CHAPTER 7

SORET AND DUFOUR EFFECTS ON MHD MIXED CONVECTION BLOOD FLOW THROUGH A STENOSED ARTERY WITH THERMAL RADIATION AND CHEMICAL REACTION
7.1 INTRODUCTION:

Blood flow (or Hemodynamics) is well known to the physiologists as one of the major mechanisms due to its applications in arterial mechanics. Blood flow problems due to its major importance in physio-pathology have received a significant attention. Blood circulation executes various types of function in a human body such as transport of oxygen, transport of nutrients, removal of carbon dioxide and removal of metabolic products. Specially, blood flows in arteries is an important field of research because arterial diseases are a major reason of death in most of western countries. In particular, the circulatory connected issues are the major causes of health problems and deaths in the present world. This is supported by the report of the World Health Organization (WHO), according to which, seventeen million deaths in 2008 are associated with the heart. The elementary cause of heart related disorders is due to occlusion, which compromise the functioning of the vital organs. The deposition of excessive fatty components and abnormal intravascular growth within the lumen of the artery that results in the formation of the stenosis. This results in the narrowing of the artery and such type of condition is known as atherosclerosis. Formation of the stenosis effects in the obstruction of the flow of blood thus resulting in abnormal deviations of the blood flow characteristics.
Now a days, magnetic therapy is broadly used for medicinal in various diseases. The blood flow in the artery which is considered as a magnetohydrodynamics fluid that will help in controlling blood pressure and has important therapeutic use in the diseases of heart and blood vessels. By applying an appropriate intensity of magnetic field, it can become effective to the conditions such as poor circulation, pain, travel sickness, muscle sprains, headaches, joint pain and strains. Magnetic therapy could be also suitable for the reperfusion of ischemic tissue or during sepsis. When blood flow to a tissue reduced or blocked then necrosis will eventually occur. Local acquaintance of a magnetic field could potentially result in blood vessel relaxation and increased blood flow. The effect of a magnetic field on blood flow has been examined theoretically by Chen (1985) taking blood as an electrically, viscus, conducting fluid. It has been described that application of a magnetic field is useful for nerve regeneration (Kort and Bassett, 1980; Sisken et al., 1990), bone grafts (Mooney, 1990) and fracture healing (Sharrard, 1990). Recently, heat and mass transfer in a magneto-biofluid flow through a non-Darcian porous medium has been studied by Sharma et al. (2013b). Recently, mhd blood flow with porous medium through coaxial vertical tapered asymmetric channel has been discussed by Ravikumar (2016). Keeping all these in attention, the presence of an external magnetic field has been paid due concern in the present study.
Radiation effect in blood flow problems is an important topic of research, as it has got many important applications in biomedical science & engineering and several medical treatment methods, especially in thermal therapeutic treatments. Heat therapy is found to be very effective in the treatment of chronic wide-spread pain (fibromyalgia), muscle spasms, myalgia (muscle pain) and permanent shortening of muscle (contracture). Infrared radiation is widely applied techniques for getting heat treatment to various parts of the human organs. This technique is desired in heat therapy, since it is possible to directly heat the blood vessels of the affected areas of the body by using infrared radiation. Ogulu and Bestman (1994) have discussed theoretical analysis of blood flow with radiative heat. Misra et al. (2010) described theoretical approximations of blood flow through arteries during the therapeutic procedure of electromagnetic hyperthermia which is used for cancer treatment. Thermal Radiation techniques are used primarily to give rise a tissue temperature for heart therapeutic purposes which was reported by Prakash et al. (2011). The purpose of thermal radiation is to improve control of disease while asserting good quality of life. Thermal radiation is one of the methods applied by medical practitioners to ease cardiovascular diseases. Electromagnetic heat, such as micro waves and short waves sends heat up to 2 inches into the muscles and tissues which works best for injuries in joints, muscles, and tendons. Heat therapy is helpful to reduce pain and thermal radiation therapy is also employed (Zee, 2002; Tashtoush and
Magableh, 2008; Kenjeres and Opdam, 2008) for cancer treatment. Sharma 
et al. (2006) analysed the radiation effect with combined thermal and mass
diffusion in magnetohydrodynamics mixed convection flow from a vertical
surface. Recently, Majee and Shit (2017) also numerically investigated
MHD blood flow through a stenosed arterial segment in the presence of
magnetic field. They have studied the effect of heat transfer in the entire
segment and concluded that the wall shear stress as well as Nusselt
number increases with a rise in the magnetic field strength.

