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Effects of Pollutants and Atmospheric Temperature Rise on Agriculture

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Abstract

Climate change is emerging as one of the most challenging problems facing the world in the 21st century. In this research work, a transient equation describing this phenomenon is presented. We assume the dusty fluid to be flowing over a flat plate while the other plate is at infinity. The dusty particles are to be uniformly distributed throughout the fluid. The two plates are to be electrically non-conducting and kept at constant temperatures. The equations to the phenomenon are solved analytically using a self similarly solution and Frobenius method. The results obtained are presented graphically and discussed. It is discovered that temperature increases as the Hartman number due to pollutants increases.

Keywords: Temperature, Pollution, Agricultural Productivity, Climate change, Greenhouse gas

1.0 Introduction

Climate change is one of the most challenging problems facing the world in the 21st century. It is important to note that failure to protect farmers from the consequences of climate change is a violation of farmers' rights [1].The agricultural sector has a multiplier effect on any nation's socio-economic and industrial fabric because of the multifunctional nature of the sector[2]. It has the potential to be the industrial and economic springboard from which the country's development can take off [3]. This sector remains the main source of livelihood for most rural communities in developing countries in general. In Africa, agriculture provides a source of employment for more than sixty per cent of the population and contributes about thirty percent of Gross Domestic Product[4].

When humans first started planting crops and raising cattle thousands of years ago, the dependence of agriculture on weather and climate was evident. Would there be enough rain for the crops to germinate and grow? Why do only certain crops or plants grow in a region? Would there be enough grass for the cattle to graze? These were probably some of the first questions that our forefathers asked when they planted crops or raised livestock. Of all human endeavours, agriculture was perhaps the first sector where humans realized that there are strong interactions between the sector and the weather.

The study of the effect of climate change on agricultural productivity is critical given its impact in changing livelihood patterns in the country. The issue of climate change has become more threatening not only to the sustainable development of socio economic and agricultural activities of any nation but to the totality of human existence [5]. Besides, the effect of climate change implies that the local climate variability which people have previously experienced and adapted to is changing and this change is observed in a relatively great speed. The threat that climate changes pose to agricultural production does not only cover the area of crop husbandry but also includes livestock and in fact the total agricultural sector. African farmers also depend on livestock for income, food and animal products [6]. Climate can affect livestock both directly and indirectly [7, 8].

Direct effects of climate variables such as air, temperature, humidity, wind speed and other climate factors influence animal performance such as growth, milk production, wool production and reproduction. Climate can also affect the quantity and quality of feed stuffs such as pasture, forage, and grain and also the severity and distribution of livestock diseases and parasite [9]. Hence the totality of agricultural sector is considered by examining agricultural productivity.

The increase in the Green House Gases (GHGs) concentration like water vapour, carbon dioxide, methane and ozone is blamed to be responsible for the rise in temperature of planet earth. Greenhouse gases are those gases that contribute to the greenhouse effect. The largest contributing source of greenhouse gas is the burning of fossil fuels leading to the emission of carbon dioxide. When sunlight reaches Earth's surface a part is absorbed and warms the earth and most of the remaining part radiated back to the atmosphere at a longer wavelength than the sun light. Some of these longer wavelengths are absorbed by

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greenhouse gases in the atmosphere before they are lost to space. The absorption of this long wave radiant energy warms the atmosphere. These greenhouse gases act like a mirror and reflect back to the Earth some of the heat energy which would otherwise be lost to space. The reflecting back of heat energy by the atmosphere is called the "greenhouse effect.

