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ENTROPY GENERATION ANALYSIS ON HYBRID DUSTY NANOFLUID FLOW OVER A HEATED STRETCHING SHEET: AEROSPACE TECHNOLOGY

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The past few years have seen enormous investments in research and development of next generation technologies with potential use in aerospace. Engine oil provides grease, air conditioning, maintenance, rust prevention, reduced sound and turbine functioning among its many functions within an airplane engine. Among these, lubrication is paramount. Without lubrication, it goes without saying that any moving components would wear out very fast. The present study investigates the significance of heat transport properties entropy generation on MHD dusty hybrid nanofluid flow over a heated stretching sheet in the presence of heat generation. By using the suitable self-similarity variables, the partial differential equation is transformed into ordinary differential equations. After then, the dimensionless equations are solved by using the MATLAB solver in bvp4c scheme. Graphs and tables are explained how the operational factors affect fluid flow efficiency. The velocity profile enhanced for increasing magnetic field values, however the energy outline exhibited the reverse behavior, which we observed. During the course of our research, we came to the conclusion that mixed nanofluids are superior to dusty small fluids in terms of their ability to transport energy transporters.
Keywords: *Entropy generation; Dusty fluid; MHD; Thermal radiation; Hybrid nanofluid*
PACS: 44.05.+e, 44.30.+v, 44.40.+a, 47.10.ad.

1. INTRODUCTION

Researchers across a wide variety of scientific and technological sectors have been increasingly interested in tiny fluids over the course of a lengthy period of time. To produce a fluid that is devoid of impurities, such as dust tiny particles, into the surroundings represents an incredibly difficult activity. This means that regular fluids' heat transmission capacities may be enhanced by adding these millimeter- or microscopic-shaped atoms, called dust tiny particles. The identification of this group may be traced back to the presence of dusty liquids. The study and investigation that is related to such substances has shown to be beneficial in a wide range of practical scenarios, such as oil transportation, combustion, reactor tubes, and a great number of other technical sectors; a number of scientific studies are available in this field [1][2][3]. Through the use of a variety of presumptions regarding dust particles, That was the calendar year 1962, Saffman [4] discovered the mathematical formulas that govern the velocity at which dust grains move. Because it was thought that dusty molecules accumulated in the belief area formed a pseudo-fluid, he neglected to take into consideration for the relationships among individual dust grains when he used his method, Marble [5] investigated the problem of a gas containing trace amounts of solid.

Over the last several years, a significant number of researchers have been concentrating their efforts on finding methods to improve heat transfer. This has happened due to the fact that this subject is significant in a variety of corporate and technical settings. It is common practice to use biological fluids in thermal transfer, including glycol, water, and crude oil. The restricted circulation of heat which is associated using these types of liquids leads in a restriction to the thermal transfer, which is an additional aspect to consider that should be taken into consideration. The concept of small liquids was conceived with the intention of including several small particles that were dispersed across the initial substance at the same time. Because of this, the word "hybrid nanofluid" came into being as a consequence [6][7][8]. In the process of creating methods for burning and cooling, mixed nanofluids represent a major step forward. Within the moment, these small particles have been used to enhance the thermal look of liquids. Incorporating a number of different kinds of tiny particles results in the formation of a fluid with improved heat transmission. The substances in question have a broad range of applications, including but not limited to the usage of steaming water and braking fluid for automobiles. Additionally, it is used in thermal transfer systems and transformations, in addition to being utilized in frequently used domestic appliances like refrigerators. Extensive research has previously been carried out by a multitude of researchers using hybrid tiny particles in their examinations, as shown in Refs. [9][10][11][12].

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Dusty liquid atoms, measuring micro meters of in size, are dispersed throughout the foundation solution. Numerous researchers and experts are currently motivated to support the movement of dusty liquid as a consequence of its present improvements and increasing importance in the demands of connected to mechanical, commercial, technical, and pharmaceutical domains. This is due to the fact that dusty liquid is becoming increasingly prevalent. Natural gas shipment, refinery cleaning, power plant transmission lines, combustion, adaptable steel coverings, substance drying out, soil preservation by natural storms, natural reliability, health, and medical care (especially in bacterial agriculture, developing stem cells differentiation, particular molding of plastic, tumors diagnosis and treatment, and cold therapies) all make utilize dusty water [13].

