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Hybrid Nanofluid on Mixed Convection Flow Past a Stretching Sheet with Irregular Heat Source/Sink

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ABSTRACT

This research studies the behaviour of hybrid nanofluid on mixed convection flow over a stretching sheet by considering the effect of non-uniform heat source/sink. The chosen base fluid is water with two different nanoparticles which are copper and aluminium oxide. The governing partial differential equations are reduced into ordinary differential equations using a similarity transformation technique. The resulting governing system then solved numerically using Keller-box method. The influence of space- and temperature-dependents of non-uniform heat source and sink parameters as well as the unsteadiness parameter is presented graphically. The current study shows that, the space- and temperature dependents of non-uniform heat source and sink significantly raises the fluid's temperature. Comparative study also shows that hybrid nanofluid has higher temperature and heat transfer coefficient than single nanofluid and conventional fluid. It can also be concluded that, the enhancement of heat transfer rate can be achieved by reducing the parameter of space- and temperature dependents of non-uniform heat source and sink.

1. Introduction

Conventional heat transfer fluid, such as water, oil, and ethylene glycol are a medium for transporting or transferring heat energy. The low conductivity of conventional heat transfer fluid has inspired the researchers to consider the implementation of combining two or more nano-size particles in a base fluid, which sizes range from 1 to 100 nanometers. The process of dispersing two or more nano-size particles into a base fluid is known as hybrid nanofluid. Muneeshwaran *et al.,* [1] found that hybrid nanofluid successfully attains a synergistic effect of high thermal conductivity. Furthermore, hybrid nanofluid has a better thermophysical and rheological properties due to its characteristic in high surface area, high dispersion stability and a reduction in pumping power. Hybrid nanofluid are widely used in applications such as heat exchangers, transportation, coolant applications and solar energy. Therefore, the investigation of the hybrid nanofluid as a heat transfer enhancement has gradually increasing in recent years. Hayat and Nadeem [2] explored the chemical reaction and heat generation as well as radiation effect on the three-dimensional rotating hybrid

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nanofluid. The study found that the considered effects significantly influenced the heat transfer rate of hybrid nanofluid compared than nanofluid. The behaviour of hybrid nanofluid on both shrinking and stretching sheet was studied by Khan *et al.,* [3], and found that the hybrid nanofluid has a greater heat transfer characteristic. The research was then extended by Mousavi *et al.,* [4], which the impact of radiation and suction were considered. The influence of radiation and slip factor on hybrid nanofluid flow over a permeable Darcy porous medium was observed by Bakar *et al.,* [5]. Jamaluddin *et al.,* [6] studied an incompressible Cross fluid over a shrinking sheet in the case of heat transfer properties in the presence of thermal radiation and suction effect.

Besides, the impact of heat source/sink are significant in heating and cooling applications. Heat source, also known as heat generation. Heat generation release heat energy into the fluid. Conversely, heat sink, also known as heat absorption, absorbs the heat energy from the fluid. The uniform heat source/sink is a constant heat generation/absorption. However, non-uniform heat source/sink is a function of space and temperature. The impact of non-uniform heat source/sink on magnetic nanofluid was analysed by Raju *et al.,* [7]. Raju and Reddy [8] who investigated the non-Newtonian Casson fluid on permeable stretching sheet discovered that the heat transfer flow was affected by irregular heat source and sink. Ragupathi *et al.,* [9] studied the 3D flow of hybrid nanofluid on a Riga plate with irregular heat source/sink. The study found that the non-uniform heat source/sink increases the thermal boundary layer. In addition, a thin nanofluid film with transverse magnetic field and thermal radiation effect which are investigated by Pal *et al.,* [10], successfully showed that the heat source produced an internal energy in the boundary layer flow, while the heat sink significantly affected the cooling process.