2.0 Pollution

Pollution is the effect of undesirable changes in our surroundings that have harmful effects on plants, animals and man. This occurs when only short-term economic gains are made at the cost of the long-term ecological benefits for humanity. No natural phenomenon has led to greater ecological changes than have been made by mankind. During the last few decades we have contaminated our air, water and land on which life itself depends with a variety of waste products. Pollutants include solid, liquid or gaseous substances present in greater than natural abundance produced due to human activity, which have a detrimental effect on our environment. The nature and concentration of a pollutant determines the severity of detrimental effects on human health. An average human requires about twelve kilogram (12kg) of air each day, which is nearly twelve to fifteen times greater than the amount of food we eat. Thus even a small concentration of pollutants in the air becomes more significant in comparison with similar levels present in food. Pollutants that enter water have the ability to spread to distant places especially in the marine ecosystem. From an ecological perspective pollutants can be classified as follows: Degradable or non-persistent pollutants: These can be rapidly broken down by natural processes. For example, domestic sewage and discarded vegetables. Slowly degradable or persistent pollutants: Pollutants that remain in the environment for many years in an unchanged condition and take decades or longer to degrade. For example, dichlorodiphenyltrichloroethane (DDT) and most plastics. Non-degradable pollutants: These cannot be degraded by natural processes. Once they are released into the environment they are difficult to eradicate and continue to accumulate. For example, toxic elements like lead or mercury.

Mathematical Formulation:

Following [1] the dusty fluid is assumed to be flowing over a flat plate located at $y=0$ while the other plate is at infinity. The dusty particles are assumed to be uniformly distributed throughout the fluid. The two plates are assumed to be electrically non-conducting and kept at constant temperature T_1 and T_2. The lower plate is assumed to be moving with a uniform velocity U while the upper plate is kept constant.

The equations governing the unsteady flow are:

The Momentum Equation

$$\rho\frac{\partial u}{\partial t}=\mu\frac{\partial^2 u}{\partial y^2}-\sigma B_o^2 u \tag{1}$$

The Energy Equation

$$\rho c_P\frac{\partial T}{\partial t}=k\frac{\partial^2 T}{\partial y^2}+\mu\left(\frac{\partial u}{\partial y}\right)^2+\sigma B_o^2 u^2 \tag{2}$$

The initial and boundary conditions are formulated as:

$$\left.\begin{array}{l} u(y,0)=0, u(0,t)=U, u(\infty,t)=0 \\ \\ T(y,0)=T_{0,}, T(0,t)=T_1, T(\infty,t)=T_2 \end{array}\right\}, \tag{3}$$

In order to write the governing equations and the relevant boundary conditions in non – dimensional form, the following dimensionless quantities are introduced:

$$\theta=\frac{T}{T_2-T_1},\ \phi=\frac{u}{U},\ y'=\frac{y}{L},\ t'=\frac{Ut}{L}, \tag{4}$$

where,

$C_p =$ Specific heat at constant pressure

$B_0 =$ Magnetic field strength

$\sigma =$ Electrical conductivity of the fluid

$\rho =$ Density of the fluid

$\mu =$ Dynamics viscosity

$\theta =$ Dimensionless temperature

$u =$ Velocity of the fluid

$\nu =$ Kinematic viscosity
$T =$ Temperature of the fluid
$K =$ Thermal conductivity
$t =$Fluid time
$y =$ Dimensionless coordinate axis
$\infty =$ Conditions at the free end
$\phi =$ Velocity of the fluid

The momentum equation (1), the energy equation (2)are now respectively given as:

$$\frac{\partial \phi}{\partial t} = \frac{1}{\text{Re}}\frac{\partial^2 \phi}{\partial y^2} - \frac{H_a^2}{\text{Re}}\phi \qquad (5)$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{Pe}\frac{\partial^2 \theta}{\partial y^2} + \frac{Ec}{\text{Re}}\left(\frac{\partial \phi}{\partial y}\right)^2 + \frac{H_a^2}{\text{Re}}\phi^2 \qquad (6)$$

The corresponding boundary conditions in dimensionless form are

$$\left.\begin{array}{l} \phi(y,0) = 0, \phi(0,t) = 1, \phi(\infty,t) = 0 \\ \theta(y,0) = \lambda, \theta(0,t) = \alpha, \theta(\infty,t) = \beta \end{array}\right\} \qquad (7)$$