In the past few decades, the study of the aggregated effects of heat and mass
transfer on bio-fluids has got quite fascinating to the researchers both from
the theoretical and observational or clinical perspective. The study of heat
and mass transfer on blood flow has become quite concerning for many
researchers both from the experimental and theoretical point of view. This is
because of the valued estimation of blood flow rate and heat generation
which is of great importance for diagnosing blood circulation illness and for
the non-invasive measuring of blood glucose. Mass transfer with chemical
reaction has distinctive significance in chemical and hydrometallurgical
industries. The effects of chemical reaction on a MHD fluid flow from a
radiative surface with variable permeability is discussed by Sharma et al.
(2013a). Recently, the effects of variable viscosity on MHD heat and mass
transfer blood flow in the presence of viscous dissipation and chemical
reaction have been discussed by Sharma and Gaur (2017).
The occurrence of Soret and Dufour effects is due to the simultaneous existence of heat and mass transfer which are affecting each other. Thermal diffusion (Dufour) effect is the Energy flux induced by concentration gradient while, mass flux can be generated due to temperature gradient which is known as Soret effect. Though, the Soret and Dufour effects are regarded a small order of magnitude due to Fourier's or Fick's law in comparison to the influences but there are many situations where such effects cannot be ignored. For example, the thermal diffusion effect is employed for isotope separation and in mixtures between gases with medium molecular weight (air, N\textsubscript{2}) and of high molecular weight (H\textsubscript{2}, He), the diffusion-thermo effect cannot be neglected. Enamul et al. (2012) discussed Soret and Dufour effects on steady magnetohydrodynamics flow past an inclined stretching sheet in presence of heat source. Steady MHD convective flow past a continuously moving porous vertical plate with Soret and Dufour effects was discussed by Sharma et al. (2012a). Further, Sharma et al. (2012) investigated the Soret and Dufour effects on mixed convection unsteady MHD flow past a radiative vertical porous plate through a porous medium with chemical reaction. Bhavana et al. (2013) analyzed the effect of Soret on unsteady MHD flow over a vertical plate with heat transfer.

Hence, the aim of this present study is to analyze the effects of Soret and Dufour parameters on MHD blood flow through a porous tapered artery in the presence of radiation. The present analysis may provide a good
understanding about blood flow in a diseased blood artery and very beneficial under various pathological states. The governing equation of blood flow model is obtained with the help of continuity, momentum, energy and concentration equations. The modeled differential equations are converted in dimensionless form and solved numerically by taking FDM with the help of MATLAB. The impact of all the physical parameters is discussed in details.

7.2 MATHEMATICAL FORMULATION:

Let $(r, \theta, z)$ be the cylindrical polar coordinate system with $\bar{u}$ and $\bar{w}$ are the radial and axial velocity components in the $\bar{r}$ and $\bar{z}$ directions, respectively, with $r = 0$ as the axis of symmetry of the tube. Consider the Newtonian viscous, incompressible fluid of viscosity $\mu$ and density $\rho$ in a tube having a length of $L$. It is also assumed that the temperature and concentration to the wall of the tube are $\bar{T}_0$ and $\bar{C}_0$, respectively. Mixed convection is considered in the presence of heat and mass transfer. Both temperature and concentration Symmetry condition is employed at the centre of the tube.

The geometry of the stenosis is defined as Mekheimer and El Kot (2008)

$$h(\bar{z}) = d(\bar{z})[1 - \bar{\eta}(b^{n-1}(\bar{z} - a) - (\bar{z} - a)^n)], a \leq \bar{z} \leq a + b$$

$$= d(\bar{z}), \text{otherwise}$$  \hspace{1cm} (7.2.1)
with $d(\bar{z}) = d_0 + \varepsilon\bar{z}$, where $d(\bar{z})$ is the radius of the segment of tapered artery in the stenotic region, $b$ is the length of the stenosis, $d_0$ is the radius of the non-tapered artery in the non-stenotic region, $\varepsilon$ is the tapering parameter, $n(\geq 2)$ is referred as the shape parameter (the symmetric stenosis occurs for $n = 2$) which is determining the shape of the constriction profile and shows its location (as shown in Fig. 7.1) as discussed in Mekheimer and El Kot (2008). The parameter $\eta$ is defined as

$$\eta = \frac{\delta^* n^{\frac{1}{n-1}}}{d_0 b^n (n - 1)}$$  \hspace{1cm} (7.2.2)

where $\delta^*$ denotes maximum height of the stenosis and located at

$$z = a + \frac{b}{n^{\frac{1}{n-1}}}$$  \hspace{1cm} (7.2.3)