Next, the study of mixed convection flow is crucial, particularly in the electronic equipment, heat exchangers, and nuclear reactors. Mixed convection flow is the combination of natural (commonly referred to as buoyancy force) and forced (commonly referred to as pressure force) convection flow, those mixed convection flow is a situation where both pressure force and buoyancy force interact. Furthermore, the study of boundary layer mixed convection flow is essential in glass fibre production, extraction of polymer, crystal growing, and hot rolling Anuar *et al.,* [11]. Armaghani *et al.,* [12] investigated the effect of heat source/sink on magneto-hydrodynamics (MHD) mixed convection flow in an L-shape cavity. El-Shorbagy *et al.,* [13] investigated the variable fin thickness on a mixed convection flow of hybrid nanofluid under the influence of magnetic field. Moreover, the flow driven by stretching sheet has several applications, including fibre spinners, metal continuous casting, cooling of large magnetite plates in a bath, and particle suspension [14].

Motivated by the cited literature, the present work examines the mixed convection flow of hybrid nanofluid over a stretching sheet. The impact of non-uniform heat source and sink effects on hybrid nanofluid (water + copper + aluminium oxide) is focused. Furthermore, the comparative studies of the thermal characteristic in Newtonian fluid (water), nanofluid (water + copper) and hybrid nanofluid are conducted. The numerical results are presented in graphical and tabular form.

2. Problem Formulation

A two-dimensional mixed convection flow of hybrid nanofluid over a stretching sheet is considered. The water-based hybrid nanofluid Cu and Al_2O_3 nanoparticles is assumed to be an unsteady incompressible viscous fluid. In this problem, the effect of uniform heat source and sink on the heat transfer behaviour is analyzed. Let, q''' be the non-uniform heat source/sink and is modeled as [15]:

$$q''' = \frac{U_w(x)k_{hnf}}{x\nu_{hnf}}\left[A(T_w - T_\infty)f'(\eta) + B(T - T_\infty)\right] \tag{1}$$

where space- and temperature - dependent of non-uniform heat source/sink parameter are defined by A and B. It is important to note that when $A, B < 0$ represent the heat sink, while $A, B > 0$ holds the heat source. The velocity of the stretching sheet is assumed to have the velocity in the form of $u_w(x) = \frac{ax}{1-ct}$ and where a is the initial rate of stretching velocity, whereas $c > 0$ is the constant with the dimension of time, respectively. Also, the temperature near the stretched surface, T_w is considered as a function of the distance *x* and time, *t* given in the following form, $T_w(x) = T_\infty + \frac{bx}{(1-ct)^2}$ and is assumed to be higher than the fluid of surrounding temperature, T_∞.The governing equations can be expressed as follow [16],

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{2}$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \frac{\mu_{hnf}}{\rho_{hnf}}\frac{\partial^2 u}{\partial y^2} + g\frac{(\rho\beta)_{hnf}}{\rho_{hnf}}(T - T_\infty) \tag{3}$$

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha_{hnf}\frac{\partial^2 T}{\partial y^2} + \frac{q'''}{(\rho C_p)_{hnf}} \tag{4}$$

subject to the initial and boundary conditions,

$$\begin{aligned} &u = u_w, v = 0, T = T_w \text{ at } y = 0 \\ &u = 0, T = T_\infty \text{ at } y \to \infty \end{aligned} \tag{5}$$

Parameter *u* and *v* are the velocity components along the direction *x* and *y* axes respectively.g signifies the gravitational acceleration and T is the temperature of the fluid, while the density of the hybrid nanofluid denotes by ρ_{hnf}, $(\rho\beta)_{hnf}$ is the thermal expansion coefficients of the hybrid nanofluid, $(\rho C_p)_{hnf}$ is the specific heat capacitance of hybrid nanofluid, k_{hnf} is thermal conductivity of hybrid nanofluid and ν_{hnf} is the kinematic viscosity of hybrid nanofluids, respectively. The considered physical properties of hybrid nanofluid for viscous Newtonian fluid referred to Refs. [17, 18] is described in the following table.