Solution of the Problem

To solve equations (5) – (6) subject to the boundary conditions (7), we seek self-similar solution of the form,

$$\phi(y,t) = t^{-\alpha} f(x),\ x = yt^{-\alpha} \qquad (8)$$

$$\theta(y,t) = t^{-\alpha} g(x),\ x = yt^{-\alpha} \qquad (9)$$

From equation (8) we have

$$\frac{\partial \phi}{\partial t} = -\alpha x t^{-\alpha-1} f' \qquad (10)$$

$$\frac{\partial \phi}{\partial y} = t^{-2\alpha} f' \qquad (11)$$

$$\frac{\partial^2 \phi}{\partial y^2} = t^{-3\alpha} f'' \qquad (12)$$

From equation (9) we have

$$\frac{\partial \theta}{\partial t} = -\alpha x t^{-\alpha-1} g' \qquad (13)$$

$$\frac{\partial \theta}{\partial y} = t^{-2\alpha} g' \qquad (14)$$

$$\frac{\partial^2 \theta}{\partial y^2} = t^{-3\alpha} g'' \qquad (15)$$

Self-similar solution exist when $\alpha = 0$. Therefore substituting equations (10) - (15) into equations (5) – (6) we have

$$\frac{1}{\text{Re}} f'' - \frac{H_a^2}{\text{Re}} f = 0,\ f(0) = 1,\ f(\infty) = 0 \qquad (16)$$

$$\frac{1}{Pe} g'' + \frac{Ec}{\text{Re}} f'^2 + \frac{H_a^2}{\text{Re}} f^2,\ g(0) = \alpha,\ g(\infty) = \beta \qquad (17)$$

Using the transformation:

$$z = e^{-x} \tag{18}$$

Equations (16) – (17) become

$$\frac{1}{\mathrm{Re}} z^2 f'' + \frac{1}{\mathrm{Re}} z f' - \frac{H_a^2}{\mathrm{Re}} f = 0,\ f(0) = 0,\ f(1) = 1 \tag{19}$$

$$\frac{1}{pe} z^2 g'' + \frac{1}{Pe} z g' + \frac{Ec}{\mathrm{Re}} z^2 f'^2 + \frac{H_a^2}{\mathrm{Re}} f^2,\ g(0) = \beta,\ g(1) = \alpha \tag{20}$$

Also, using the transformation:

$$m = 2z - 1 \tag{21}$$

Then equations (19) - (20) become

$$(m+1)^2 f'' + (m+1) f' - H_a^2 f = 0 \quad f(-1) = 0,\ f(1) = 1 \tag{22}$$

$$(m+1)^2 g'' + (m+1) g' + \frac{EcPe}{\mathrm{Re}} (m+1)^2 f^2 + \frac{H_a^2}{\mathrm{Re}} f'^2 = 0,\ g(-1) = \beta,\ g(1) = \alpha \tag{23}$$

Using Frobenius method, we let

$$f = \sum_{n=0}^{\infty} a_n m^{n+r} \tag{24}$$

and

$$g = \sum_{n=0}^{\infty} e_n m^{n+s} \tag{25}$$

Taking the first, second derivative of equation (24) and substituting into equations (22) give

$$\left.\begin{aligned} & a_0 r(r-1) m^{r-2} + a_1 (r+1) r m^{r-1} + a_2 (r+2)(r+1) m^r + a_3 (r+3)(r+2) m^{r+1} \\ & + a_4 (r+4)(r+3) m^{r+2} + \ldots + a_0 r(2r-1) m^{r-,} + a_1 (r+1)(2r+1) m^r \\ & + a_2 (r+2)(2r+3) m^{r+1} + a_3 (r+3)(2r+5) m^{r+2} + a_4 (r+4)(2r+7) m^{r+3} \\ & + \ldots + a_0 \left(r^2 - H_a^2\right) m^r + a_1 \left[(r+1)^2 - H_a^2\right] m^{r+1} + a_2 \left[(r+2)^2 - H_a^2\right] m^{r+2} \\ & + a_3 \left[(r+3)^2 - H_a^2\right] m^{r+3} + a^4 \left[(r+4)^2 - H_a^2\right] m^{r+4} + \ldots = 0 \end{aligned}\right\} \tag{26}$$

