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GENERATION OF ENTROPY FOR MHD FLOW OF CASSON FLUID PAST A VERTICAL CONE WITH DUFOUR EFFECT

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Entropy generation is a crucial aspect of fluid dynamics and happens during all flow processes. In a sense, entropy indicates how to minimise thermal energy losses. This study examines entropy generation for a magnetohydrodynamic Casson fluid flow subject to a vertical cone. Here, impact of reaction by chemical and diffusion-thermo is scrutinized. Physical aspects of radiative flux transverse to the surface are deliberated. The governing non-linear PDEs and the total entropy expression are non-dimensionalized with the dimensionless quantities. Finite difference technique is implemented to get numerical and graphical results for the non-linear system. Entropy generation and Bejan number for the heat transfer has been analysed through plots and tables. The obtained results demonstrate that the embedded flow parameters have a considerable influence on both Bejan number and entropy generation. Bejan number with the influence of Casson parameter has a proportional effect with the Hartmann number and it falls with the rise in Dufour effect.

Key words: MHD, Casson, Dufour, FDM, entropy.

1. Introduction

The improvement of different machines and upgraded technologies have influenced researchers in flow of fluid past a vertical cone. Various industrial and engineering phenomenon have application of fluid flow through cone-shaped geometry. Extensive experimental analytical studies have been carried out for free convection with incorporation of varies conditions along vertical cone as well as inclined plane. Takhar *et al.* [1] discussed the convective flow through vertical cone with magnetic field and time-dependent angular velocity. Their results indicate the significant impact of magnetic field on velocity and temperature. The influence of the decreasing angular velocity on the temperature and the velocity fields is not directly proportional to the increasing angular velocity.

With the extension of research in MHD field, researchers have extended their work to non-Newtonian fluid where the flow characteristics are more explicable than the flow characteristics of Newtonian fluid. Casson fluid with the properties of shearing thinning is most commonly used non-Newtonian fluid. MHD flow of a Casson fluid through vertical cone has recently been able to draw the attention of many researchers.

Chamkha and Rashad [2] numerically analysed the influence of Dufour and Soret effect with incorporation of reaction by chemical and magnetic field through rotating vertical cone. Vijayaragavan *et al.* [3] have presented the analysis of Casson fluid through an inclined plate Dufour effect and reaction by chemical. Here perturbation method is used to obtain the expression for fluid velocity, concentration, and temperature. Venkateswarlu and Narayana [4] investigated the convective Casson fluid with the influence of variable thermal conductivity. They have considered electrically conducting fluid flow which is induced by Stretching surface. Their results indicate the significant impact of thermal conductivity parameter on the heat

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and mass transfer rate. Seth *et al.* [5] investigated the MHD convective flow in non-Darcy porous medium. The process of heat transfer can be accompanied by entropy generation or thermodynamic irreversibility. Entropy generation may be owing to viscous effects and heat transfer in a flow process.

Generation of entropy for a MHD flow have recently been able to grab the attention for different researchers. Many researchers have contributed their work on entropy generation for a MHD flow. Bejan [6] analysed in detail the generation of entropy owing to heat transfer and viscous effects along finite temperature gradients. Bassam *et al.* [7] analysed the entropy for free convective flow from a rotating cylinder. Their results displayed that buoyancy parameter and Reynolds number proportionally rise with the rise in entropy generation. Mahmud and Islam [8] examined numerically the entropy generation inside a wavy enclosure.

Hussain *et al.* [8] analysed the impact of magnetic field of Casson fluid with Galerkin finite element method. He further analysed entropy for double diffusive free convection in staggered cavity. Their findings show that entropy generation rise for lower values of Hartmann number. Oliveski *et al.* [10] has numerically analysed the entropy generation for a free convection in rectangular cavities. He deliberated entropy generation owing to flow friction and transfer of heat.

Abdelhameed [11] examined the entropy generation of MHD flow in case of Newtonian fluid. He applied both finite difference methods and Laplace transform to find the solution. Hooman *et al.* [12] have analysed the viscous dissipative effect on heat transfer with entropy analysis. Shit *et al.* [13] examined entropy generation for unsteady MHD flow of nanofluid in a porous medium. Afsana *et al.* [14] have investigated the entropy generation for a ferrofluid in a wavy enclosure by finite volume method. Khan *et al.* [15] have deliberated entropy generation of a MHD flow through rotating cone with the influence of Dufour and Soret effect. His results provide excellent agreement with the previous results.

The present study of entropy generation for a MHD flow of a Casson fluid through a vertical cone is expected to be of great importance in various fields of energy storage systems and in heat exchangers. Heat transfer can be accompanied by entropy generation which has its various applications in different engineering processes. Hence, from the above literature and its numerous applications have inspired the current analysis. The novelty of the present analysis are as follows:

- To examine entropy generations of MHD flow through a vertical cone in addition with the features of flow velocity, temperature and concentration.
- Bejan number for the heat transfer has been analysed with the incorporation of chemical reaction, radiation effect on rate of heat transfer and diffusion-thermo for a convective flow.
- Entropy generation and Bejan number are analysed in accordance with the magnetic parameter.
- The non-dimensional governing equations are solved numerically by FDM in MATLAB.

2. Flow analysis and formation of problem

An unsteady flow of a viscous and incompressible MHD flow of a Casson fluid past a vertical cone is considered. The fluid is electrically conducting with the effect of reaction by chemical and Dufour effect. The surface concentration and temperature are assumed to be non-uniform. Along the boundary layer, the pressure gradient and viscous dissipative effect is chosen to be negligible. On the surface of the cone a uniform magnetic field B_0 is applied normally. The radiative heat flux q_r exist transverse to the cone surface.

The temperature on the cone's surface and surrounding the fluid is considered to be same, i.e., T_∞ and the temperature at a time $t>0$ increases to $T_\infty + ax^n$. The concentration C_∞ on the cone's surface and surrounding the fluid is assumed to be same and at a time $t>0$ the concentration changes to $C_\infty + bx^m$. According to the Fig.1 the x denotes the surface distance from the apex of the cone and y denotes the outside distance.

