MODELING THE IMPACTS OF INDUCED MAGNETIC FIELD ON CLAY-LOAM SOIL'S TEMPERATURE WITH EXPONENTIATED BOUNDARY CONDITION

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Abstract

This paper explores the potential of induced magnetic field on the temperature of clay-loam soil using a mathematical model. In an ideal environment which is assumed to be the setting where the flow takes place, some important postulations were made. Governing equations were then modeled, reduced to non-dimensional form and then to ordinary differential equation. This was afterward solved analytically. The basic physical factors that emerged, that is, the Hartman number (which is the induced magnetic field parameter), radiation parameter and internal heat were examined on the temperature of the clay-loam soil. The numerical results were then graphed using MATLAB R2009b which provided insight into the effects and potential impacts of induced magnetic fields on the temperature of the clay-loamy soil. The results indicate that there is significant difference in the temperature of clay-loam soil exposed to an induced magnetic field and the standard clay-loam soil (without magnetic field). The induced magnetic field increases the temperature of clay-loam soil. This effect is visible both in the short-term and long-term.

KEYWORDS: Boundary condition, clay-loam soil, magnetic field, internal heat, radiation parameter.

Introduction

Soil treatment with magnetic fields is a process that can be used to improve the soil fertility and crop yield of agricultural land. The process can follow different methods. One of which can involves adding fine particles of magnetic materials to soil in order to increase the magnetic filed within the soil. This process allows for better uptake of beneficial ions such as iron, calcium, and magnesium, which can improve the overall soil quality. Additionally, soil treated with magnetic fields can reduce weed growth and improve water infiltration, resulting in greater crop yields. The most common method for introducing magnetic particles to soils is by adding ferromagnetic materials such as magnetite, ilmenite or hematite. These materials can be mixed into the soil or applied with a spreader. In addition, a magnetic separator can be used to magnetically treat soils without the addition of ferromagnetic particles. This process involves passing a current through a soil sample to create a magnetic field. The benefits of magnetic soil treatment can be maximized by carefully selecting the soil type, magnetic material, and application method. Soil type should be selected based on its existing pH level and organic matter content and it should be tested for the presence of ferromagnetic particles before application. The type of magnetic material should be chosen based on kits particle size and surface area, and it should be applied in a uniform manner. Moreover, the application method should be selected in order to ensure the even distribution of magnetic particles throughout the soil. When used correctly, magnetic soil treatment can help to improve the fertility and crop yields of agricultural lands. Although, as with any management practice, it is important to understand the benefits and risks associated with magnetically treated soils before application.

There are various authors/researchers who have delved into the study of soil temperature in order to improve agricultural produce and some to properly guide the miners. The list include Amrollah (2014) who surveyed the thermal properties of clay-loam soil, Ludynia and Orman (2013) that selected some soil types and conducted some preliminary tests of their thermal conductivities, Souza *et al.* (2006) who under pasture and forest in Maraba, Brazil, investigated soils heat fluxes and thermal conductivities, Ekwue *et al.*, (2011) considered some soils that are common in Trinidad and test their thermal conductivities.

Few others include Akinpelu *et al*, (2020) who compared the solar radiation effects on clay-loam & sandy-loam soils under a convective boundary condition, and Lier and Durigon (2013) that estimated thermal diffusivity of soils using data from the properties of single soil component and its temperature.

In view of the above, the present work modeled the impacts of induced magnetic field on clay-loam soil's temperature using an exponentiated boundary condition.

Mathematical Analysis

The flow is assumed to be two dimensional (y and z). The flow along the horizontal axis (y) is infinite leaving the flow to become a function of z and t being unsteady. The soil provides an optically environment and solar radiation is in line with gravity. The boundary condition is considered to be exponentially varying with time. Under these conditions, the governing equations were modeled using Boussinesq's approximation.