Equating the coefficient of the least power of m to zero to obtain the root of the indicial equation i.e. $a_0 r(r-1) = 0 \Rightarrow r = 0, r = 1, a_0 \neq 0.$

when $r = 0$ equation (26) shows that a_1 is an arbitrary constant.

Equating terms in powers of m, we have,

For

$r = 0$:

$$a_2 = \left(\frac{a_0 H_a^2 - a_1}{2}\right) \tag{27}$$

$$a_3 = -\left(\frac{3(a_0 H_a^2 - a_1) + a_1(1 - H_a^2)}{6}\right) \tag{28}$$

$$a_4 = -\left\{\frac{\frac{-15}{6}\left[3(a_0H_a^2 - a_1) + a_1(1 - H_a^2)\right] + \frac{(4 - H_a^2)(a_0H_a^2 - a_1)}{2}}{12}\right\} \tag{29}$$

Then

$$f_1(m) = a_0 + a_1 m + \left(\frac{a_0H_a^2 - a_1}{2}\right)m^2 - a_3m^3 - a_4m^4 + \ldots \tag{30}$$

For $r = 1,\ b_1 = 0$

$$b_2 = -\frac{\left(6b_1 + \left(1 - H_a^2\right)b_0\right)}{6} = -\frac{\left(1 - H_a^2\right)b_0}{6} \tag{31}$$

$$b_3 = \frac{15\left(1 - H_a^2\right)b_0}{72} \tag{32}$$

$$b_4 = \frac{\left[\frac{20\times 15\left(1 - H_a^2\right)b_0}{72} - \frac{\left(9 - H_a^2\right)\left(1 - H_a^2\right)b_0}{6}\right]}{20} \tag{33}$$

Then

$$f_2(m) = b_0 m - \frac{\left(1 - H_a^2\right)b_0}{6}m^3 + \frac{15}{72}\left(1 - H_a^2\right)b_0 m^4 + b_4 m^5 + \ldots \tag{34}$$

By hypothesis, $b_0 = a_0 = 1$

Taking $a_0 = a_1$, since a_1 is an arbitrary constant.

$$f(m) = C_1 f_1(m) + C_2 f_2(m) \tag{35}$$

$$\left.\begin{aligned} f(m) &= C_1\left\{1 + m + \left(\frac{H_a^2 - 1}{2}\right)m^2 - a_3m^3 - a_4m^4 + \ldots\right\} \\ &+ C_2\left\{m - \left(\frac{1 - H_a^2}{6}\right)m^3 + \frac{15}{72}\left(1 - H_a^2\right)m^4 + b_4m^5 + \ldots\right\}\end{aligned}\right\} \tag{36}$$

$$\begin{aligned} f(-1) &= C_1\left\{\left(\frac{H_a^2 - 1}{2}\right) + a_3 - a_4\right\} \\ &+ C_2\left\{-1 + \left(\frac{1 - H_a^2}{6}\right) + \frac{15}{72}\left(1 - H_a^2\right) - b_4 + \ldots\right\} = 0 \end{aligned} \tag{37}$$

$$\begin{aligned} f(1) &= C_1\left\{2 + \frac{\left(H_a^2 - 1\right)}{2} - a_3 - a_4 + \ldots\right\} \\ &+ C_2\left\{1 - \frac{\left(1 - H_a^2\right)}{6} + \frac{15}{72}\left(1 - H_a^2\right) + b_4 + \ldots\right\} = 1 \end{aligned} \tag{38}$$