The equations governing the flow problem according to Dutta and Sharma [16] and under Boussinesq approximation are:

$$\frac{\partial(ru)}{\partial x} + \frac{\partial(rv)}{\partial y} = 0, \tag{2.1}$$

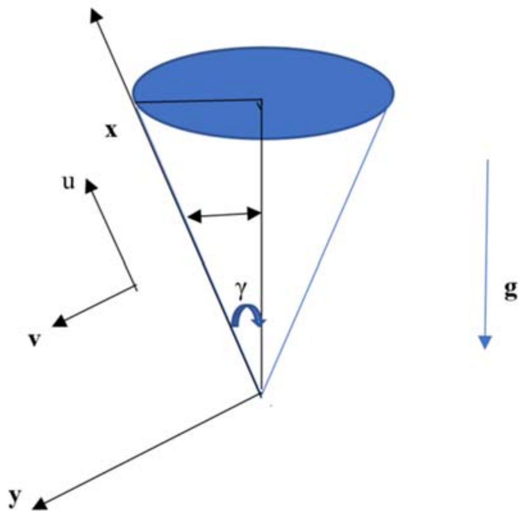


Fig.1. Configuration of the problem.

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu\left(1+\frac{1}{\alpha}\right)\frac{\partial^2 u}{\partial y^2}+g\beta(T_w-T_\infty)\cos\gamma+g\beta^*(C_w-C_\infty)\cos\gamma-\frac{\sigma}{\rho}B_0^2u, \tag{2.2}$$

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\lambda\frac{\partial^2 T}{\partial y^2}-\frac{1}{\rho C_p}\frac{\partial q_r}{\partial y}+\frac{D_M K_T}{C_s C_p}\left(\frac{\partial^2 C}{\partial y^2}\right), \tag{2.3}$$

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_M\frac{\partial^2 C}{\partial y^2}-K(C-C_\infty), \tag{2.4}$$

$$\begin{aligned}&t\le 0: u=0,\ v=0,\ T=T_\infty,\ C=C_\infty \ \text{ for all } x \text{ and } y,\\ &t>0: u=1,\ v=0,\ T_w(x)=T_\infty+ax^n,\ C_w(x)=C_\infty+bx^m \ \text{ at } y=0,\end{aligned} \tag{2.5}$$

$$\begin{aligned}&u=0,\ T=T_\infty,\ C=C_\infty \ \text{ at } x=0,\\ &u\to 0,\ T\to 0,\ C\to 0 \ \text{ as } y\to\infty.\end{aligned} \tag{2.6}$$

Non-dimensional quantities are:

$$y'=\frac{y}{L}(Gr_L)^{\frac{1}{4}},\quad x'=\frac{x}{L},\quad r'=\frac{r}{L}\quad \text{where}\quad r=x\sin\phi,$$

$$u'=\frac{uL}{\nu}(Gr_L)^{\frac{-1}{2}},\quad v'=\frac{vL}{\nu}(Gr_L)^{\frac{-1}{4}},\quad t'=\frac{\nu t}{L^2}(Gr_L)^{\frac{1}{2}},\quad \theta=\left(\frac{T-T_\infty}{T_w-T_\infty}\right),\quad \phi=\left(\frac{C-C_\infty}{C_w-C_\infty}\right),$$

$$Gr_L=\frac{g\beta(T_w-T_\infty)L^3\cos\gamma}{\nu^2},\quad Gr_C=\frac{g\beta^*(C_w-C_\infty)L^3\cos\gamma}{\nu^2},\quad Pr=\frac{\nu}{\lambda},\quad Sc=\frac{\nu}{D_M},$$

$$M=\frac{\sigma B_0{}^2L^2}{\nu}\left(Gr_L\right)^{\frac{-1}{2}},\ N=\left(\frac{Gr_c}{Gr_L}\right),\ Ra=\frac{K_e\rho\lambda C_p}{4\sigma_s T_\infty^3},\ k'=\frac{KL^2}{\nu}\left(Gr_L\right)^{\frac{-1}{2}},\ Du=\frac{D_M K_T\left(C_w-C_\infty\right)}{\nu C_s C_p\left(T_w-T_\infty\right)}.$$

The radiative term $\frac{\partial q_r}{\partial y}$ present in (2.3) can be simplified by using Rosseland approximation as Seth *et al.* [5] is:

$$q_r=-\frac{4\sigma_s}{3k_e}\frac{\partial T^4}{\partial y} \tag{2.7}$$

where Stefan-Boltzmann constant is σ_s and the mean absorption coefficient is k_e.

The temperature difference is not significantly enough within the flow, so we may expand T^4 into Taylor's series about the free-stream degree of heat. The approximation's outcome takes on the form by ignoring the higher order elements:

$$T^4\cong 4T_\infty^3 T-3T_\infty^4\,. \tag{2.8}$$

Using the approximations (2.7) and (2.8), the energy Eq.(2.3) transforms to:

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\lambda\frac{\partial^2 T}{\partial y^2}+\frac{1}{\rho C_p}\frac{16\sigma_s T_\infty{}^3}{3k_e}\frac{\partial^2 T}{\partial y^2}+\frac{\mu D_M K_T}{C_s\rho C_p}\left(\frac{\partial^2 C}{\partial y^2}\right). \tag{2.9}$$