The following assumptions are made for the development of mathematical model:

(i) The flow is considered as incompressible so that the equation of state for a Boussinesq fluid holds in gravitational field that acts in the opposite direction to $z$. (ii) The temperature difference of the blood and artery is high enough so that the radiative heat transfers to be valid. (iii) Mild and symmetric about the axis of the tube stenosis is considered. (iv) A constant strength magnetic field is applied externally in the perpendicular direction to
the flow. Under the above mentioned assumptions, the governing equations are as follows:

\[
\frac{\partial \bar{u}}{\partial \bar{r}} + \frac{\bar{u}}{\bar{r}} + \frac{\partial \bar{w}}{\partial \bar{z}} = 0 \tag{7.2.4}
\]

\[
\rho \left[ \bar{u} \frac{\partial \bar{u}}{\partial \bar{r}} + \bar{w} \frac{\partial \bar{u}}{\partial \bar{z}} \right] = -\frac{\partial \bar{p}}{\partial \bar{r}} + \frac{\partial}{\partial \bar{r}} \left[ 2\mu \frac{\partial \bar{u}}{\partial \bar{r}} \right] + \frac{2\mu}{\bar{r}} \left[ \frac{\partial \bar{u}}{\partial \bar{r}} - \frac{\bar{u}}{\bar{r}} \right] + \frac{\partial}{\partial \bar{z}} \left[ \mu \left( \frac{\partial \bar{u}}{\partial \bar{z}} + \frac{\partial \bar{w}}{\partial \bar{r}} \right) \right]. \tag{7.2.5}
\]

Fig. 7.1: Geometry of Stenosis in a Porous Artery
\[ \rho \left[ \frac{\partial \bar{w}}{\partial \bar{r}} + \bar{w} \frac{\partial \bar{w}}{\partial \bar{z}} \right] = -\frac{\partial \bar{p}}{\partial \bar{z}} + \frac{\partial}{\partial \bar{z}} \left[ 2\mu \frac{\partial \bar{w}}{\partial \bar{z}} \right] + \frac{1}{r} \frac{\partial}{\partial \bar{r}} \left[ \mu \bar{r} \left( \frac{\partial \bar{u}}{\partial \bar{z}} + \frac{\partial \bar{w}}{\partial \bar{r}} \right) \right] - \]

\[ \sigma_1 \mu_0^2 H_0^2 \bar{w} - \frac{\mu \bar{w}}{k_1} + \rho g \alpha (\bar{T} - T_0) + \rho g \alpha (\bar{C} - C_0) \quad (7.2.6) \]

\[ \rho c_p \left[ \frac{\partial \bar{T}}{\partial \bar{r}} + \bar{w} \frac{\partial \bar{T}}{\partial \bar{z}} \right] = k \left[ \frac{\partial^2 \bar{T}}{\partial \bar{r}^2} + \frac{1}{\bar{r}} \frac{\partial \bar{T}}{\partial \bar{r}} + \frac{\partial^2 \bar{T}}{\partial \bar{z}^2} \right] + \left( \frac{\partial \bar{w}}{\partial \bar{z}} \right)^2 - \frac{\partial q_r}{\partial \bar{z}} + \]

\[ \frac{D_mK_T}{T_m} \left[ \frac{\partial^2 \bar{C}}{\partial \bar{r}^2} + \frac{1}{\bar{r}} \frac{\partial \bar{C}}{\partial \bar{r}} + \frac{\partial^2 \bar{C}}{\partial \bar{z}^2} \right] \quad (7.2.7) \]

\[ \left[ \frac{\partial \bar{c}}{\partial \bar{r}} + \bar{w} \frac{\partial \bar{c}}{\partial \bar{z}} \right] = D \left[ \frac{\partial^2 \bar{C}}{\partial \bar{r}^2} + \frac{1}{\bar{r}} \frac{\partial \bar{C}}{\partial \bar{r}} + \frac{\partial^2 \bar{C}}{\partial \bar{z}^2} \right] + \frac{DK_T}{T_m} \left[ \frac{\partial^2 \bar{T}}{\partial \bar{r}^2} + \frac{1}{\bar{r}} \frac{\partial \bar{T}}{\partial \bar{r}} + \frac{\partial^2 \bar{T}}{\partial \bar{z}^2} \right] + k_1 \bar{C} \]

\[ \quad . \quad (7.2.8) \]