Let

$$A = \left(\frac{H_a^2 - 1}{2}\right) + a_3 - a_4 \tag{39}$$

$$B = -1 + \left(\frac{1 - H_a^2}{6}\right) + \frac{15}{72}\left(1 - H_a^2\right) - b_4 \tag{40}$$

$$C = 2 + \left(\frac{H_a^2 - 1}{2}\right) - a_3 - a_4 \tag{41}$$

$$E = 1 - \left(\frac{1 - H_a^2}{6}\right) + \frac{15}{72}\left(1 - H_a^2\right) + b_4 \tag{42}$$

Substituting equations (39) – (42) into equations (37) and (38)give

$$AC_1 + BC_2 = 0 \tag{43}$$

$$CC_1 + EC_2 = 1 \tag{44}$$

Multiplying equation (43) by E and equation (44) by B and solve simultaneously give

$$C_1 = -\frac{B}{(AE - BC)} \tag{45}$$

$$C_2 = \frac{A}{(AE - BC)} \tag{46}$$

Let

$$p_0 = C_1 = -\frac{B}{(AE - BC)} \tag{47}$$

$$p_1 = \frac{H_a^2 - 1}{2} \tag{48}$$

$$p_2 = a_3 = -\left(\frac{3\left(a_0 H_a^2 - a_1\right) + a_1\left(1 - H_a^2\right)}{6}\right) \tag{49}$$

$$p_4 = -\left(\frac{\frac{-15}{6}\left[3\left(a_0 H_a^2 - a_1\right) + a_1\left(1 - H_a^2\right)\right] + \frac{\left(4 - H_a^2\right)\left(a_0 H_a^2 - a_1\right)}{2}}{12}\right) \tag{50}$$

$$p_5 = \left(\frac{A}{(AE - BC)}\right) \tag{51}$$

$$p_6 = \frac{1 - H_a^2}{6} \tag{52}$$

$$p_7 = \frac{15}{72}\left(1 - H_a^2\right) \tag{53}$$

$$p_8 = b_4 = \frac{\left[\frac{20 \times 15\left(1 - H_a^2\right)b_0}{72} - \frac{\left(9 - H_a^2\right)\left(1 - H_a^2\right)b_0}{6}\right]}{20} \tag{54}$$

Substituting equations (47) – (54) into (36) we obtain

$$f(m)=p_0\left(1+m+p_1m^2-p_2m^3-p_4m^4+\ldots\right)$$
$$+p_5\left(m-p_6m^3+p_7m^4+p_8m^5+\ldots\right) \tag{55}$$

Also,taking the first, second derivative of equations (25) and substituting into equation (23), we obtain

$$e_0s(s-1)m^{s-2}+e_1(s+1)sm^{s-1}+e_2(s+2)(s+1)m^s$$
$$+e_3(s+3)(s+2)m^{s+1}+e_4(s+4)(s+3)m^{s+2}$$
$$+\ldots+e_0s(2s-1)m^{s-1}+e_1(s+1)(2s+1)m^s$$
$$+e_2(s+2)(2s+3)m^{s+1}+e_3(s+3)(2s+5)m^{s+2}$$
$$+e_4(s+4)(2s+7)m^{s+3}+\ldots+e_0s^2m^2+d_1(s+1)^2m^{s+1}$$
$$+e_2(s+2)^2m^{s+2}+e_3(s+3)^2m^{s+3}$$
$$+e_4(s+4)^2m^{s+4}+\ldots+\frac{EcPe}{\text{Re}}\left(m^2+2m+1\right)\left(f^1\right)^2+\frac{H_a^2Pe}{\text{Re}}(f)^2=0 \tag{56}$$

Equating the coefficient of the least power of m to zero to obtain the root of the indicial equation, i.e.

$$e_0s(s-1)=0\Rightarrow s=0,s=1$$

and

$$e_0\neq 0$$

when $s=0,$ equation (56) shows that e_1 is an arbitrary constant.