The governing equations in their non-dimensional version are:

$$\frac{\partial\left(ru'\right)}{\partial x'}+\frac{\partial\left(rv'\right)}{\partial y'}=0\,, \tag{2.10}$$

$$\frac{\partial u'}{\partial t'}+u'\frac{\partial u'}{\partial x'}+v'\frac{\partial u'}{\partial y'}=\left(1+\frac{1}{\alpha}\right)\frac{\partial^2 u'}{\partial y'^2}+\left(\theta+N\phi\right)-Mu'\,, \tag{2.11}$$

$$\frac{\partial\theta}{\partial t'}+u'\frac{\partial\theta}{\partial x'}+v'\frac{\partial\theta}{\partial y'}=\frac{1}{\Pr}\left(1+\frac{4}{3Ra}\right)\frac{\partial^2\theta}{\partial y'^2}+Du\left(\frac{\partial^2\phi}{\partial y'^2}\right), \tag{2.12}$$

$$\frac{\partial\phi}{\partial t'}+u'\frac{\partial\phi}{\partial x'}+v'\frac{\partial\phi}{\partial y'}=\frac{1}{Sc}\frac{\partial^2\phi}{\partial y'^2}-Kr\phi\,. \tag{2.13}$$

Non-dimensional boundary conditions:

$$t'\le 0: u'=0,\ v'=0,\ \theta=0,\ \phi=0 \quad \text{for all} \quad x', y', \tag{2.14}$$

$$t'>0: u'=1,\ v'=0,\ \theta=x'^{n},\ \phi=x'^{m} \quad \text{at} \quad y'=0, \tag{2.15}$$

$$u'=0,\ \theta=0,\ \phi=0, \quad \text{at} \quad y'=0, \tag{2.16}$$

$$u'\to 0,\ \theta\to 0,\ \phi\to 0 \quad \text{as} \quad y'\to\infty. \tag{2.17}$$

3. Solution of the problem

The non-dimensional governing equation for the unsteady MHD flow problem past through a vertical cone is solved numerically by finite difference method. It is distinguished technique which is applied to solve the results graphically and in tabular form. The primary goal of FDM is to replace continuous derivatives with difference formulas that contain discrete values associated with mesh positions. Its application is to substitute all derivatives with difference formulas. The entropy generation for a free convection is associated with transfer of heat and flow friction of the fluid. The total entropy (S_t), according to Bejan [6] is expressed as follows:

$$S_t = \frac{k}{T_0^2}\left[\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2\right] + \frac{\mu}{T_0}\left[2\left(\frac{\partial u}{\partial x}\right)^2 + 2\left(\frac{\partial v}{\partial y}\right)^2 + \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)^2\right] \tag{3.1}$$

where T_0 is the bulk degree of heat and k represents thermal conduction.
Using non-dimensional quantities, the total entropy transforms to the following equation:

$$S_T = \left[\left(\frac{\partial \theta}{\partial x'}\right)^2 + \left(\frac{\partial \theta}{\partial y'}\right)^2\right] + \xi\left[2\left(\frac{\partial u'}{\partial x'}\right)^2 + 2\left(\frac{\partial v'}{\partial y'}\right)^2 + \left(\frac{\partial u'}{\partial y'} + \frac{\partial v'}{\partial x'}\right)^2\right] \tag{3.2}$$

where $\xi = \frac{\mu T_0}{k}\left(\frac{\lambda}{L(T_w - T_\infty)}\right)^2$ is the proportion of thermal and viscous irreversibilities and $T_0 = \frac{T_w + T_\infty}{2}$ is the bulk degree of heat. The first term (S_H) of Eq.(2.16) is the dimensionless entropy generation owing to transfer of heat and the second term (S_V) is the dimensionless entropy generation owing to viscosity.

For the quantification of fluid irreversibility and heat transfer, it is important to calculate the Bejan number. It is expressed as follows:

$$Be = \frac{S_H}{S_T}. \tag{3.3}$$

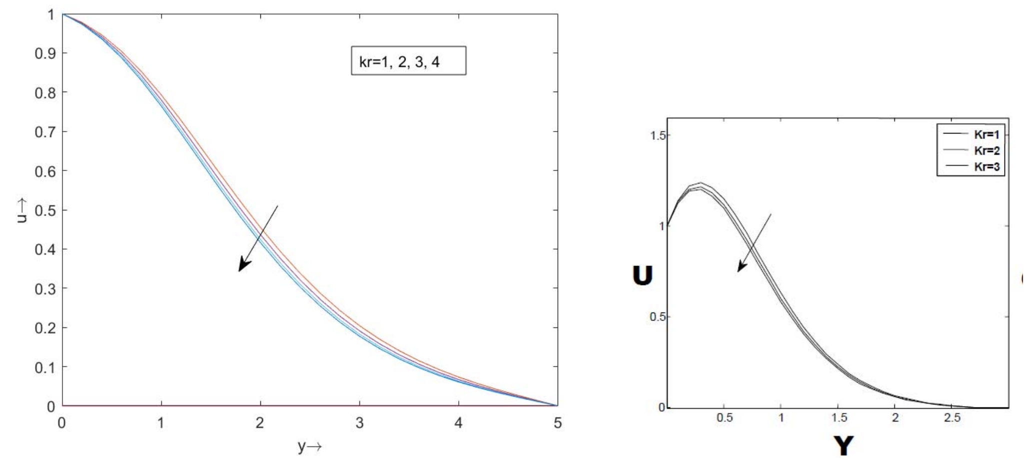
4. Results and discussion

With the application of finite difference method different properties of the flow problem is observed under the incorporation of different existing parameters. Here the outcomes of the finite difference are computed using MATLAB. Together with the impact of the parameters, numerical findings have been displayed through figures and tables. Throughout our study we have selected a few standard values for the parameters for instance Soret number (Sr), Prandtl number (Pr), radiation parameter (Ra), Casson parameter (α), chemical reaction parameter (Kr) and Schmidt number (Sc). The standard values that are used are given below:

$$Pr = 0.7, \quad Ra = 5, \quad Sr = 1, \quad Sc = 0.22, \quad Kr = 1, \quad \alpha = 0.5.$$