The present study aims to scrutinize the carrying of hybrid nanofluid across a stretching sheet in existence of MHD and porosity with engine oil as base fluid. Also, thermal radiation is taken into account. Notwithstanding the utility of the investigation, the flow framework in problem has never been shared before and its movement characteristics have never been tested. The availability of several research addressing the industrial uses and improvements of mixed nanofluids generated the investigation. A computer technique called the bvp4c method is used to resolve the mathematical framework. In this study, we provide a qualitative evaluation of the system's characteristics. The present model may be applicable in the aerospace industry. Considering that oil is used over cooling functions in aviation machines much more frequently than water is used in automobile engines.

2. MATHEMATICAL MODEL

In the current of dusty hybrid particles, steady 2D leading hybrid nanofluid flow has been considered into the model. In this model we considered the sheet is taken as along the $x-$axis and the flow confined to $y > 0$. Here we taken the $y-$axis is normal to the sheet. The movement of the heated stretching sheet taking the $x-$axis is $U=rx$. And also, an additional M field strength B_0 is forced through $x-$axis see in (Fig. 1). Table 1 show that clear-cut outputs of the base fluid and nanoparticles. The arranged governing flow equations are [14][15][16].

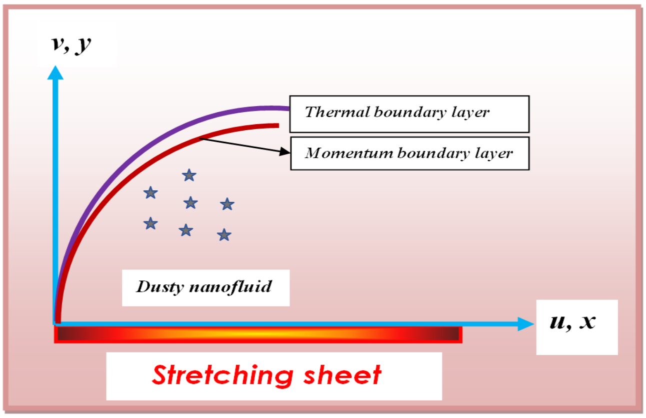

Figure 1. Geometry of the problem

Fluid phase

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\frac{\mu_{hnf}}{\rho_{hnf}}\left(\frac{\partial^2 u}{\partial y^2}\right)+\frac{KN}{\rho_{hnf}}\left(u_p-u\right)-\frac{\sigma_{hnf}B^2}{\rho_{hnf}}\left(u\right), \tag{2}$$

$$\begin{aligned} u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=&\frac{k_{hnf}}{\left(\rho c_p\right)_{hnf}}\left(\frac{\partial^2 T}{\partial y^2}\right)+\frac{N_1\left(c_p\right)_f}{\tau_T}\left(T_p-T\right)+\frac{N_1}{\tau_v}\left(u_p-u\right)^2\\ &-\frac{1}{\left(\rho c_p\right)_{hnf}}\left(\frac{\partial q_r}{\partial y}\right)+\frac{\sigma_{hnf}B^2}{\left(\rho c_p\right)_{hnf}}u^2. \end{aligned} \tag{3}$$

Dusty phase

$$\frac{\partial \overline{u_p}}{\partial x}+\frac{\partial \overline{v_p}}{\partial y}=0, \tag{4}$$

$$\overline{u_p}\frac{\partial \overline{u_p}}{\partial x}+\overline{v_p}\frac{\partial \overline{u_p}}{\partial y}=\frac{K}{m}\left(u-\overline{u_p}\right), \tag{5}$$

$$N_1 r_m\left(\overline{u_p}\frac{\partial \overline{T_p}}{\partial x}+\overline{v_p}\frac{\partial \overline{T_p}}{\partial y}\right)=\frac{N_1\left(c_p\right)_f}{\tau_T}\left(\overline{T_p}-T\right). \tag{6}$$

The appropriate flow boundary requirements that have been enforced for hybrid nano- fluid and dust phases can be stated as follows:

$$\left.\begin{array}{ll} u=U=u_w(x),\quad v=0,\ T=T_w & at\quad y=0 \\ u\to 0, \overline{u_p}\to 0, \overline{v_p}\to v, T\to T_\infty, \overline{T_p}\to T_\infty & as\quad y\to\infty \end{array}\right\}. \tag{7}$$