Equating terms in powers of m, we obtain

For $s=0$

$$e_2=-\left\{\frac{\frac{EcPe}{\text{Re}}(p_0+p_5)^2+\frac{H_a^2Pe}{\text{Re}}p_0^2+e_1}{2}\right\} \tag{57}$$

$$e_3=-\left(\frac{\frac{EcPe}{\text{Re}}4(p_0+p_5)^2+\frac{H_a^2Pe}{\text{Re}}(p_0+p_5)2p_0+6e_2+e_1}{6}\right) \tag{58}$$

Then

$$g_1(m)=e_0+e_1m+e_2m^2+e_3m^3+\ldots \tag{59}$$

For s=1

$$d_2=-\left(\frac{\frac{EcPe}{\text{Re}}2\left((p_0+p_5)^2+p_1(1+2p_0p_5)\right)+\frac{H_aPe}{\text{Re}}2p_0(p_0+p_5)+d_0}{6}\right) \tag{60}$$

Then

$$g_2(m)=d_0m+d_2m^3+\ldots \tag{61}$$

By hypothesis, $d_0=e_0=1$, taking $e_0=e_1$ since e_1 is an arbitrary constant.

$$g(m)=C_1g_1(m)+C_2g_2(m) \tag{62}$$

i.e.

$$g(m) = C_1\left(1 + m + e_2 m^2 + e_3 m^3 + ...\right) + C_2\left(m + d_2 m^3 + ...\right) \quad (63)$$

$$g(-1) = C_1\left(e_2 - e_3 + ...\right) + C_2\left(-1 - d_2 + ...\right) = \beta \quad (64)$$

$$g(1) = C_1\left(2 + e_2 + e_3 + ...\right) + C_2\left(1 + d_2 + ...\right) = \alpha \quad (65)$$

Let

$$q_1 = e_2 - e_3 \quad (66)$$

$$q_2 = -1 - d_2 \quad (67)$$

$$q_3 = 2 + e_2 + e_3 \quad (68)$$

$$q_4 = 1 + d_2 \quad (69)$$

Substituting equations (66) – (69) into equations (64) and (65) give

$$C_1 q_1 + C_2 q_2 = \beta \quad (70)$$

$$C_1 q_3 + C_2 q_4 = \alpha \quad (71)$$

Multiplying (70) by q_4 and (71) by q_2 and solve simultaneously gives

$$C_1 = \frac{\left(q_4\beta - q_2\alpha\right)}{\left(q_1 q_4 - q_2 q_3\right)} \quad (72)$$

$$C_2 = \frac{\left(q_1\alpha - q_3\beta\right)}{\left(q_1 q_4 - q_2 q_3\right)} \quad (73)$$

Then,

$$g(m) = C_1\left(1 + m + e_2 m^2 + e_3 m^3\right) + C_2\left(m + d_2 m^3\right) \quad (74)$$

with the values of C_1 and C_2 given above

3.0 Analysis and Discussion of Results

The system of partial differential equations describing the physical processes governing the effects of pollutants and atmospheric temperature rise on Agriculture are solved analytically using Frobenius method and seeking a self-similar solution technique. Analytical solutions of equations (3.65) – (3.67) are computed for the values of Re = 0.3, 0.6, 1.0. H_a = 0.2, 0.4, 0.8. Ec = 0.1, 0.2 0.4 and Pe = 0.2, 0.4, 0.6.

The numerical result for the effects of pollutants and atmospheric temperature rise and its implications on agriculture are shown in Figures 4.1 – 4.6.