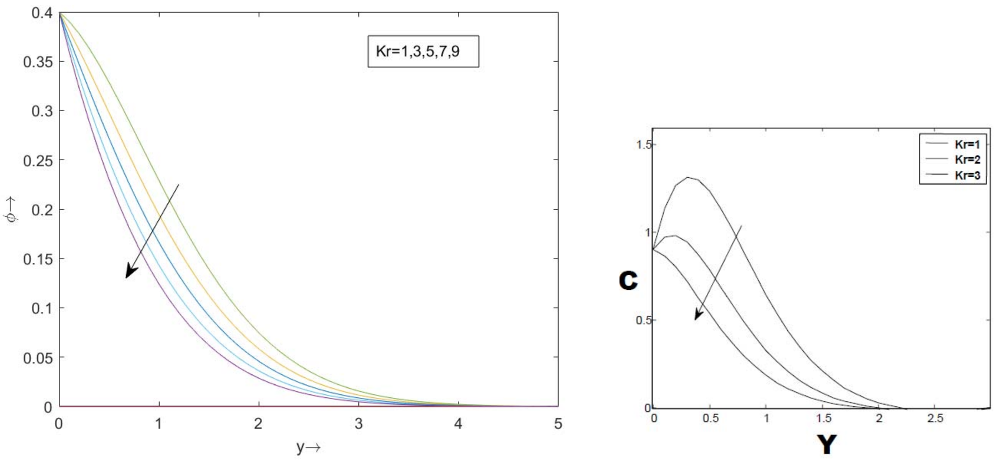
4.1. Velocity and concentration profiles

Figures 2 and 7 respectively examines the influence of varying chemical reaction and Schmidt number parameter against the concentration. It is observed that the profile of concentration falls with the rise in chemical reaction, i.e., the concentration boundary layer's thickness drops.



(a) (b)

Fig.2. Variation of chemical reaction on velocity (a) present study and (b) Dutta and Sharma [16].



(c) (d)

Fig.3. Variation of chemical reaction on velocity (c) present study and (d) Dutta and Sharma [16].

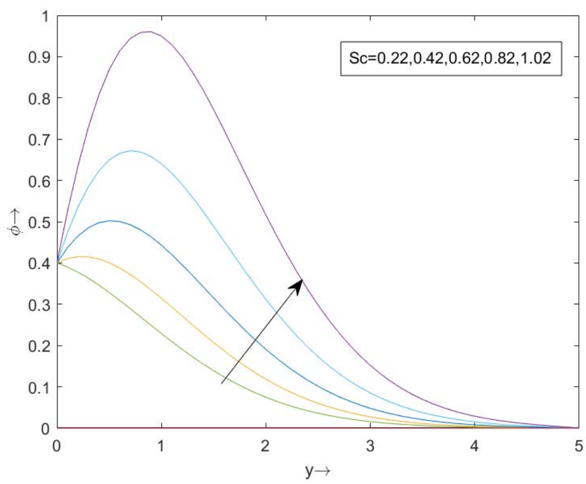


Fig.4. Variation of Schmidt number on concentration.

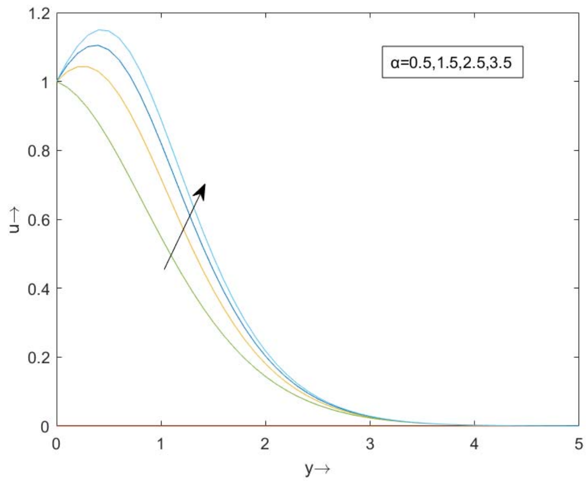


Fig.5. Variation of Casson parameter on velocity.

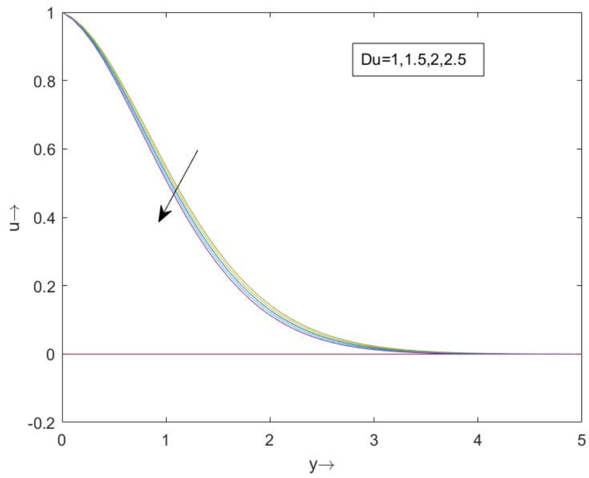


Fig.6. Variation of Dufour effect on velocity.

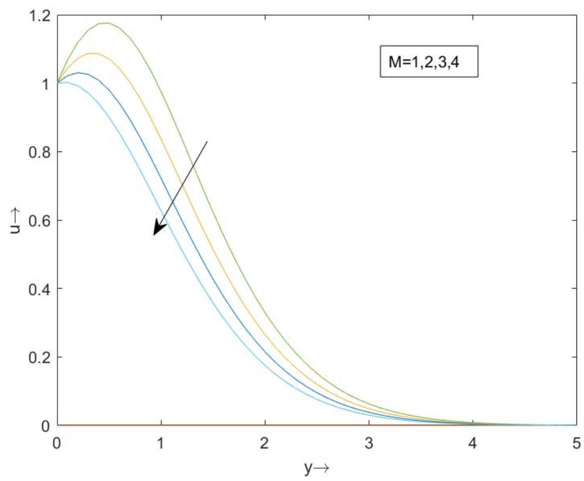


Fig.7. Variation of Hartmann number on velocity.

Figure 4 clearly illustrates the rise of concentration profile with the rise in Schmidt number, which describes that the width of the concentration boundary layer increases as the ratio of momentum diffusivity to mass diffusivity of the species increases.