Table 1
The physical properties of hybrid nanofluid

Thermophysical	Expression of hybrid nanofluid
Density	$\rho_{hnf} = (1-\varphi)\rho_f + \varphi_{1p}\rho_{1p} + \varphi_{2p}\rho_{2p}$, where $\varphi = \varphi_{1p} + \varphi_{2p}$
Dynamic viscosity	$\mu_{hnf} = \frac{\mu_f}{(1-\varphi)^{2.5}}$
Thermal conductivity	$\frac{k_{hnf}}{k_f} = \frac{k_{1p} + k_{2p} + 2(1-\varphi)k_f + 2\varphi_{1p}k_{1p} + 2\varphi_{2p}k_{2p}}{k_{1p} + k_{2p} + (2+\varphi)k_f - \varphi_{1p}k_{1p} - \varphi_{2p}k_{2p}}$
Specific heat capacitance	$(\rho C_p)_{hnf} = (1-\varphi)(\rho C_p)_f + \varphi_{1p}(\rho C_p)_{1p} + \varphi_{2p}(\rho C_p)_{2p}$
Thermal expansion coefficient	$(\rho\beta)_{hnf} = (1-\varphi)(\rho\beta)_f + \varphi_{1p}(\rho\beta)_{1p} + \varphi_{2p}(\rho\beta)_{2p}$

In this table, φ represent the nanoparticle volume fraction where φ_{1p} and φ_{2p} denotes Cu and Al_2O_3 nanoparticles. Moreover. The subscript *hnf*, *f* and *p* represent the hybrid nanofluid, base fluid, and solid particle, respectively. Consider, the following similarity transformation [16]:

$$\eta = \sqrt{\frac{a}{v_f(1-ct)}}y, \psi(x,y,t) = \sqrt{\frac{av_f}{1-ct}}xf(\eta), \theta(\eta) = \frac{T-T_\infty}{T_w-T_\infty} \tag{6}$$

where η is the similarity variable and is the stream function that is defined by:

$u = \frac{\partial\psi}{\partial y}$ and $v = -\frac{\partial\psi}{\partial x}$

By applying the similarity transformations (6), the governing Eq. (2) to Eq. (4) also boundary conditions (5) are then transformed to:

$$\frac{\partial^3 f}{\partial\eta^3} + (1-\varphi)^{2.5}\left[D_1\left[f\frac{\partial^2 f}{\partial\eta^2} - \left(\frac{\partial f}{\partial\eta}\right)^2 - S\left(\frac{\partial f}{\partial\eta} + \frac{\eta}{2}\frac{\partial^2 f}{\partial\eta^2}\right)\right] + D_2\lambda\theta\right] = 0 \tag{7}$$

$$\frac{\partial^2\theta}{\partial\eta^2} + (1-\varphi)^{2.5} D_1\left[A\frac{\partial f}{\partial\eta} + B\theta\right] + \frac{\Pr D_3}{D_4}\left[f\frac{\partial\theta}{\partial\eta} - \frac{\partial f}{\partial\eta}\theta - S\left(2\theta + \frac{\eta}{2}\frac{\partial\theta}{\partial\eta}\right)\right] = 0, \tag{8}$$

where D_1, D_2, D_3 and D_4 are constants, which are defined:

$$D_1 = (1-\varphi) + \varphi_{1p}\frac{\rho_{1p}}{\rho_f} + \varphi_{2p}\frac{\rho_{2p}}{\rho_f},$$

$$D_2 = (1-\varphi) + \varphi_{1p}\frac{(\rho\beta)_{1p}}{(\rho\beta)_f} + \varphi_{2p}\frac{(\rho\beta)_{2p}}{(\rho\beta)_f},$$

$$D_3 = (1-\varphi) + \varphi_{1p}\frac{(\rho C_p)_{1p}}{(\rho C_p)_f} + \varphi_{2p}\frac{(\rho C_p)_{2p}}{(\rho C_p)_f},$$

$$D_4 = \frac{k_{hnf}}{k_f}.$$

The same procedure of transformation technique is also applied on the initial and boundary conditions (4). As a result, the transformed conditions are given below:

$$\begin{aligned} &\frac{\partial f}{\partial\eta} = 1, f = 0, \theta = 1, \text{ at } \eta = 0, \\ &\frac{\partial f}{\partial\eta} = 0, \theta = 0, \text{ at } \eta \to \infty, \end{aligned} \tag{9}$$

Here, θ is the dimensionless temperature, $\mathrm{Pr} = {(rC_p)_f v_f} \big/ {k_f}$ is Prandtl number, $S = \frac{c}{a}$ is the unsteadiness parameter and $\lambda = \frac{gb(\rho\beta)_f}{\rho_f a^2}$ is buoyancy parameter. Furthermore, the local heat transfer rate is the physical quantity of interest in this research, which the local heat transfer rate is measured in terms of the Nusselt number, Nu_x. Thus, the heat transfer coefficient, $Nu_x \big/ \mathrm{Re}_x^{1/2}$ is given by:

$$\frac{Nu_x}{\mathrm{Re}_x^{1/2}} = -\ D_4 q'(0) \tag{10}$$

given that Reynold number, Re_x is defined as $\mathrm{Re}_x = \frac{xU_w}{v_f}$ [19].