The corresponding boundary conditions are given by:

\[ \frac{\partial \bar{w}}{\partial \bar{r}} = 0, \frac{\partial \bar{T}}{\partial \bar{r}} = 0, \frac{\partial \bar{C}}{\partial \bar{r}} = 0 \quad \text{at } \bar{r} = 0 \]

\[ \bar{w} = \bar{T} = \bar{C} = 0 \quad \text{at } \bar{r} = h(\bar{z}) \quad (7.2.9) \]

where \( h(\bar{z}) = d(\bar{z}) [1 - \eta (b^{n-1}(\bar{z} - a) - (\bar{z} - a)^n)] \).

Above equations are converted into dimensionless form by introducing the following dimensionless parameters:

\[ r = \frac{\bar{r}}{d_0}, \quad z = \frac{\bar{z}}{b}, \quad w = \frac{\bar{w}}{u_0}, \quad u = \frac{b \bar{u}}{u_0 \delta}, \quad p = \frac{d_0^2 \bar{p}}{u_0 \delta}, \quad h = \frac{\bar{h}}{d_0}, \quad Re = \frac{\rho b u_0}{\mu}, \]

\[ \theta = \frac{(\bar{T} - T_0)}{T_0}, \quad \sigma = \frac{\bar{c} - C_0}{C_0}, \quad P_r = \frac{\mu c_p}{k}, \quad R = \frac{k^* k_{\infty}}{4 \sigma^* T^3}, \quad M = \sigma_1 \mu_m H_0 \sqrt{\frac{\sigma_1}{\mu}}, \]
\[
K = \frac{k_1}{d_0}, \quad E_c = \frac{u_0^2}{c_p(T_0 - T_1)}, \quad S_c = \frac{\mu}{\rho D_m}, \quad S_r = \frac{D_m K_T \rho T_0}{\mu T_m \bar{c}_0}, \quad D_f = \frac{D_m K_T \bar{c}_0}{c_s c_p T_0},
\]

\[
K_r = \frac{k_1 u}{u_0}, \quad Gr = \frac{g \alpha d_0^3 \bar{T}_0^3}{v^2}, \quad Cr = \frac{g \alpha d_0^3 \bar{T}_0^3}{v^2}
\]

By using these dimensionless number and by adopting additional conditions (Mekheimer and El Kot, 2008)

\[
Re \frac{\delta n^{n-1}}{b} \ll 1 \quad (7.2.10)
\]

\[
d_0 n^{n-1} \frac{1}{b} \sim O(1) \quad (7.2.11)
\]

The dimensionless equations take the following form for the case of mild stenosis (\(\frac{\delta}{d_0} \ll 1\))

\[
\frac{\partial u}{\partial r} + \frac{u}{r} + \frac{\partial w}{\partial z} = 0 \quad (7.2.12)
\]

\[
\frac{\partial p}{\partial r} = 0 \quad (7.2.13)
\]

\[
\frac{\partial p}{\partial z} = \frac{1}{r} \frac{\partial}{\partial r} \left[ r \left( \frac{\partial w}{\partial r} \right) \right] - \left( M^2 + \frac{1}{K} \right) w + Gr \theta + Cr \sigma \quad (7.2.14)
\]

\[
\left( 1 + \frac{4}{3R} \right) \frac{1}{r} \frac{\partial}{\partial r} \left[ r \left( \frac{\partial \theta}{\partial r} \right) \right] + E_c Pr \left( \left( \frac{\partial w}{\partial r} \right)^2 \right) + D_f Pr \left( \frac{1}{r} \left( \frac{\partial}{\partial r} \left( r \frac{\partial \sigma}{\partial r} \right) \right) \right) = 0 \quad (7.2.15)
\]
\[
\frac{1}{Sc} \left( \frac{1}{r} \frac{\partial}{\partial r} \left( r \frac{\partial \sigma}{\partial r} \right) \right) + \frac{1}{Sr} \left( \frac{1}{r} \frac{\partial}{\partial r} \left( r \frac{\partial \theta}{\partial r} \right) \right) - Kr \sigma = 0 \quad (7.2.16)
\]