Figures 5-7 is sketched for the velocity profile against variations of Casson parameter, Dufour effect and Hartmann number. Casson fluid is a non-Newtonian fluid with high viscosity shear thinning fluid properties and yield stress. Its influence on velocity profile is expected to be of great importance. Increasing value Casson parameter leads to a rise in rate of velocity whereas rate of velocity decays for higher values of Dufour the effect. Figure 7 prominently examines that velocity falls for higher values of Hartmann number. There is a decrease in velocity profile as the ratio of electromagnetic force to viscosity decreases because the presence of magnetic field introduces a resistive force that act against the flow.

4.2. Variation of skin-friction, Nusselt number and Sherwood number

Table 1. Nusselt number with change in Prandtl number (*Pr*).

Pr	*Sc*	*Du*	α	Nusselt number
.25	.22	1	.5	-0.9285
.50	.22	1	.5	-0.9272
.75	.22	1	.5	-0.9268
1	.22	1	.5	-0.9266

Table 2. Nusselt number with change in Schmidt number (*Sc*).

Pr	*Sc*	*Du*	α	Nusselt number
.7	.05	1	.5	-1.0179
.7	.10	1	.5	-0.9897
.7	.15	1	.5	-0.9626
.7	.20	1	.5	-0.9368

Table 3. Nusselt number with change in Dufour number (*Du*).

Pr	*Sc*	*Du*	α	Nusselt number
.7	.22	1	.5	-0.9269
.7	.22	1.5	.5	-0.8879
.7	.22	2	.5	-0.8476
.7	.22	2.5	.5	-0.8060

Table 4. Nusselt number with change in Casson parameter (α).

Pr	*Sc*	*Du*	α	Nusselt number
.7	.22	1	0.5	-0.9269
.7	.22	1	1.5	-0.9383
.7	.22	1	2.5	-0.9443
.7	.22	1	3.5	-0.9480

Table 5. Sherwood number with change in Dufour number (*Du*).

Du	*Kr*	*M*	α	Sherwood number
1	*.22*	*1*	*.5*	*0.0089*
1.5	*.22*	*1*	*.5*	*0.0086*
2	*.22*	*1*	*.5*	*0.0082*
2.5	*.22*	*1*	*.5*	*0.0079*

Table 6. Sherwood number with change in chemical reaction (*Kr*).

Du	*Kr*	*M*	α	Sherwood number
1	*.5*	*1*	*.5*	*0.0154*
1	*1*	*1*	*.5*	*0.0089*
1	*1.5*	*1*	*.5*	*0.0027*
1	*2*	*1*	*.5*	*-0.0033*

Table 7. Sherwood number with change in Hartmann number (*M*).

Du	*Kr*	*M*	α	Sherwood number
1	*.22*	*1*	*.5*	*0.0179*
1	*.22*	*2*	*.5*	*0.0153*
1	*.22*	*3*	*.5*	*0.0130*
1	*.22*	*4*	*.5*	*0.0109*

Table 8. Sherwood number with change in Casson parameter (α).

Du	*Kr*	*M*	α	Sherwood number
1	*.22*	*1*	*0.5*	*0.0089*
1	*.22*	*1*	*1.5*	*0.0126*
1	*.22*	*1*	*2.5*	*0.0144*
1	*.22*	*1*	*3.5*	*0.0154*

Table 9. Skin friction with change in Dufour number (*Du*).

Du	*Kr*	*M*	α	Skin friction
1	*.22*	*1*	*.5*	*-0.0411*
1.5	*.22*	*1*	*.5*	*-0.0440*
2	*.22*	*1*	*.5*	*-0.0468*
2.5	*.22*	*1*	*.5*	*-0.0497*

Table 10. Skin friction with change in chemical reaction (*Kr*).

Du	*Kr*	*M*	α	Skin friction
1	*1*	*1*	*.5*	*-0.0411*
1	*3*	*1*	*.5*	*-0.0422*
1	*5*	*1*	*.5*	*-0.0433*
1	*7*	*1*	*.5*	*-0.0443*

Table 11. Skin friction with change in Hartmann number (*M*).

Du	*Kr*	*M*	α	Skin friction
1	*.22*	*1*	*.5*	*0.1676*
1	*.22*	*2*	*.5*	*0.1089*
1	*.22*	*3*	*.5*	*0.0547*
1	*.22*	*4*	*.5*	*0.0048*

Table 12 : Skin friction with change in Casson parameter (α).

Du	*Kr*	*M*	α	Skin friction
1	*.22*	*1*	*.5*	*-0.0411*
1	*.22*	*1*	*1.5*	*0.0696*
1	*.22*	*1*	*2.5*	*0.1162*
1	*.22*	*1*	*3.5*	*0.1407*

Tables 1-4 numerically illustrates the effect of variations of embedded fluid parameters on the Nusselt number. The rate of conduction and convection of heat transmission is measured using the Nusselt number, a non-dimensional heat transfer coefficient. From Tabs 1-4 a reverse behaviour of Nusselt number is observed for the higher values of Casson parameter. Whereas for the other parameters the behaviour is directly proportional. Sherwood number determines the mass transfer rate in a convective fluid flow. Tables 5-8 respectively examines the influence of *Du*, *Kr*, *M*, and α on the Sherwood number. All these parameters except Casson parameter (α) behave inversely with decrease of Sherwood number.

Tables 9-12 shows that skin friction reduces with the rise in Dufour effect, chemical reactions, and Hartmann number whereas, for higher values of Casson parameter, the skin friction increases, i.e., the surface drag force is enhanced.

4.3. Variation of different parameters on entropy.

Figures 8-18 shows generation of entropy owing to heat transfer and viscous effects for a fluid flow problem. It also displays the total entropy and Bejan number with the influence of different values of existing parameter of the fluid.