Thermo-physical properties of *hnf* are:

$$\mathbb{Z}_1=\frac{\mu_{hnf}}{\mu_f}, \mathbb{Z}_2=\frac{\rho_{hnf}}{\rho_f}, \mathbb{Z}_3=\frac{\sigma_{hnf}}{\sigma_f}, \mathbb{Z}_4=\frac{(\rho c_p)_{hnf}}{(\rho c_p)_f}, \mathbb{Z}_5=\frac{k_{hnf}}{k_f}, \tag{8}$$

$$\upsilon_{hnf}=\frac{\mu_{hnf}}{\rho_{hnf}},\quad \alpha_{hnf}=\frac{k_{hnf}}{(\rho c_p)_{hnf}}.$$

$$\left.\begin{array}{l} \mathbb{Z}_1=\dfrac{1}{\left(1-\phi_1\right)^{2.5}\left(1-\phi_2\right)^{2.5}}, \\ \mathbb{Z}_2=\left\{\left(1-\phi_2\right)\left[\left(1-\phi_1\right)+\phi_1\left(\dfrac{\rho_{s_1}}{\rho_f}\right)\right]+\phi_2\dfrac{\rho_{s_2}}{\rho_f}\right\}, \\ \mathbb{Z}_3=\dfrac{\sigma_{s_2}+2\sigma_{nf}-2\phi_2(\sigma_{nf}-\sigma_{s_2})}{\sigma_{s_2}+2\sigma_{nf}+\phi_2(\sigma_{nf}-\sigma_{s_2})}\times\dfrac{\sigma_{s_1}+2\sigma_f-2\phi_1(\sigma_f-\sigma_{s_1})}{\sigma_{s_1}+2\sigma_f+\phi_1(\sigma_f-\sigma_{s_1})}, \\ \mathbb{Z}_4=\left(1-\phi_2\right)\left[\left(1-\phi_1\right)+\phi_1\left(\dfrac{(\rho c_p)_{s_1}}{(\rho c_p)_f}\right)\right]+\phi_2\dfrac{(\rho c_p)_{s_2}}{(\rho c_p)_f}, \\ \mathbb{Z}_5=\dfrac{k_{s_1}+2k_{bf}-2\phi_2(k_{bf}-k_{s_2})}{k_{s_2}+2k_{bf}+\phi_2(k_{bf}-k_{s_2})}\times\dfrac{k_{s_1}+2k_f-2\phi_1(k_f-k_{s_1})}{k_{s_1}+2k_f+\phi_1(k_f-k_{s_1})} \end{array}\right\}. \tag{9}$$

Defining the similarity variables and transformations are

$$\left.\begin{array}{l} u=rxf'(\eta),\ v=-\sqrt{\upsilon_f r}f(\eta),\ \eta=\sqrt{\dfrac{r}{\upsilon_f}}y,\ \theta(\eta)=\dfrac{T-T_\infty}{T_w-T_\infty} \\ \overline{u_p}=rxF_p'(\eta),\ \overline{v_p}=-\sqrt{\upsilon_f r}F_p(\eta),\ \theta_p(\eta)=\dfrac{\overline{T_p}-T_\infty}{T_w-T_\infty} \end{array}\right\}. \tag{10}$$

The following is a transformation of equations (2)–(6) and their corresponding boundary conditions using mathematical equations (8)–(10) and the corresponding authorities.
Fluid phase

$$\frac{\mathbb{Z}_1}{\mathbb{Z}_2}f'''-\left(f'\right)^2+ff''+\frac{1}{\mathbb{Z}_2}I^*\beta^*\left(F'-f'\right)-\frac{\mathbb{Z}_3}{\mathbb{Z}_2}Mf'=0, \tag{11}$$

$$\frac{1}{\mathbb{Z}_4}\left(\frac{k_{hnf}}{k_f}+\frac{4}{3}Rd\right)Pr\theta''+Prf\theta'+PrI^*\beta_t\left(\theta_p-\theta\right)+\beta_v EcPr\left(F'-f'\right)^2+\frac{\mathbb{Z}_3}{\mathbb{Z}_4}MEc\left(f'\right)^2=0. \tag{12}$$

Dusty phase

$$\left(F'\right)^2-FF''-\beta^*\left(f'-F'\right)=0, \tag{13}$$

$$F\theta_p'+\gamma\beta_t\left(\theta_p-\theta\right)=0, \tag{14}$$

$$\left.\begin{array}{ll} f'(\eta)=1, f(\eta)=0, \theta(\eta)=1, & at\ \ \eta=0 \\ f'(\eta)=0, F'(\eta)=1, F(\eta)=f(\eta), \theta(\eta)=0, \theta_p(\eta)=0 & as\ \ \eta\to\infty \end{array}\right\} \tag{15}$$

The nondimensional parameters are:

$I^* = \dfrac{Nm}{\rho_f}$ Dust particles with mass concentration	$Br = \dfrac{\mu_f U^2}{k\Delta T}$ Brinkman number
$\alpha = \dfrac{\Delta T}{T_w}$ is the Temperature ratio parameter	$\beta_v = \dfrac{1}{r\tau_v}$ Fluid - particle interaction parameter
$\gamma = \dfrac{(c_p)_f}{r_m}$ Ratio of specific heat	$M = \dfrac{\sigma_f B^2}{r\rho_f}$ magnetic field parameter
$Rd = \dfrac{4\sigma^* T_1^3}{3k^* k_f}$ Radiation parameter	$Ec = \dfrac{U^2}{(c_p)_f (T_w - T_\infty)}$ Eckert number
$\beta_t = \dfrac{1}{r\tau_T}$ Fluid - particle interaction parameter for temperature	$Pr = \dfrac{\mu_f (c_p)_f}{k_f}$ Prandtl number
$\beta^* = \dfrac{K}{rm}$ Particle interaction parameter	

The dimensional form of C_f and Nu_r are given by

$$C_f = \frac{\tau_w}{\rho_f u_w^2} \tag{16}$$

Where shear stress τ_w is

$$\tau_w = \mu_{hnf} \left.\frac{\partial u}{\partial y}\right|_{y=0}$$

$$Nu_r = -\left(k_{hnf} + \frac{16\,\sigma^* T_1^3}{3k^* k_f}\right) \frac{r\left(\dfrac{\partial T}{\partial z}\right)_{z=0}}{(T_w - T_\infty)} \tag{17}$$

The non-dimensional form of Eqs. (16 –17) are converted as

$$Re_r^{1/2} C_f = \mathbb{Z}_1 f''(0), \tag{18}$$

$$(Re_r)^{-1/2}\; Nu_r = -\left(\frac{k_{hnf}}{k_f} + \frac{4}{3} Rd\right)\theta'(0) \tag{19}$$

Where Re_r is the local Reynolds number.

Entropy generation analysis

$$S'''_{gen} = \frac{k_f}{T_\infty^2}\left[k_{hnf} + \frac{16\sigma^* T_1^3}{3k^* k_f}\right]\left(\frac{\partial T}{\partial z}\right)^2 + \frac{\mu_{hnf}}{T_w}\left(\frac{\partial u}{\partial y}\right)^2 + \left(\frac{\sigma B^2}{T_w}\right)u^2 \tag{20}$$

The Entropy generation number N_G becomes

$$\begin{aligned} N_G &= \frac{S'''_{gen}}{\left(k_f r \Delta T / T_w \upsilon_f\right)} \\ &= \alpha\left(\mathbb{Z}_5 + \frac{4}{3} Rd\right)(\theta')^2 + \frac{Br}{(1-\phi_1)^{2.5}(1-\phi_2)^{2.5}}(f'')^2 + MBr(f')^2 \end{aligned} \tag{21}$$

The Bejan number is

$$Be = \frac{\alpha\left(\mathbb{Z}_5 + \frac{4}{3} Rd\right)(\theta')^2}{\alpha\left(\mathbb{Z}_5 + \frac{4}{3} Rd\right)(\theta')^2 + \dfrac{Br}{(1-\phi_1)^{2.5}(1-\phi_2)^{2.5}}(f'')^2 + MBr(f')^2} \tag{22}$$

Table 1. Hybrid nanoparticles of thermo physical properties [17][18][19].

Property	Engine oil	Cu	Al_2O_3
Density ρ (kgm^{-3})	884	8933	3970
Specific heat C_p $(Jkg^{-1}K^{-1})$	1910	385	375
Heat conductivity k_f $(Wm^{-1}K^{-1})$	0.144	401	40
Electrical conductivity σ $(\Omega m)^{-1}$	0.125×10^{-11}	5.96×10^{7}	131.7×10^{-2}

3. NUMERICAL METHOD

The Bvp4c method was used to numerically solve the non-dimensional system of Eqs. (11) – (14) and (15). With this technique, we started by transforming the fundamental Differential equations into a set of first-order ODEs, so that we introduced the new set of variables are

$$f = j_1, f' = j_2, f'' = j_3, f''' = j_3', \theta = j_4, \theta' = j_5, \theta'' = j_5', F = j_6,$$
$$F' = j_7, F'' = j_7', \theta_p = j_8, \theta_p' = j_8'$$