The corresponding dimensionless boundary conditions are

\[
\frac{\partial w}{\partial r} = 0, \quad \frac{\partial \theta}{\partial r} = 0, \quad \frac{\partial \sigma}{\partial r} = 0 \quad \text{at} \quad r = 0
\]

\[
w = 0, \quad \theta = 0, \quad \sigma = 0 \quad \text{at} \quad r = h(z) \quad (7.2.17)
\]

where

\[
h(z) = (1 + \varepsilon z)[1 - \eta_1((z - \theta) - (z - \theta)^n)], \sigma \leq z \leq \sigma + 1
\]

and

\[
\eta_1 = \frac{\delta^* n^{n-1}}{(n-1)}, \delta^* = \frac{\delta}{d_0}, \theta = \frac{a}{b}
\]

\[
\varepsilon = \tan(\varphi), \quad \varphi \quad \text{is called tapered angle of artery and for non-tapered artery} \quad (\varphi = 0), \quad \text{the diverging tapering} \quad (\varphi > 0)\text{converging tapering} \quad (\varphi < 0)
\]

(Mekheimer and El Kot, 2008).

**7.3 SOLUTION OF THE PROBLEM:**

The above non-linear dimensionless partial differential equations with prescribed boundary conditions have been solved numerically by explicit finite difference method. The discretization for first order derivatives terms are based on the first order forward difference scheme and for second order terms are based on central difference scheme. To obtain the difference equations, the region of the blood flow is divided into a grid or mesh lines. Set of these difference schemes are obtained at the intersection of these grid lines called nodes. These discretized equations are converted into algebraic
equations by taking varying $i$ from 0 to $h(z)$ and $j$ is varied from 0 to 1. Initially values are assumed for $\theta$ and $\sigma$ and then algebraic equations form tridiagonal matrix at every $j$ step which are solved using Thomas algorithm. For second iteration values obtained for temperature and concentration equations are used for calculating velocity and that velocity again is used to calculate temperature and concentration. This is repeated iteratively till there is no significant change in values of temperature and concentration.

\[
\left(\frac{\partial p}{\partial z}\right)_{i,j} = \frac{1}{r_{i,j}} \frac{w_{i+1,j} - w_{i,j}}{\Delta r} + \frac{w_{i+1,j} - 2w_{i,j} + w_{i-1,j}}{(\Delta r)^2} - \left( M^2 + \frac{1}{K} \right) w_{i,j} + Gr \theta_{i,j} + Cr \sigma_{i,j} \tag{7.3.1}
\]

\[
0 = \left( 1 + \frac{4}{3R} \right) \left( \frac{1}{r_{i,j}} \frac{\theta_{i+1,j} - \theta_{i,j}}{\Delta r} + \frac{\theta_{i+1,j} - 2\theta_{i,j} + \theta_{i-1,j}}{(\Delta r)^2} \right) + E_c P_r \left( \frac{(w_{i+1,j} - w_{i,j})^2}{(\Delta r)^2} \right) + D_f P_r \left( \frac{1}{r_{i,j}} \frac{\sigma_{i+1,j} - \sigma_{i,j}}{\Delta r} + \frac{\sigma_{i+1,j} - 2\sigma_{i,j} + \sigma_{i-1,j}}{(\Delta r)^2} \right) + S_c \left( \frac{1}{r_{i,j}} \frac{\theta_{i+1,j} - \theta_{i,j}}{\Delta r} + \frac{\theta_{i+1,j} - 2\theta_{i,j} + \theta_{i-1,j}}{(\Delta r)^2} \right) - K_r \sigma_{i,j} = 0 \tag{7.3.2}
\]

\[
\frac{1}{S_c} \left( \frac{1}{r_{i,j}} \frac{\sigma_{i+1,j} - \sigma_{i,j}}{\Delta r} + \frac{\sigma_{i+1,j} - 2\sigma_{i,j} + \sigma_{i-1,j}}{(\Delta r)^2} \right) + S_r \left( \frac{1}{r_{i,j}} \frac{\theta_{i+1,j} - \theta_{i,j}}{\Delta r} + \frac{\theta_{i+1,j} - 2\theta_{i,j} + \theta_{i-1,j}}{(\Delta r)^2} \right) - K_r \sigma_{i,j} = 0 \tag{7.3.3}
\]
7.4 RESULTS AND DISCUSSION:

Influence of heat and mass transfer of mixed convection on Newtonian incompressible blood flow in the presence of magnetic field in porous vertical tapered artery is observed through figures. In order to get physical understanding, the numerical calculations for the axial velocity, temperature and concentration across the stenosis throat for various parameters have been carried out. The Values chosen for numerical calculations are $z = 0.5$, $n = 2$, $\vartheta = 0$, $\varepsilon = 0.005$, $\delta^* = 0.6$ and other dimensionless parameters are varied to get blood flow behavior.

**Velocity Profiles:**

Velocity profiles for different values of Grashoff number $Gr$ is shown in Fig. 7.2. It is observed that an increase in the Grashoff number would directly increase the velocity due to the increased Boussinesq source terms and hence the magnitude of the velocity. It is also noted that the velocity is maximum around the central line of the artery for all position of $z$. It is observed from the Fig. 7.3 that as permeability parameter ($K$) increases, the velocity profiles also increase. Physically, this means that the impact of porous medium on the boundary layer growth is significant as the thickness of the thermal boundary layer increase. It is predictable that, an increase in the permeability of the porous medium leads to the rise in the flow of fluid through the region. The resistance of the medium may be neglected when the
holes of the porous medium become large. From the Fig. 7.4, it is observed that the velocity of the fluid decreases with increase in the strength of magnetic field. This is due to the fact that the effect of the magnetic field on an electrically conducting fluid gives rise the Lorentz force (a resistive force) called. The Lorentz force has the tendency to slow down the motion of the fluid in the boundary layer. The result is qualitatively agreeing with the expectation; as magnetic field exerts retarding force on the natural convection flow. The effect of Prandtl number \((Pr)\) and radiation parameter \((R)\) on velocity profile is shown in Fig. 7.5 and Fig. 7.6, respectively. It is depicted that velocity profile increases with increasing \(Pr\) or \(R\). Since, the radiation acts as a heat source within the blood, therefore arterial blood temperature should gradually increase with increasing radiation dosage. The increase in temperature of fluid flow correspondingly increases the Boussinesq source terms in the momentum equation and therefore, increases the blood velocity. Soret and Dufour effects on velocity profile is shown in Fig. 7.7 and 7.8, respectively. It is noted that velocity profile decreases with increasing Soret parameter, while, reverse effect is noticed for Dufour parameter, which is quite obvious as the Soret number and Dufour number behave opposite to each other.
Fig. 7.2: Velocity Profile for varying values of $Gr$

Fig. 7.3: Velocity Profile for varying values of $K$

Fig. 7.4: Velocity Profile for varying values of $M$
Fig. 7.5: Velocity Profile for varying values of $Pr$

Fig. 7.6: Velocity Profile for varying values of $R$

Fig. 7.7: Velocity Profile for varying values of $Sr$
Temperature profiles:

Temperature profile for various parameters has been shown in Figures (7.9-7.14). From Fig. 7.9, it is observed that increases in the Brinkman number would correspondingly increase the magnitude of the viscous heating and thus increase the arterial blood temperature. It is observed from Fig. 7.10 that temperature of blood in presence of stenosis decreases with increase in magnetic field. Increasing value of $Pr$, frictional forces become dominant and hence increase in blood flow temperature as revealed in Fig. 7.11. It is observed from Fig. 7.12 that the blood flow temperature increases with increasing thermal radiation parameter. Physically, in pathological conditions, thermal therapy is used in order to expose body tissue and cancerous tumor to high temperature. Due to thermal radiation parameter the increase in blood temperature will make cancer cells more sensitive to...
radiation, therefore damage and kill cancer cells associated with tumors with nomial injury to normal tissues. The effect of $D_f$ on the temperature profile is depicted in Fig. 7.13. It is observed that increasing values of Dufour parameter enhances the blood temperature in the vicinity of boundary layer, since $D_f$ refers to the involvement of concentration gradient to the thermal energy flux inside the fluid flow. Also, the temperature is higher along center of artery as $D_f$ increases. While, reverse effect is observed on temperature profile for increasing values of $Sr$ as shown in Fig. 7.14, i.e. temperature decreases with increase in $Sr$. This is a good agreement with the fact that Soret number has opposite behavior to that of Dufour number.