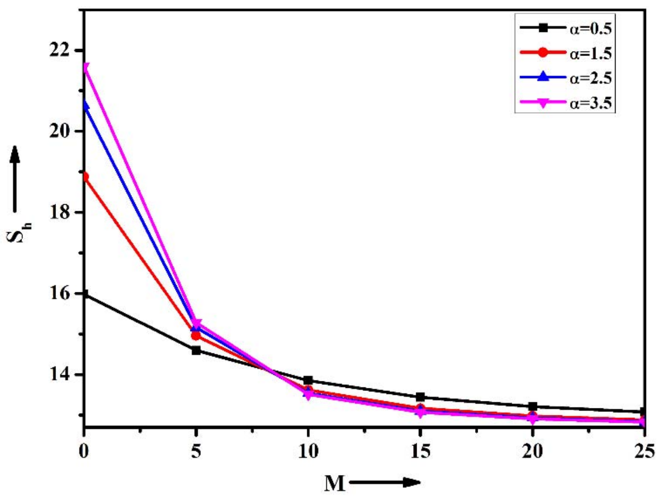


Fig.8. Entropy generation due to heat transfer with influence of Casson parameter.

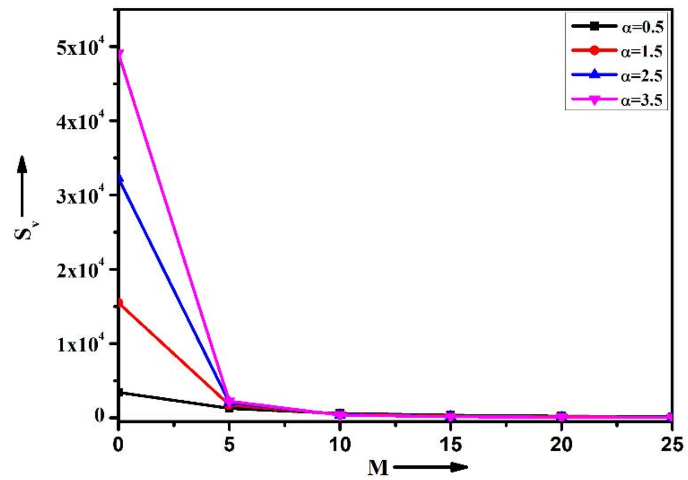


Fig.9. Entropy generation due to viscous dissipation with influence of Casson parameter.

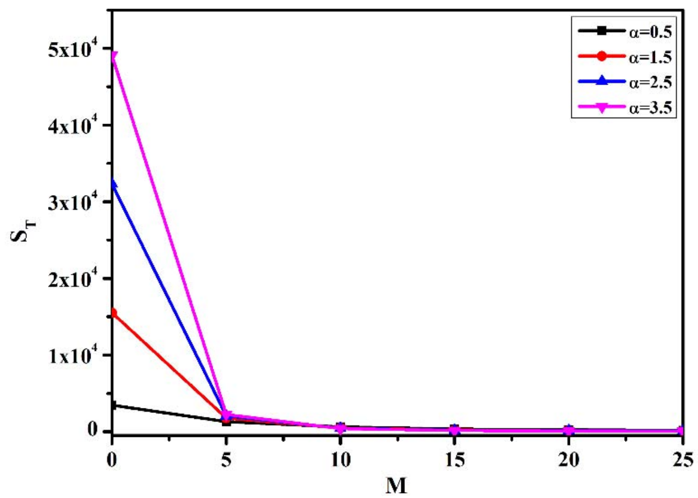


Fig.10. Total entropy with influence of Casson parameter.

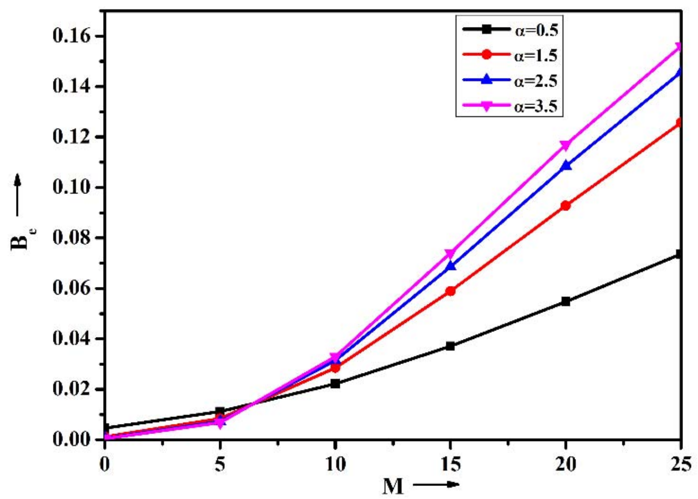


Fig.11. Bejan number with influence of Casson parameter.

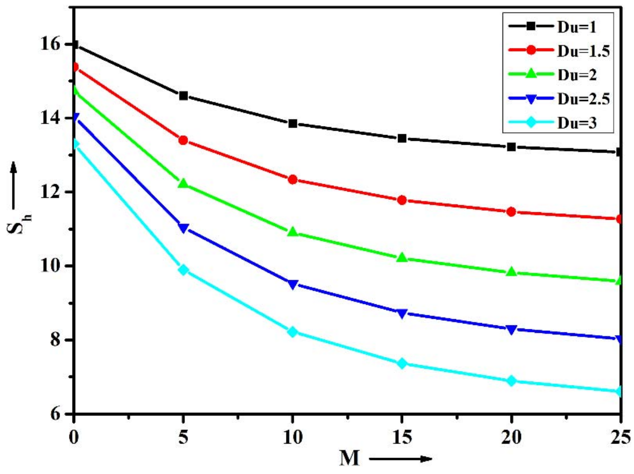


Fig.12. Entropy generation due to heat transfer with influence of Dufour effect.