$$\begin{cases} j_1' = j_2 \\ j_2' = j_3 \\ j_3' = -\left[\dfrac{-\left(j_2\right)^2 + j_1 j_3 + \dfrac{1}{\mathbb{Z}_2} I^* \beta^* \left(j_7 - j_2\right) - \dfrac{\mathbb{Z}_3}{\mathbb{Z}_2} M j_2}{\dfrac{\mathbb{Z}_1}{\mathbb{Z}_2}}\right] \\ j_4' = j_5 \\ j_5' = -\left[\dfrac{Pr\ j_1 j_5 + Pr I^* \beta_t \left(j_8 - j_4\right) + \beta_v Ec Pr \left(j_7 - j_2\right)^2 + \dfrac{\mathbb{Z}_3}{\mathbb{Z}_4} MEc \left(j_2\right)^2}{\dfrac{1}{\mathbb{Z}_4}\left(\dfrac{k_{hnf}}{k_f} + \dfrac{4}{3} Rd\right) Pr}\right] \\ j_6' = j_7 \\ j_7' = -\left[\dfrac{\left(j_7\right)^2 - \beta^* \left(j_2 - j_7\right)}{j_6}\right] \\ j_8' = j_9 \\ j_9' = -\left[\dfrac{\gamma \beta_t \left(j_8 - j_4\right)}{j_4}\right] \end{cases}$$

As well as the boundary conditions are

$$\begin{cases} j_2\left(0\right) = 1, \\ j_1\left(0\right) = 0, \\ j_4\left(0\right) = 1, \\ j_2\left(\infty\right) = 0, \\ j_6\left(\infty\right) = 0, \\ j_7\left(\infty\right) = 0, \\ j_4\left(\infty\right) = 0, \\ j_8\left(\infty\right) = 0. \end{cases}$$

4. CODE VALIDATION

The results of the present code were compared to those obtained by Mishra et al. for the case of various values of Prandtl number, as shown in Table 2. We discovered a significant level of convergence between the current findings. In this case, the step size in the technique is $(h = 0.001)$, and the operation is frequent until the desired level (1×10^{-8}) of accuracy is reached. As a result, the current code is justified.

Table 2. Comparison of $-\theta'(0)$ for $\beta = \beta_T = Ec = \phi_1 = \phi_2 = \phi_p = 0$

Pr	Mishra et al.[14]	Present results (Bvp4c)
0.72	1.088623	1.088621
1	1.333333	1.333333
10	4.796819	4.796818

5. RESULTS AND DISCUSSION

The comparison results are obtained from Table 2, which shows the in local heat transfer rate for different values of the Pr. The findings of both investigations were determined to be quite accurate. The *M, Rd,* β_v ,I^* all are given a physical explanation in this section. The trend of M against the $f'(\eta)$ and $\theta(\eta)$ outlines are presented in Figs 2 and 4. For the larger values of M the $f'(\eta)$ outline decreased. Physically, the magnetic field M increases, it generates a Lorentz force, which converts slows down the fluid movement. Notwithstanding the fact that the Lorentz force operates in opposite to the movement of a liquid, causing it to accelerate down and consequently diminishing the velocity field, we noticed that the opposite trend was seen with regards to the profile of temperatures. The impact of I* on the velocity outline is presented in Fig 3. For the higher values of I* parameter the velocity profile declined. The impact of Rd on energy profile is seen in Fig. 5. Increasing the values of the radiation parameter will result in an improvement to the thermal profile. When viewed from a physical viewpoint, the energy barrier layer is connected to the greater temperature.