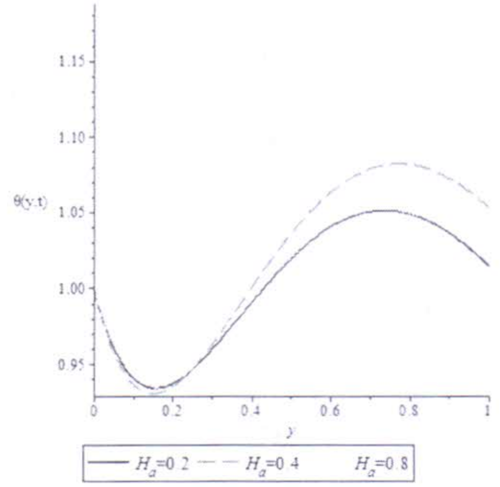

Figure 4.1: Variation of Hartmann number (Ha) with temperature $\theta(y,t)$ against space y for H_a=0.2, 0.4 and 0.8.

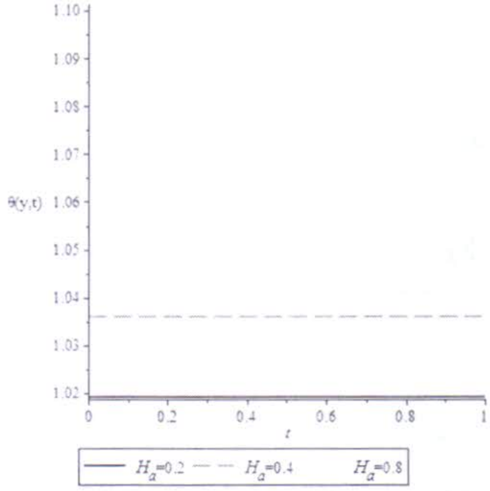

Figure 4.2: Variation of Hartmann number (Ha) with temperature $\theta(y,t)$ against time t for H_a=0.2, 0.4 and 0.8.

Figure 4.1 indicates that as the Hartman number(Ha) increases the temperature increases. This may be as a result of an increase in the greenhouse gases. Increase in temperature will likely result in decreasing agricultural productivity. This may be that high temperature depletes soil nutrient making it hard on agricultural production generally.
Figure 4.2 indicates that as the Hartman number(Ha) increases the temperature also increases. This may militates against agricultural production.

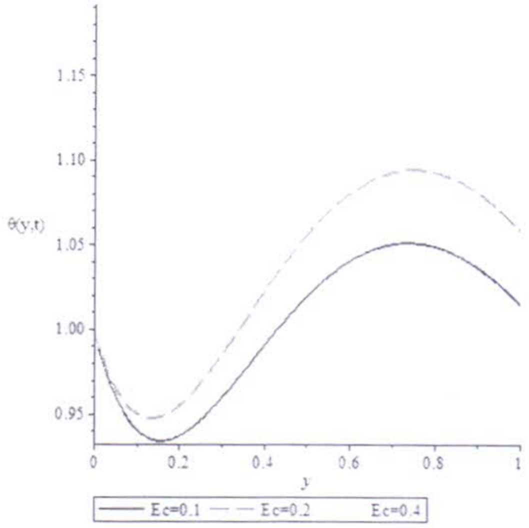

Figure 4.3: Variation of Eckert number with temperature $\theta(y,t)$ against space y.