Fig. 7.9: Temperature Profile for varying values of $Br$
Fig. 7.10: Temperature Profile for varying values of $M$

Fig. 7.11: Temperature Profile for varying values of $Pr$

Fig. 7.12: Temperature Profile for varying values of $R$
Concentration Profiles:

Concentration profiles for various parameters have been shown in Figures (7.15-7.18). For concentration profile, we can see a significant change as we change the value of chemical reaction parameter $Kr$ as shown in Fig. 7.15. It is noted that an increase in $Kr$ results a decrease in absolute values of concentration profile. This is due to the fact that the destructive chemical
reaction \((Kr > 0)\) has the tendency to reduce diffusion so there is a decrease in chemical molecular diffusivity of the concentration species. Because of which species concentration experiences retarding effect and minimize the mass transfer. Fig. 7.16 shows the effect of Schmidt number \((Sc)\) on concentration profile. It is observed that an increase in \(Sc\) results a decrease in concentration profile. This causes the concentration buoyancy effects to decrease in the fluid velocity. The reductions in the velocity and concentration profiles are convoyed by simultaneous fall in the momentum and concentration boundary layers thickens. The variation of concentration profile for different values of \(Sr\) is depicted in Fig.7.17. It is noted that the fluid concentration is an increasing function of \(Sr\). This phenomenon is a good agreement with the fact that the effect of Soret parameter refers to mass flux from lower to higher solute concentration which produced by temperature gradient. While, it is observed from Fig. 7.18 that Dufour parameter \(D_f\) has opposite phenomenon on concentration profile, i.e. increasing values of Dufour parameter reduce the concentration of fluid. It is reasonably obvious as the Soret and Dufour behave opposite behavior to each other. Physically, due to combined effects of thermal and solutal concentration higher values of \(D_f\) enhances the convection velocity which leads to increase the temperature of the fluid by depressing concentration of species. It is also noted that the concentration profile has a reverse phenomenon as compared with the temperature profile.
Fig. 7.15: Concentration Profile for varying values of \( Kr \)

Fig. 7.16: Concentration Profile for varying values of \( Sc \)

Fig. 7.17: Concentration Profile for varying values of \( Sr \)
CONCLUSIONS:

The effects of Soret and Dufour on MHD mixed convection blood flow of a viscous incompressible electrically conducting fluid through a stenosed artery has been discussed in this chapter. The numerical estimates presented here elucidate the effects of various parameters involved in our present problem. The major outcomes of the present analysis are summarized below:

(a) It is observed that the blood temperature increases with an increase in thermal radiation parameter. In pathological situations, thermal therapy is usually used in order to expose body tissue and cancerous tumor to high temperature.

(b) It is noticed that increasing values of (Dufour parameter) $D_f$ enhances the fluid temperature in the vicinity of boundary layer, as $D_f$ corresponds to the contribution of concentration gradient to the thermal energy flux inside the
fluid. It is also seen that temperature is higher along center of artery as $D_f$ increases. On the other hand, reverse effect is seen on temperature profile for increasing values $Sr$.

(c) It is observed that fluid concentration is an increasing function of Soret parameter ($Sr$) while reverse effect is observed for Dufour parameter ($Du$). This behavior is in agreement with the fact that Soret effect refers to mass flux from lower to higher solute concentration produced by temperature gradient.

(d) It is noted that an increase in chemical reaction parameter ($Kr$) results in a decrease in absolute values of concentration profile.

In order to treat the patients more accurately with an aim to get better results in thermal therapy for relieving pain, the theoretical estimates presented here will be useful. The study will also be of sufficient interest to clinicians who are engaged in the treatment of cancers and tumors by using the method of electromagnetic hyperthermia. This is because this technique involves overheating the affected tissues, usually above 43 °C. The subject provides a rich arena for mathematical simulation and it is also hoped that the present investigation will further stimulate experimental studies of magnetic propulsion and heat transfer in stenosed arterial blood flow problems. The study may bear the potential of significant applications in the field of Biomedical Engineering and Technology.