Continuity Equation

$$\frac{\partial w^*}{\partial z^*} = 0 \tag{1}$$

Energy Equation

$$\frac{\partial T^*}{\partial t^*} + w^* \frac{\partial T^*}{\partial z^*} = \frac{k}{\rho C_p}\frac{\partial^2 T^*}{\partial z^{2*}} - \frac{1}{\rho C_p}\frac{\partial q_r^*}{\partial z^*} + \frac{1}{\rho C_p}\left(\sigma B_0^2 w^2\right) + \frac{Q_0}{\rho C_p}\left(T^* - T_\infty^*\right) \tag{2}$$

Subject to:

$$T^*(0,t) = T_w^* + \lambda^* e^{i\omega^* t^*} \tag{3}$$

$$T^*(\infty,t) \to T_\infty^* \tag{4}$$

Where z^* is the dimensional vertical axis that measures the soil's depth, w^* stands for the dimensional suction velocity, ρ is the density, t^* is time in dimensional form, C_p is capacity of specific heat, T^* is temperature in dimensional type, q_r^* is heat flux, k is thermal conductivity, T_w^* & T_∞^* are both wall & free stream temperatures in that order, B & σ are strength of the magnetic field & electrical conductivity.

Applying some dimensionless parameters that are standardized as used by Olaleye *et al. (2019)*:

$$w = \frac{t^* w_0^2}{t} \, , \, \theta = \frac{T^* - T_\infty^*}{T_w^* - T_\infty^*} \, , \, z = \frac{w_0 z^*}{w} \, , \, t = \frac{t^*}{L} \, , \, \omega = \frac{\omega^* w}{w_0^2} \tag{5}$$

Moreover, consequent to Mohammed (2013), time varying suction velocity is adopted:

$$w^* = -w_0 (1 + \varepsilon A e^{i w^* t^*}) \tag{6}$$

Soil is alluring heat from electromagnetic waves emitted by the sun. As a result, subsequent to Akinpelu *et al* (2020), heat flux is definite as:

$$\frac{\partial q_r^*}{\partial z^*} = 4\alpha^2 (T^* - T_\infty^*) \tag{7}$$

In addition, relating to Akinpelu *et al* (2016), taking into consideration a thermal conductivity fickle with time:

$$k = \chi_0 + \chi_0 x t \tag{8}$$

Putting equations (5) through (8) into (2):

$$\theta'(t) - \theta'(z) - \varepsilon A e^{nt} \theta'(z) = \left(\frac{1 + xt}{P_r} \right) \theta''(z) - R^2 + Q\theta + (Ha)^2 Ec \tag{9}$$

where,

$$P_r = \frac{w \rho C_p}{\chi_0}$$ (Prandtl number)

$$Q = \frac{Q_0 w}{w_0^2 \rho C_p}$$ (internal heat parameter)

$$R^2 = \frac{4 w \alpha^2 \theta}{w_0^2 \rho C_p}$$ (radiation parameter)

$$Ha = (B_0) \left(\sqrt{\frac{\sigma}{\rho}} \right)$$ (Hartman number)

$$Ec = \frac{w^3}{w_0^2 C_p (T_w^* - T_\infty^*)}$$ (Eckert number)

Also, substituting equation (5) into equation (3) and (4), the boundary conditions became:

$$\theta(0,t) = 1 + \eta e^{i\omega t} \tag{10}$$

$$\theta(\infty,t) \to 0 \tag{11}$$

Method of Solution

Shrinking equation (9) which is partial differential equation of order two using perturbation technique into ordinary one as adopted by Nwaigwe (2010), the solution is assumed to be:

$$\theta(z,t) = \theta_0(z) + \varepsilon A e^{i\omega t}\theta_1(z) + \varepsilon^2 A^2 e^{2i\omega t}\theta_2(z) + \cdots \tag{12}$$

However, the product of εA is far less than one, i.e. $\varepsilon A << 1$. Therefore, the higher order terms $(\varepsilon A)^2$ is negligible.