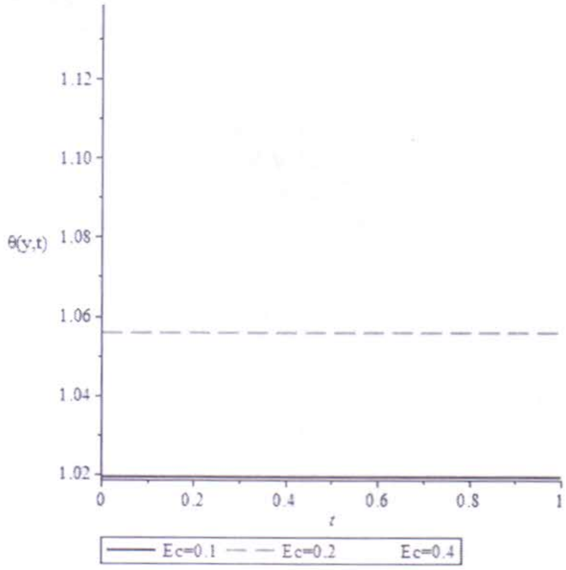

Figure 4.4: Variation of Eckert number (Ec) with temperature

Figure 4.3 shows that as the Eckert number (Ec) increases temperature increases. This may be as a result of an increase in the greenhouse gas concentration. This may also reduce agricultural productivity.
Figure 4.4 indicates that as the Eckert number(Ec) increases the temperature increases. This may be as a result of an increase in the greenhouse gases. Increase in temperature will likely decrease agricultural productivity.

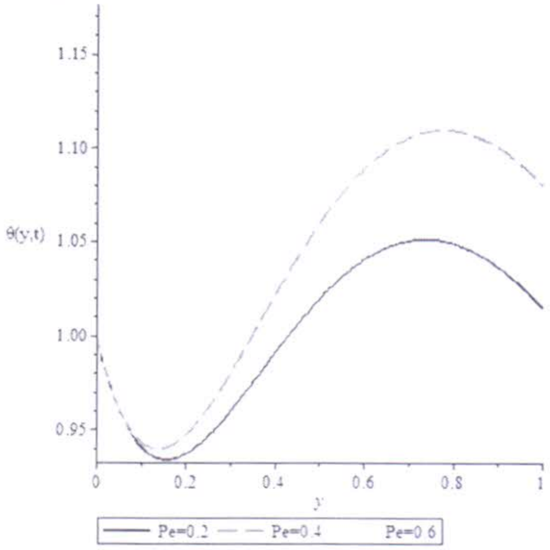

Figure 4.5: Variation of Peclet number (Pe) with temperature $\theta(y,t)$ against Space y for Pe = 0.2, 0.4 and 0.6.

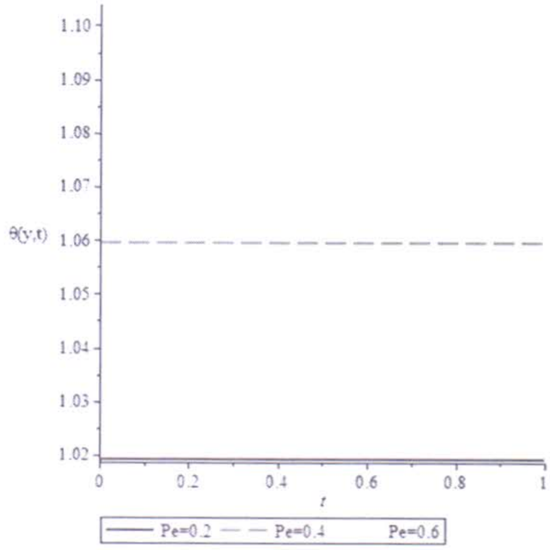

Figure 4.6: Variation of Peclet number (Pe) with temperature $\theta(y,t)$ against time t.

Figure 4.5 indicates that as the Peclet number(Pe) increases the temperature also increases and higher temperatures are harmful to agriculture. This may reduce agricultural production.
Figure 4.6 shows that as the Peclet number(Pe) increases the temperature also increases. This may also reduce agricultural production.

4.0 Summary and Conclusion

In this paper, the system of partial differential equations describing the effects of pollutants and atmospheric temperature rise on Agriculture is solved analytically using Frobenius method and seeking a self-similar solution technique.
From the studies made on this work, we conclude as follows:

i. As the Hartman number(Ha) increases the atmospheric temperature increases.
ii. As the Eckert number (Ec) increases the atmospheric temperature increases.
iii. As the Peclet number (Pe) increases the atmospheric temperature also increases

5.0 References

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