraction parameter on Ns

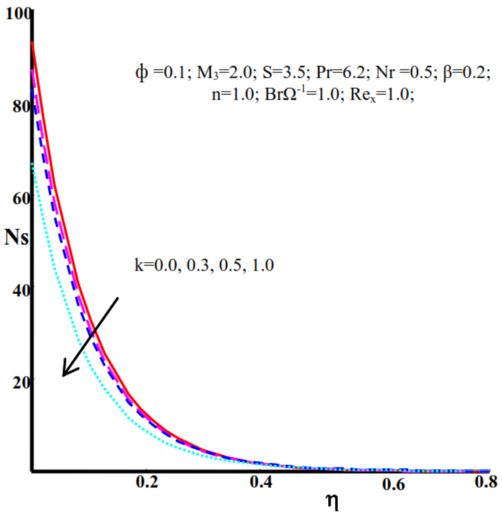

Figure 14. Impact of porosity parameter on Ns

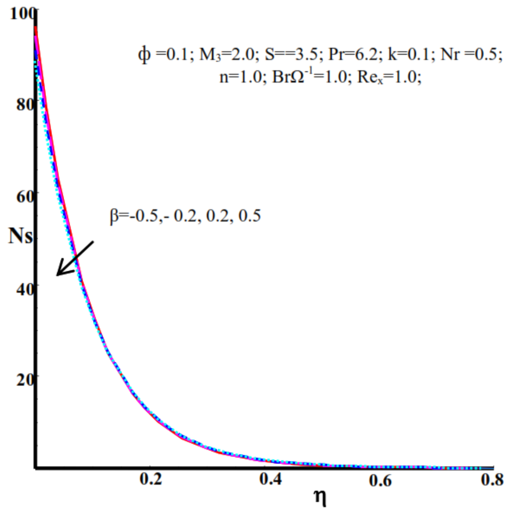

Figure 17. Impact of heat source/sink parameter on Ns

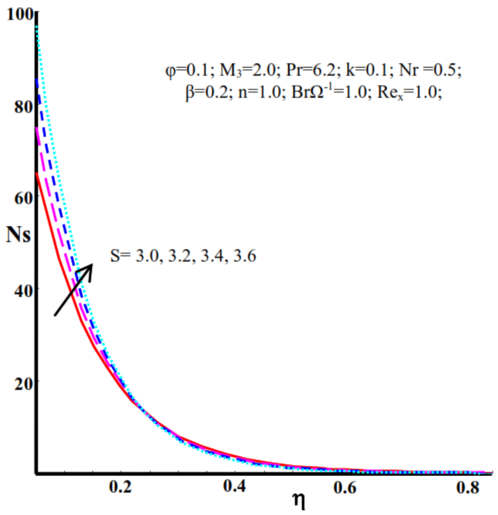

Figure 15. Impact of suction parameter on Ns

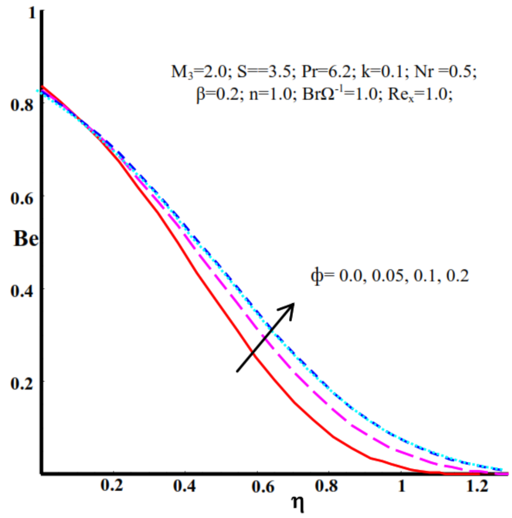

Figure 18. Impact of nanoparticles volume fraction parameter on Be

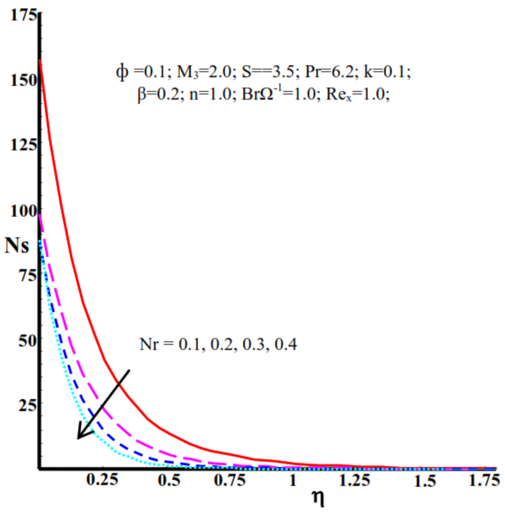

Figure 16. Impact of radiation parameter on Ns

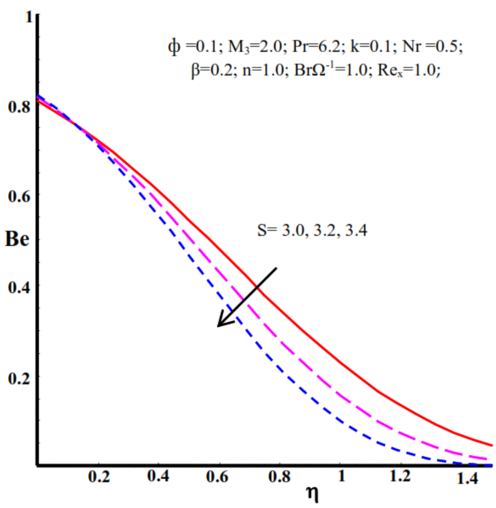

Figure 19. Impact of suction parameter onBe

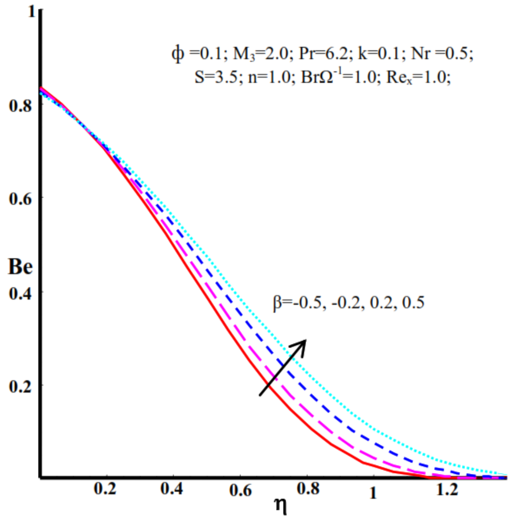

Figure 20. Effect of heat source/sink parameteron Be

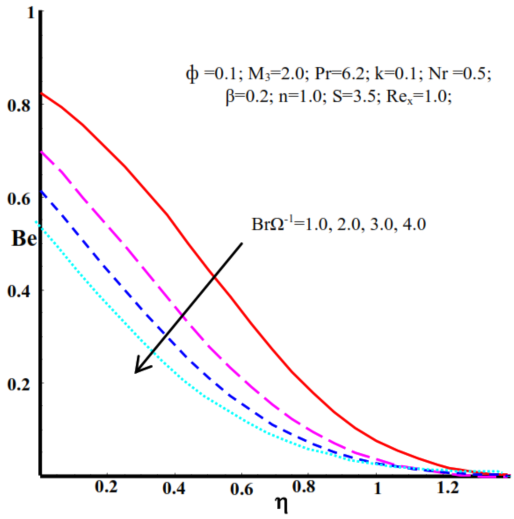

Figure 21. Impact of $Br\Omega^{-1}$on Be

TABLE 1. Thermo-physical properties of ethylene glycol and nanoparticles [42]

	$\rho(kg/m^3)$	C_p(j/kgk)	k (W/m.k)
Ethylene glycol	1110	2400	0.26
Fe_3O_4	*5200*	*670*	*6*

TABLE 2. Evaluate solution of Skin friction for different values of S with M_3 = 2 When ϕ=k=0

S	[39]	[40]	Present results
2	2.414214	2.414217	2.41421
3	3.302776	3.302772	3.30278
4	4.236068	4.236073	4.23607

6. CONCLUSIONS

We have presented an analytical approach pertaining to entropy generation on Fe_3O_4-Ethylene glycol MHD nanofluid through a shrinking wall with porous medium in the presents of heat sink or source and thermal radiation. We have obtainedthe important results, as follows:

- The velocity of Fe_3O_4-ethylene glycol nanofluidis enhanced with the increase in the suction parameters, but it slows down with respect to the nanosolid volume fraction and porosity parameters. The heat of Fe3O4-Ethylene glycol nanofluidis enhanced with the increase in the heat source,nanosolid volume fraction and porosity and its decreases with the heat sink, suction and radiation parameters.The presence of Fe3O4 nanoparticle enhances with the temperature profile. This is because Fe3O4 particles have high thermal conductivity, so the thermal boundary layer thickness increases. The porosity parameter also develops the thermal boundary layer thickness. But the presence of thermal radiation and suction parameters are reduces the thermal boundary layer thickness.