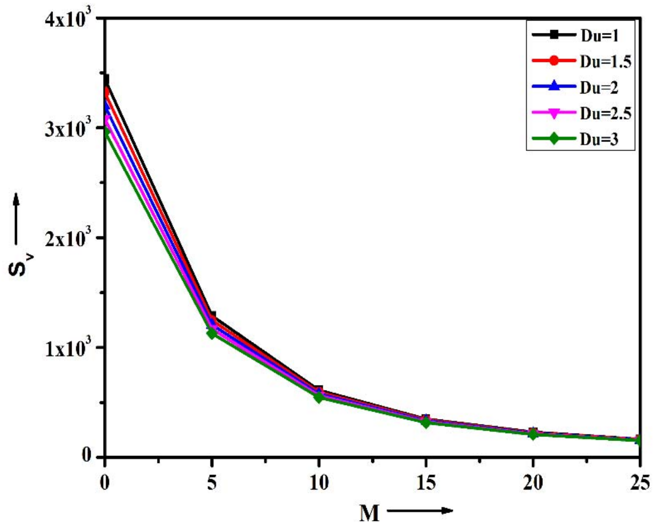


Fig.13. Entropy generation due to viscous dissipation with influence of Dufour effect.

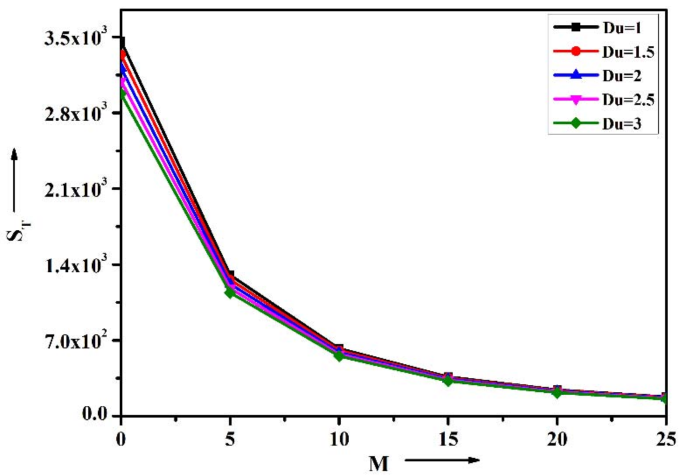


Fig.14. Total entropy with influence of Dufour effect.

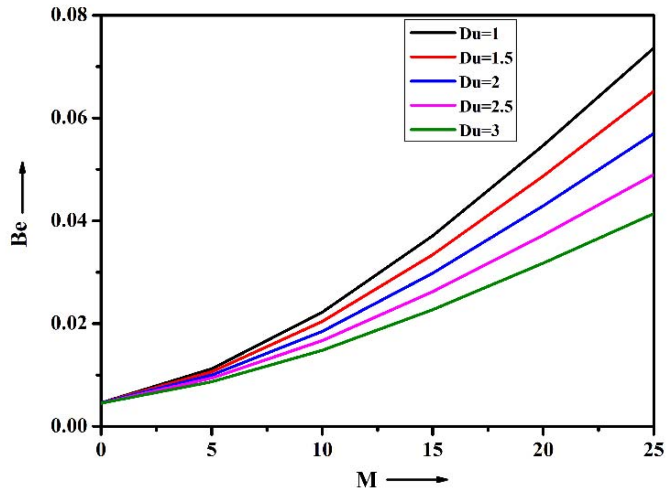


Fig.15. Bejan number with influence of Dufour effect.

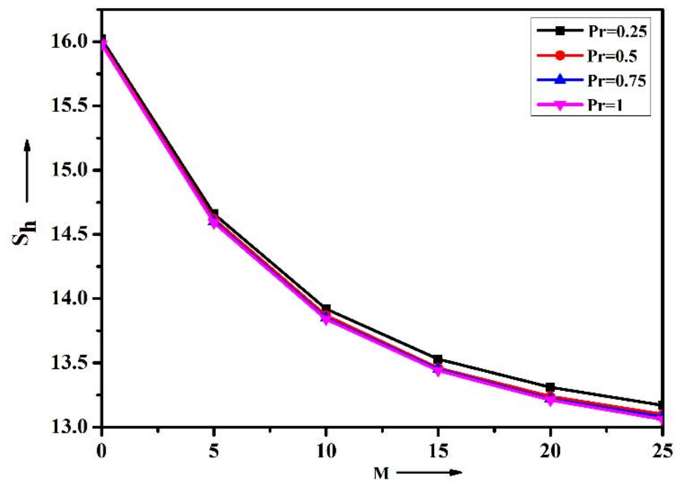


Fig.16. Entropy generation due to heat transfer with influence of Prandtl number.

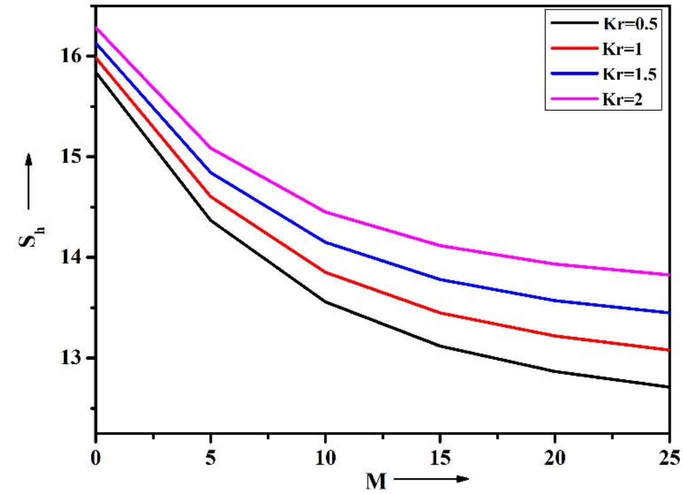


Fig.17. Entropy generation due to heat transfer with influence of chemical reaction parameter.