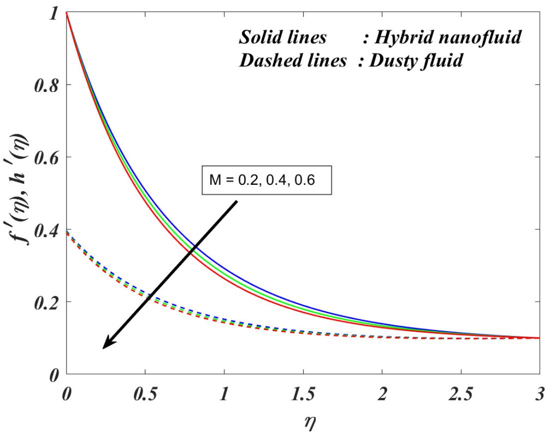

Figure 2. Sway of M on $f'(\eta), F_p'(\eta)$

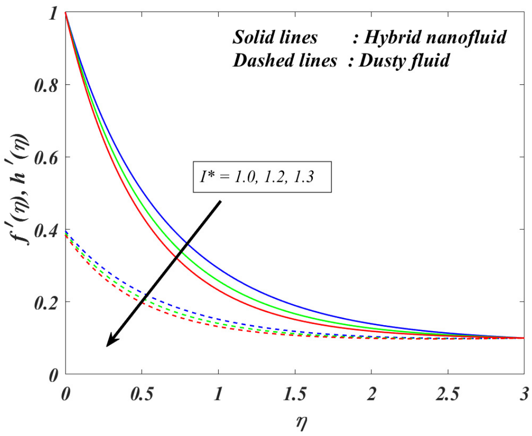

Figure 3. Sway of I^* on $f'(\eta), F_p'(\eta)$

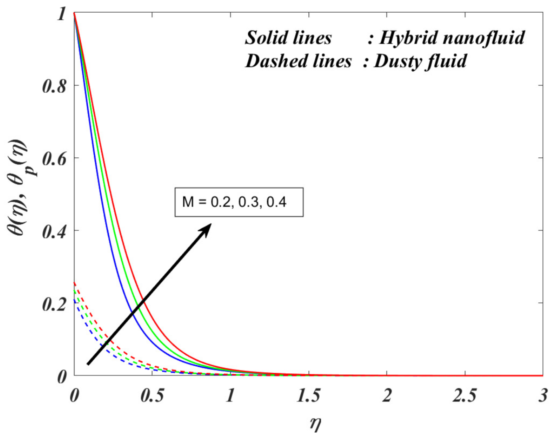

Figure 4. Sway of M on $\theta(\eta), \theta_p(\eta)$

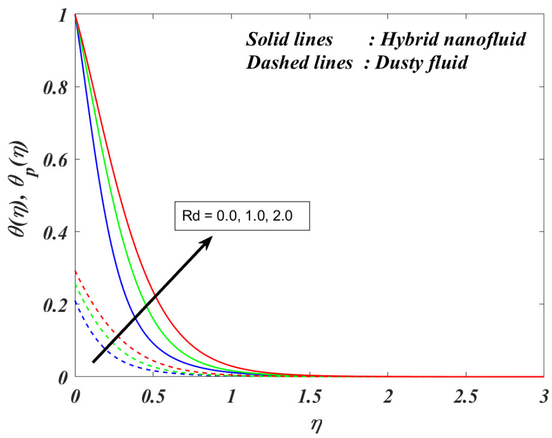

Figure 5. Sway of Rd on $\theta(\eta), \theta_p(\eta)$

Fig 6 impacts on the energy profile by changing the β_v parameter. When greater values are assigned, the β_v parameter for both the hybrid and dusty scenarios decreased, influencing the temperature profile. Fig 7 demonstrates the impact of the I^* and M on $C_f\,(Re)_r^{0.5}$.

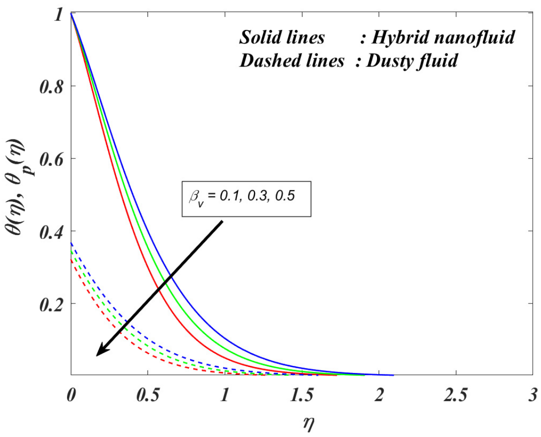

Figure 6. Sway of β_v on $\theta(\eta), \theta_p(\eta)$

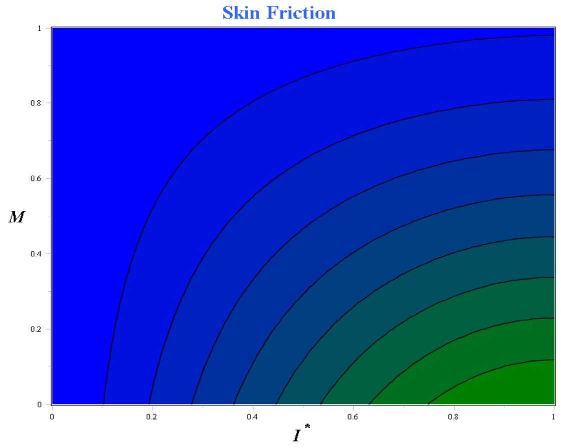

Figure 7. Sway of I^* and M on $C_f\left(Re\right)_r^{0.5}$

It shows that the $C_f\left(Re\right)_r^{0.5}$ is decreasing in increasing values of M, while the enhanced nature we noticed on enlarging the M parameter values, which is presented in Fig 8.