Putting equation (13) & its derivatives into equation (10), and taking order of $(\varepsilon A)^0$ and εA :

$$\theta_0''(z) + P_r(1+xt)^{-1}\theta_0'(z) + P_r(1+xt)^{-1}Q\theta_0(z) = P_r(1+xt)^{-1}R^2 - P_r(1+xt)^{-1}(Ha)^2 Ec \tag{13}$$

$$\theta_1''(z) + P_r(1+xt)^{-1}\theta_1'(z) + P_r(1+xt)^{-1}(Q-n)\theta_1 = -P_r(1+xt)^{-1}\theta_0'(z) \tag{14}$$

Additionally, revising equations (10) & (11) using equation (12);

$$\theta_0(0,t) = 1 + \eta e^{i\omega t} \qquad \theta_1(0,t) = 0 \tag{15}$$

$$\theta_0(\infty,t) \to 0 \quad , \qquad \theta_1(\infty,t) \to 0 \tag{16}$$

Equations (14) & (15) subjected to (16) & (17), the ambient soil temperature basically became;

$$\theta = (C_2 + C_6 \varepsilon A e^{i\omega t})e^{m_2 z} + C_3 + \varepsilon A e^{nt}\left(C_5 e^{m_4 z}\right) \tag{17}$$

where,

$$m_1 = -\frac{P_r}{2(1+xt)} + \sqrt{\frac{1}{4}\left(\frac{P_r}{1+xt}\right)^2 - \frac{P_r Q}{1+xt}}$$

$$m_2 = -\left(\frac{P_r}{2(1+xt)} + \sqrt{\frac{1}{4}\left(\frac{P_r}{1+xt}\right)^2 - \frac{P_r Q}{1+xt}}\right)$$

$$m_3 = -\frac{P_r}{2(1+xt)} + \sqrt{\frac{1}{4}\left(\frac{P_r}{1+xt}\right)^2 - \frac{P_r(Q-i\omega)}{1+xt}}$$

$$m_4 = -\left(\frac{P_r}{2(1+xt)} + \sqrt{\frac{1}{4}\left(\frac{P_r}{1+xt}\right)^2 - \frac{P_r(Q-i\omega)}{1+xt}}\right)$$

$$C_2 = 1+\eta e^{i\omega t} \qquad C_3 = \frac{R^2 - (Ha)^2 Ec}{Q} \qquad C_5 = -C_6$$

$$C_6 = \frac{-P_r C_2 m_2 (1+\mu t)^{-1}}{m_2^2 + P_r(1+\mu t)^{-1} m_2 + P_r(Q-i\omega)(1+\mu t)^{-1}}$$

Results and Discussion

Equation (17) is the solution of the formed model that the physical factors were to be examined on. An important thermo-physical property of Clay-loam soil, which is the sample soil adopted is presented on table 1.

As of a field work, it is assumed that a plot of land was chosen and then two stage experiments were to be performed: Firstly, a standard amount of clay-loam soil was put without involvement of magnetic field, while in the second stage, the land/soil was exposed to an inducted magnetic field. The two stages were left for an established interval of time when solar radiation increases to ensure for observation. It is assumed that using pertinent instruments, the surface temperature and magnetic field strength for the two sections were recorded at regular intervals during the experiment.

The emerged factors comprise of radiation parameter, Hartman number, Eckert number, internal heat and Prandtl number. Matlab software was deployed to graph the results.

Also, following some existing works like that of Mohammed (2013), present on table 2 were the default values of some other parameters involved in the work, or else otherwise specified.