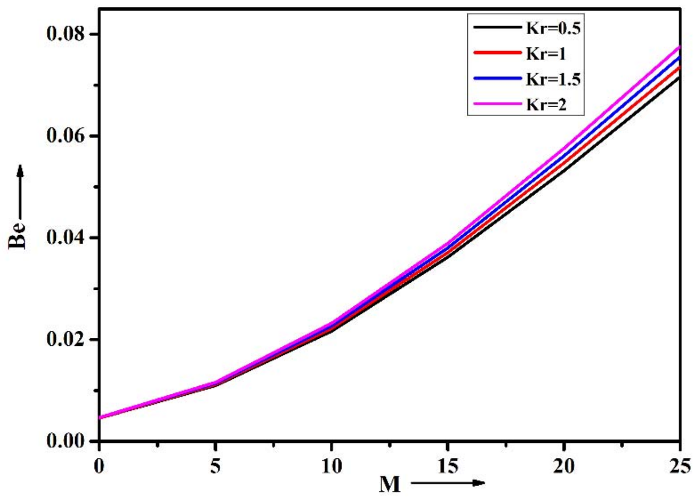


Fig.18. Bejan number with influence of chemical reaction parameter.

The entropy generated by heat transfer as a function of Hartmann number is shown in Fig.8 together with the impact of Casson parameter. As the Casson parameter increases, the amount of entropy generated as a result of heat transfer increases. Figures 9 and 10 is sketched to illustrates respectively the generation of entropy owing to viscosity and total entropy with the influence of Casson parameter. With the increase in Casson parameter S_v and S_T decreases.

Figure 11 reveals the Bejan number with the influence of Casson parameter in relation to Hartmann number. With the influence of Casson parameter Bejan number has a proportional effect with the Hartmann number. Figures 12-15 illustrates the influence of variation of Dufour effect on generation of entropy owing to transfer of heat and viscosity effects.

It also illustrates total entropy and Bejan number of the heat transfer problem. In the Fig.12 the generation of entropy owing to heat is shown for varying effect of Dufour. It has been noted that as the Dufour effect rise, the entropy generation by heat transfer decreases i.e., entropy behaves in contrast with the higher values of Dufour effect. In Fig.13 entropy generation due to viscous effect versus Hartmann number is examined for Dufour effect. It is found that Dufour effect has an inverse influence on the entropy generation. As the Dufour effect grows the entropy lowers. Figure 14 is plotted to illustrate the total entropy generation against Dufour effect. It reveals that total entropy generation is inversely proportional to the rise in Dufour effect. It behaves oppositely for larger values of Dufour effect. Figure 15 is plotted to examine the Bejan number versus magnetic parameter with the influence of Dufour effect. It is noted that Bejan number lowers with the rise in Dufour effect and is directly proportional to the magnetic parameter.

Figure 16 is plotted to reveal the entropy generation due to heat transfer versus magnetic parameter (M) against Prandtl number. It reveals that entropy generation lowers for higher values of Prandtl number.

Figures 17 and 18 illustrates the entropy generation owing to transfer of heat and Bejan number against chemical reaction parameter. In Fig.17 it is observed that chemical reaction parameter causes rise in entropy generation. Physically the figure illustrates that higher values of Kr enhances the irreversibility. From Fig.18 it is found that Bejan number rise proportionately with the rise in chemical reaction parameter.

5. Conclusion

This present work is mainly focused on entropy generation for an unsteady MHD flow of a Casson fluid past a vertical cone. Here, influence of different embedded parameters on the flow problem is scrutinized. Variations of the properties of fluid is also analysed. The radiative effect and the reaction due to chemicals has played a significant role in the rate of heat and mass transfer. Many engineering phenomena focus on the manner in which geometry is selected to minimize the entropy generation. So, entropy generation and Bejan number have huge engineering applications in various fields of energy storage systems and in heat exchangers. Some of the important conclusions are summarized below:

- Concentration profile lowers with rise in chemical reaction and rise with the rise in Schmidt number.
- High values of Casson parameter increase the velocity rate, whereas rate of velocity lowers with the increase in Dufour effect and Hartmann number.
- Nusselt number lowers for higher values of Casson parameter.
- Sherwood number boost up with the rise in Casson parameter.
- Surface drag force is enhanced for higher values of Casson parameter.
- Total entropy lowers for higher values of Casson parameter and Dufour effect.
- Bejan number with the influence of Casson parameter has a proportional effect with the Hartmann number and it falls with the rise in Dufour effect.
- Bejan number rise proportionately with the rise in the effect of chemical reaction.

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Nomenclature

B_0 – magnetic field $[T]$

C – species concentration

C_p – specific heat at constant pressure $\left[J\,kg^{-1}k^{-1}\right]$

C_s – concentration susceptibility

C_w – species concentration in the cone

C_∞ – species concentration in the free stream

D_m – mass diffusivity $\left[m^2 s^{-1}\right]$

Gr_L – Grashof number for heat transfer

Gr_C – Grashof number for mass transfer

g – acceleration due to gravity $\left[m\,s^{-2}\right]$

K – chemical reaction parameter

Kr – chemical reaction rate constant

K_T – thermal diffusion ratio

M – Hartmann number

Nu – Nusselt number

Pr – Prandtl number

R – radiation parameter

r – radius of the cone, $[m]$

Sc – Schmidt number

Sh – Sherwood number

Sr – Soret number

T – fluid temperature

T_w – temperature of the cone [K]

T_∞ – temperature in free stream [K]

q_r – radiative heat flux $\left[W\,m^2\right]$

u – velocity component along x-direction

u' – dimensionless velocity along x'-direction

v – velocity component along y-direction

v' – dimensionless velocity along y'-direction

α – Casson parameter

β – thermal expansion coefficient

β^* – mass expansion coefficient

γ – angle of inclination [rad]

θ – dimensionless temperature

λ – thermal diffusivity of the viscous fluid

ρ – fluid density $\left[kg\,m^{-3}\right]$

σ – electrical conductivity $\left[s\,m^{-1}\right]$

υ – kinematic viscosity $\left[m^2 s^{-1}\right]$

τ – skin friction

ϕ – dimensionless concentration

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