- The skin friction increases with the Hartmann number, but decreases with nanosolid volume fraction. The Nusselt number is enhanced with radiation and suction parameters, but it is reduced with nanosolid volume fraction.
- The entropy generation profile is maximized with suction and heat sink, but it is minimized with nanosolid volume fraction, porosityand heat source. It is clear that the presence of Fe_3O_4 nanofluid volume fraction, porosity parameter, thermal radiation, uniform heat source parameters are control the more entropy production. But the suction parameter develop the entropy production.

The Bejan number increases with nanosolid volume fraction and heat source, but decreases with suction, Brinkman number and heat sink. In the future, this paper can be extended for different nanofluids considering the effect of magnetic field with nonlinear thermal radiation in different types of boundary conditions.

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Persian Abstract

چکیده

این تحقیق عمدتاً بر تأثیرات جذب / تولید گرما و تابش بر جریان هیدرو مغناطیسی نانوسیال Fe_3O_4–اتیلن گلیکول از طریق دیواره کوچک شده با محیط متخلخل و محاسبه تولید آنتروپی متمرکز است. ما معادلات دیفرانسیل معمولی حاکم را با استفاده از راه‌حل‌های مشابهت مناسب به معادلات دیفرانسیل جزئی در نظر می‌گیریم. علاوه بر این، عملکرد هندسی بیش از حد برای تعیین مسئله فرموله شده استفاده می‌شود. ما اثرات پارامترهای فیزیکی مناسب را بر روی تعداد Bejan، تولید آنتروپی، تعداد Nussult، اصطکاک پوست، دمای مایع و پروفیل سرعت تجزیه و تحلیل می‌کنیم. علاوه بر این، نتیجه حاصل از مطالعه حاضر با نتایج موجود در ادبیات موجود مقایسه می‌شود. ما متذکر شدیم که وجود پارامترهای جذب حرارت و مکش، تعداد Bejan را کاهش می‌دهد و باعث افزایش تولید آنتروپی می‌شود و پارامترهای تابش منبع حرارت، محیط متخلخل، تولید آنتروپی را به حداقل می‌رسانند. وجود پارامتر تخلخل سرعت سیال را کاهش می‌دهد، دمای سیال را بهبود می‌بخشد و تولید آنتروپی را به حداقل می‌رساند. پارامتر کسری حجمی نانوسولید هم تعداد Nussult و هم ضریب اصطکاک پوست را کاهش داد.