Table 1: Clay-Loam soil Thermo-physical property

Soil	Thermal Conductivity (W/m K)	Humidity (%)
Clay-Loam	0.36	1.4

Table 2: Preset values of parameters concerned

P_r	R	Q	Ha	Ec	x	t	A	ω	ε	η

0.71	0.01	0.01	0.01	0.01	0.36	0.1	0.5	$\pi/2$	0.01	1.0

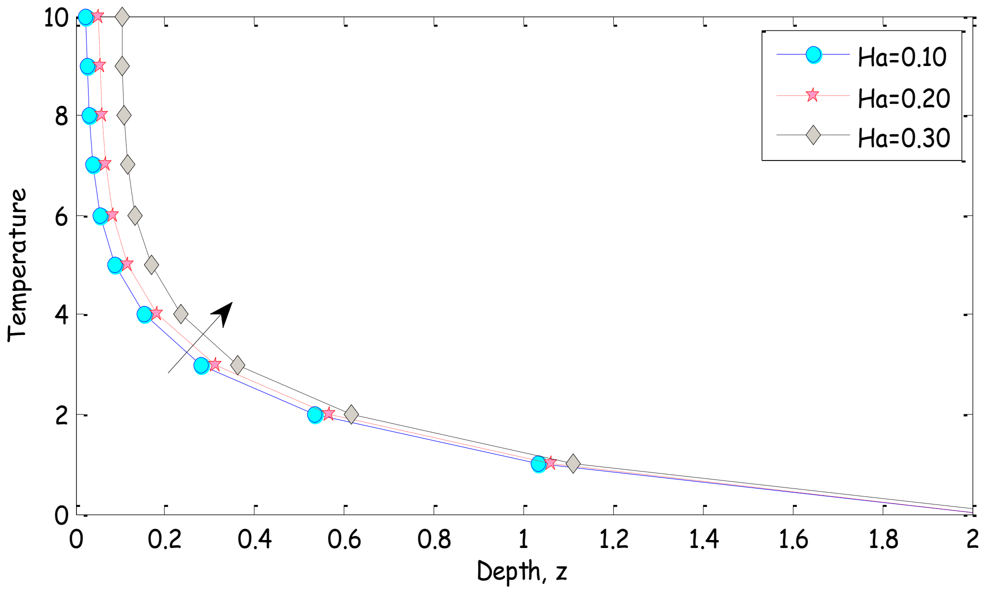

Figure 1: Impact of Hartman number on Clay-Loam soil’s temperature with increasing depth

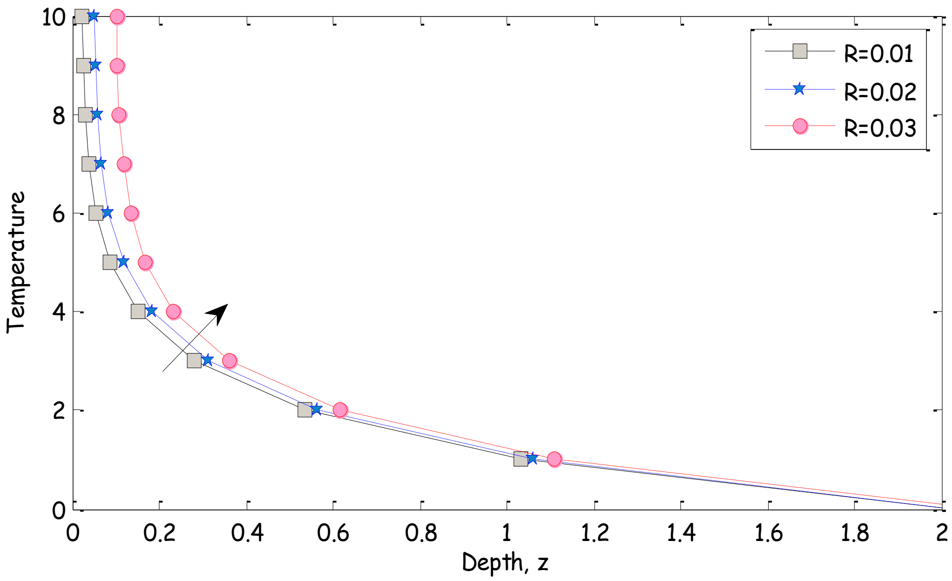

Figure 2: Impact of Radiation on Clay-Loam soil’s temperature with increasing depth