Fig 9. Impact of Br parameter on entropy generation outline. When increasing Br values the entropy generation profile enhanced. From a strictly physical point of view, when the Br rises, viscous dissipation becomes more important than heat transfer. The presence of an increased Brinkman number suggests that the entire system is experiencing an increased amount of viscous dissipation. In the process of viscous dissipation, the transformation of mechanical force towards temperature takes place inside the movement of the liquid. This is a consequence of the motion of friction that happens inside the fluid itself.

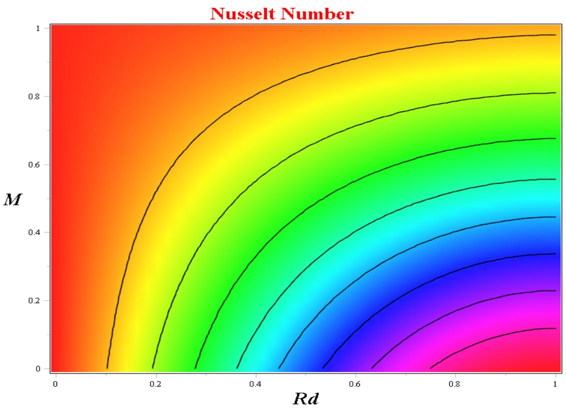

Figure 8. Sway of Rd and M on $Nu_r\left(Re\right)_r^{-0.5}$

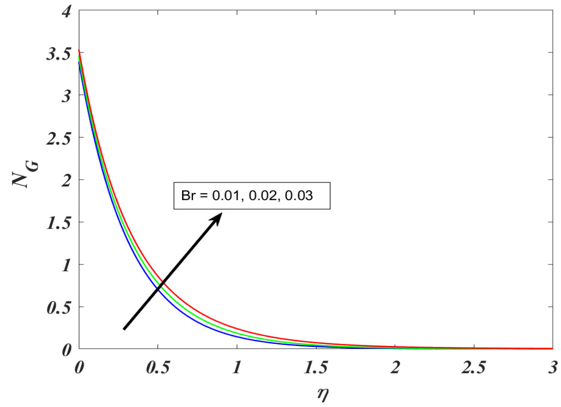

Figure 9. Sway of Br on N_G

Inside the liquid, the creation of entropy is facilitated by the transformation of energy from movement towards thermal power via this process, while the opposite trend we noticed on Fig 10.

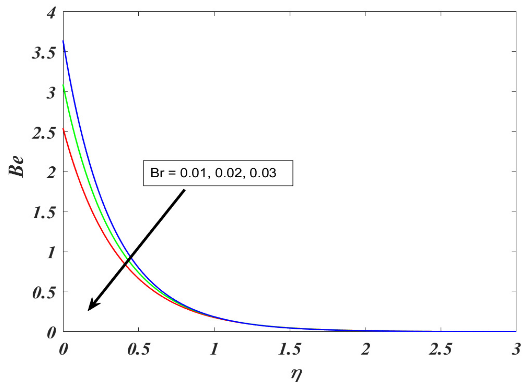

Figure 10. Sway of Br on Be

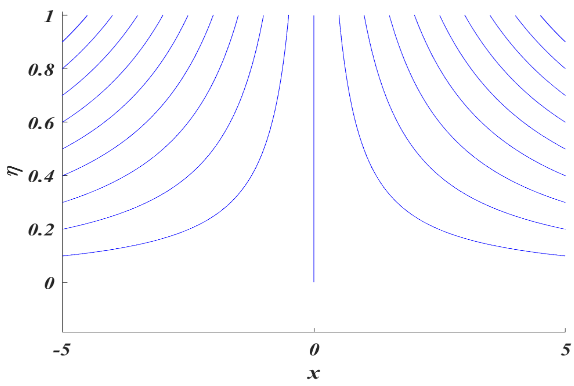

Figure 11. Sway of $M = 1.0$ for Stream lines

Through the utilization of streamlines, it is possible to demonstrate the flow of a fluid throughout a particular area in an approach that is not only clear but also simple for anyone to understand. It is possible that the utilization of streamlines will allow for an improved understanding of significant flow characteristics, such as the places for splitting, recycling zones, and areas of differential motion. The flow of fluids in a variety of structures, such as pipes, pathways, through things, and other infrastructure, may be shown and described with the use of streamlines, which are designed to guide investigators and programmers.

Figs 11, 12 and 13 shows that the $(M = 1.0, 2.0, 3.0)$ impacts on streamlines. Changing the magnetic field intensity may influence streamlines in a moving fluid structure, especially in MHD fluxes where the liquid is conductive to electricity and combines with a field of magnets. The major explanation for the influence that raising the intensity of the field of magnetic attraction has on streamlines is the Lorentz force, and this is a consequence of the relationship among the magnet domain and the positively charged particles that are present in the liquid.