3. Results and Discussion

The Keller-box method is used to solve the system of coupled ordinary differential Eq. (7) – Eq. (8) and transformed boundary conditions (9). The Keller-box method consists of four major steps, which is given in Figure 1. The analysis is focused on the flow behaviour as well as the heat transfer properties by considering the various values of space- and temperature- dependent of non-uniform heat source/sink parameter, A and B as well as the unsteadiness parameter, S. Table 2 indicates the thermophysical properties of the chosen base fluid and nanoparticles [20, 21].

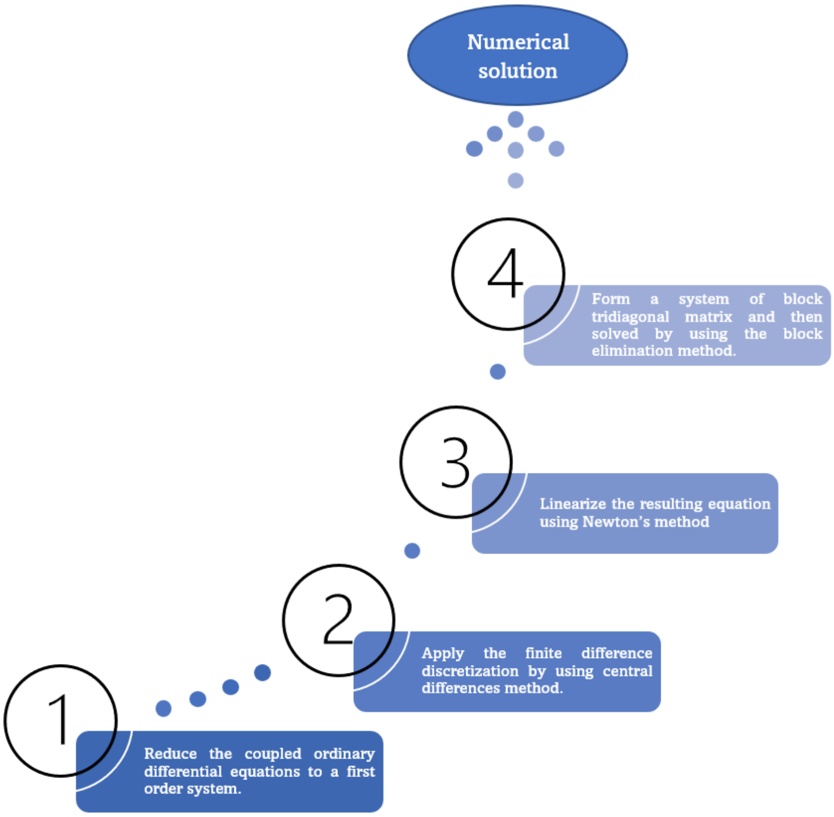


Fig. 1. Major steps in Keller-box method

Table 2
The physical properties of chosen base fluid and nanoparticles

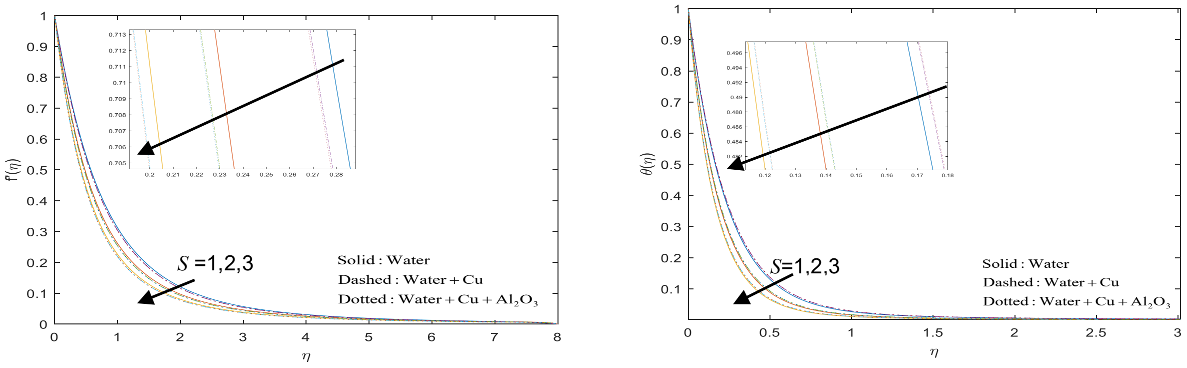
Physical Properties	Density $r\left(\mathrm{kg/m^3}\right)$	Thermal expansion $b\left(\mathrm{K^{-1}}\right)$	Thermal conductivity k $\left(\mathrm{W/mK}\right)$	Specific heat capacity $C_p\left(\mathrm{J/kgK}\right)$
Water, H_2O	997.1	0.00021	4179	0.613
Copper, Cu	8933	0.0000167	385	401
Aluminium Oxide, Al_2O_3	3970	0.0000085	765	40

A comparison study is conducted by comparing the present results with published works to measure the accuracy of the method as depicted in Table 3. The present results were in a good agreement with the cited literature. Next, the profiles of the mixed convection flow of hybrid nanofluid with the presence of non-uniform heat source/sink is graphically presented in Figures 2 – 4. For the graphical results, the parameters are fixed as $S = 0.5$, $A = 0.5$, $B = 0.5$, $\lambda = 0.5$, $\varphi_{1p} = 0.01$, $\varphi_{2p} = 0.01$, and Prandtl number, $\Pr = 6.2$. In addition, the numerical results for all considered parameter is presented for three different types of fluid, which are Newtonian fluid $\left(\varphi_{1p} = \varphi_{2p} = 0\right)$, single nanofluid $\left(\varphi_{2p} = 0\right)$ and hybrid nanofluid.