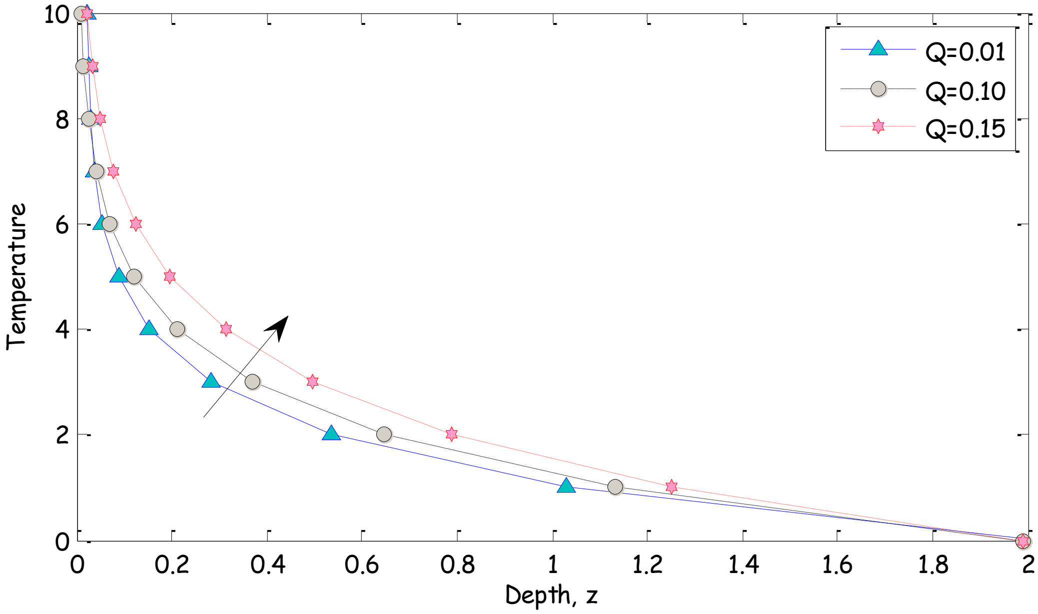

Figure 3: Impact of Internal heat on Clay-Loam soil's temperature with increasing depth