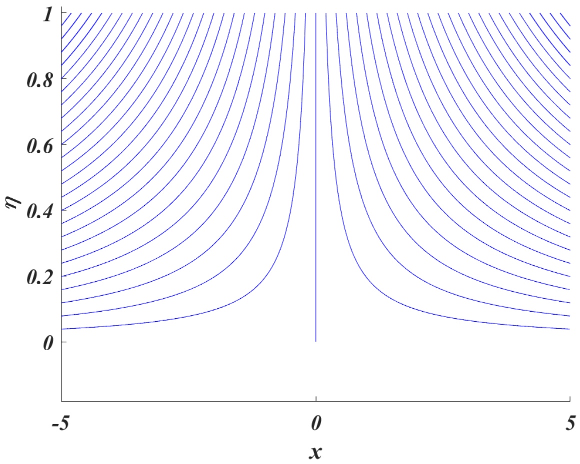

Figure 12. Sway of $M = 2.0$ for Stream lines

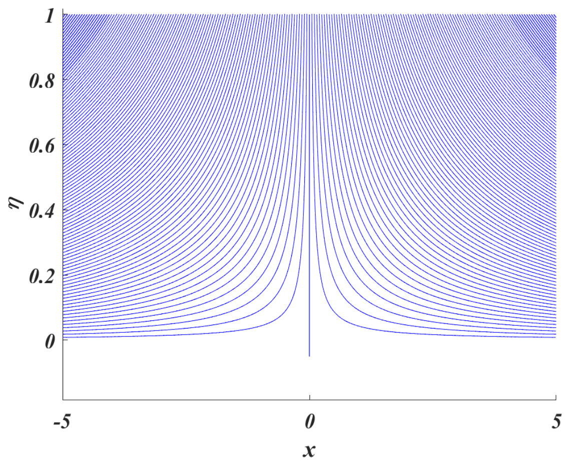

Figure 13. Sway of $M = 3.0$ for Stream lines

6. CONCLUSIONS

An investigation of a numerical model used in the entropy generation on MHD of hybrid nanofluid composed of Cu-Al_2O_3 and engine oil was carried out in the present investigation. For the purpose of resolving the problem of velocity and temperature, the numerical approach, also known as the bvp4c method. The research produced several of interesting findings, which are listed below:

- Velocity profile declined for the higher values of the magnetic field parameter values.
- The energy profile enhanced with an increasing radiation parameter value.
- The skin friction factor decreased for the larger values of the *M* parameter.
- The *Nu* outline increased, for the increasing values of the *M*.
- Streamlines have an oscillating character, which is necessary for magnifying the magnetic field parameter.

Disclosure statement
No potential conflict of interest was reported by the author(s).

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АНАЛІЗ ГЕНЕРАЦІЇ ЕНТРОПІЇ НА ГІБРИДНОМУ ПИЛОВОМУ ПОТОКУ НАНОРІДИНИ НАД НАГРІТИМ РОЗТЯГУЮЧИМ ЛИСТОМ: АЕРОКОСМІЧНА ТЕХНОЛОГІЯ

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За останні кілька років було зроблено величезні інвестиції в дослідження та розробку технологій наступного покоління з потенційним використанням в аерокосмічній галузі. Моторна олива забезпечує мастило, кондиціонування повітря, технічне обслуговування, запобігання іржі, зниження шуму та роботу турбіни серед багатьох функцій двигуна літака. Серед них першочергове значення має змащення. Зрозуміло, що без змащення будь-які рухомі компоненти дуже швидко зношуються. У цьому дослідженні досліджується значення генерації ентропії теплотранспортних властивостей у потоці пилової гібридної нанорідини МГД над нагрітим листом, що розтягується, за наявності тепла. Використовуючи відповідні змінні самоподібності, диференціальне рівняння в частинних похідних перетворюється на звичайне диференціальне рівняння. Після цього безрозмірні рівняння розв’язуються за допомогою розв’язувача MATLAB у схемі bvp4c. Графіки та таблиці пояснюють, як експлуатаційні фактори впливають на ефективність потоку рідини. Профіль швидкості посилювався для збільшення значень магнітного поля, однак енергетичний контур демонстрував зворотну поведінку, яку ми спостерігали. У ході нашого дослідження ми дійшли висновку, що змішані нанофлюїди перевершують пилоподібні невеликі рідини з точки зору їх здатності транспортувати переносники енергії.

Ключові слова: *генерація ентропії; пилова рідина; МГД; теплове випромінювання; гібридна нанофлюїд*