Table 3
Result comparison for local Nusselt number, $-\theta'(0)$ at $\varphi = \lambda = S = A = B = 0$

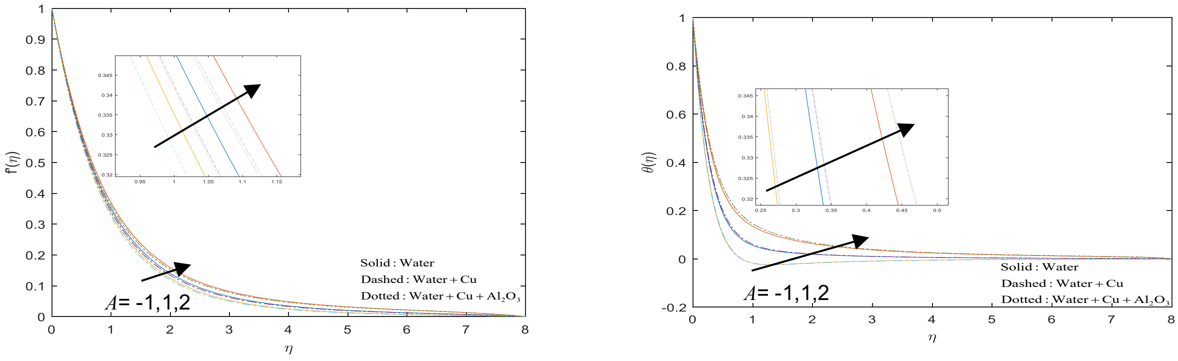
Pr	Ishak *et al.,* [22]	Elgazery *et al.,* [16]	Present results
0.72	0.8086	0.80863	0.8088
1	1.0000	1.00001	1.0001
3	1.9237	1.92368	1.9237
7	3.0723	3.07224	3.0724

Figure 2 present the velocity, $f'(\eta)$ and temperature profiles, $\theta(\eta)$ for different values of S, respectively. It is observed that increasing S decrease the velocity and temperature profiles. In this study, the unsteadiness parameter depends on the ratio of time and stretching velocity. Basically, the higher value of S is due to a lower stretching surface velocity and lower thermal boundary layer. Lower stretching surface velocity led to the velocity profile to decrease, while lower thermal boundary layer decreases the temperature profile. Next, the analysis on the effect of *A* is illustrated in Figures 3(a) and 3(b). It can be observed that, the increase of *A* enhances both velocity and temperature profiles. It is apparent from Figure 3(b) that, the variation of $\theta(\eta)$ change very significantly for three different types of fluids. It can also be noticed that the influence of *B* possesses the similar behaviour on $f'(\eta)$ and $\theta(\eta)$. It is worth mentioning that the increment of *B* generates more heat energy and consequently increase the thermal boundary layer as well as the thermal diffusivity of the fluids.



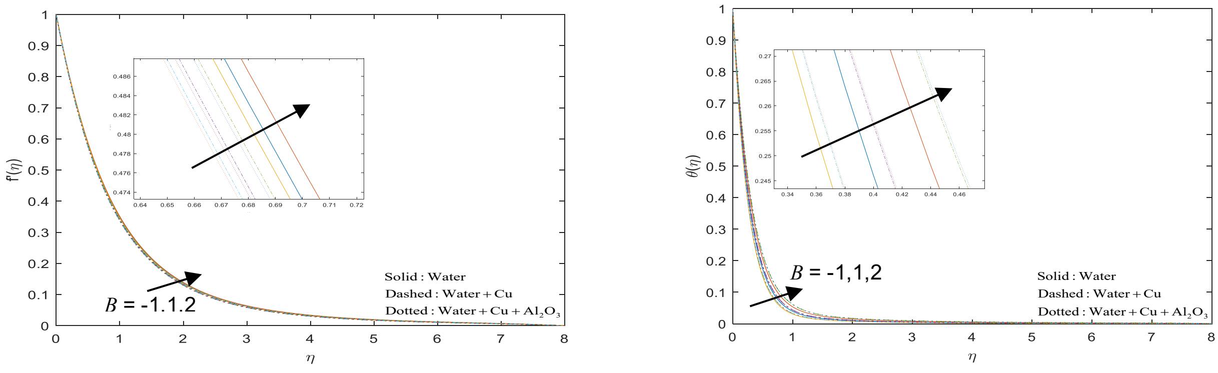
(a) (b)

Fig. 2. Velocity and temperature profiles for different values of S for three different fluids



(a) (b)

Fig. 3. Velocity and temperature profiles for different values of A for three different fluids



(a) (b)

Fig. 4. Velocity and temperature profiles for different values of B for three different fluids

The impact of S, A, and B on the heat transfer coefficient, $Nu_x \big/ \mathrm{Re}_x^{1/2}$ for three different types of fluid are shown in Table 4. It can be observed that, the increment of S improves the heat transfer coefficient for Newtonian fluid, single nanofluid and hybrid nanofluid, respectively. However, the reverse trend has been observed for the increasing values of A and B. In addition, it is summarized that the heat transfer coefficient of nanofluid and hybrid nanofluid are higher than Newtonian fluid.

Table 4

The impact of S, A, and B on heat transfer coefficient, $Nu_x / \mathrm{Re}_x^{1/2}$.

Parameter		Newtonian	Nanofluid	Hybrid nanofluid
S	1	4.2030	4.2437	4.2363
	2	5.3456	5.4071	5.3984
	3	6.2854	6.3625	6.3526
A	-1	3.8653	3.9254	3.9198
	1	3.3742	3.3884	3.3813
	2	3.1254	3.1162	3.1085
B	-1	3.7129	3.7618	3.7560
	1	3.4227	3.4400	3.4330
	2	3.2667	3.2656	3.2578

4. Conclusions

Numerical solution for mixed convection flow of hybrid nanofluid past a stretching sheet with the presence of non-uniform heat source/sink is presented in this paper. The following conclusions which can be draws from the results are:

i. Hybrid nanofluid has higher temperature profile and lower velocity profile when compared with single nanofluid and Newtonian fluid.
ii. The enhancement of   improves the heat transfer coefficient by 49.55% for Newtonian fluid, 49.93% for single nanofluid and 49.96% for hybrid nanofluid, respectively.
iii. The decrement of A and B have increased the heat transfer rate of hybrid nanofluid by 26.01% and 15.29%.

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