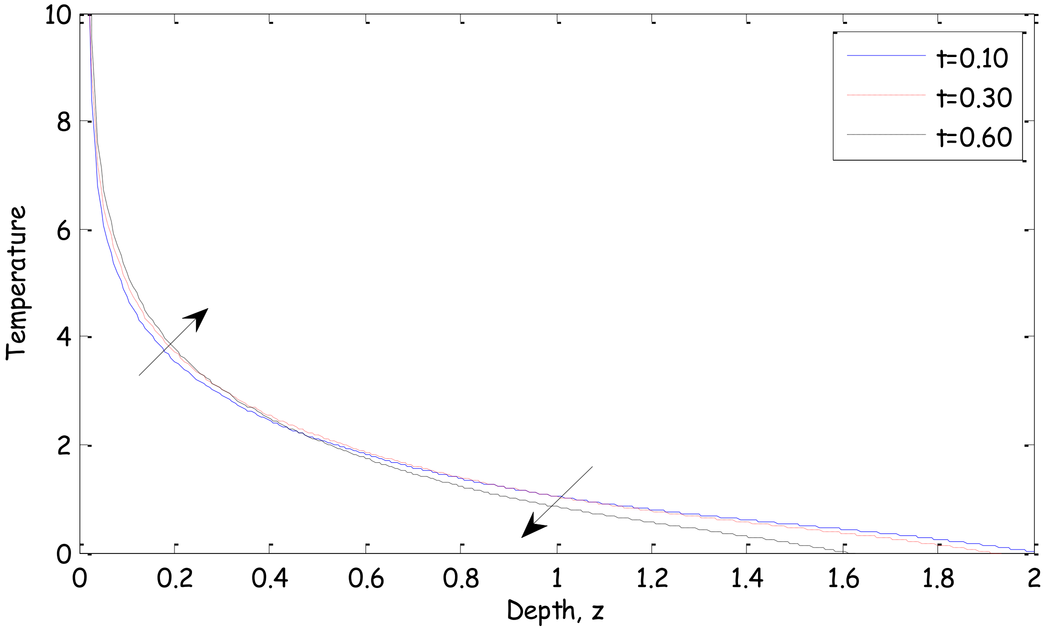

Figure 4: Impact of time on Clay-Loam soil's temperature with increasing depth

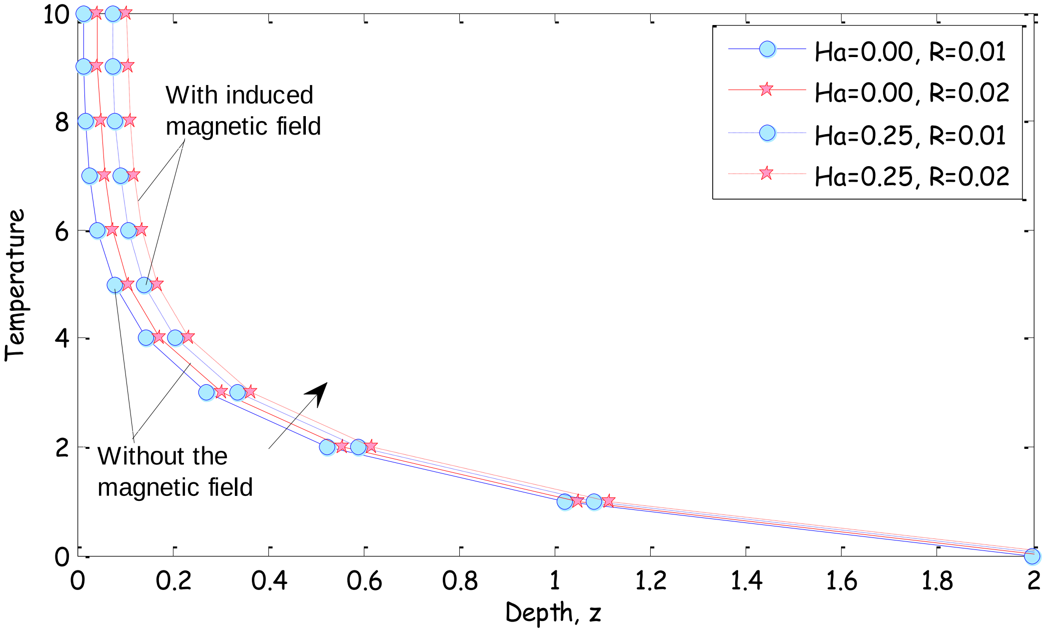

Figure 5: Impact of radiation on the temperature of the clay-loam soil with and without the magnetic field

The results according to the first figure indicate that when the intensity of the magnetic field increases, the temperature of the clay-loam soil is boosted accordingly.

In figure 2 moreover, the solar radiation which is one of the main factors that influence soil's temperature of a truth increases the temperature of the clay-soil as it rises. The electromagnetic waves which are released by the sun and increases with its higher intensity are obviously what are responsible for the increase in the soil's temperature because the soil has the ability to absorb a good portion of the electromagnetic wave.

Figure 3 portrays the impact which the internal heat has on Clay-Loam soil's temperature with increasing depth. The result is an eye opener to the fact that the soil temperature is also heightened by its rise.

In figure 4, when all the parameters are kept constant, as time passes, the soil temperature gradually increases to a particular depth. But after a while, as the depth increases, the temperature of the soil began to drop.

In figure 5, the soil was considered in two stages. Firstly, in the absence of magnetic field, and secondly, when the magnetic field is induced. The results show that at the absence of the magnetic field, the soil temperature is boosted by the increasing solar radiation (which follows from the above figure 2). However, when the soil is induced by the magnetic field, the increment becomes more significant.

Conclusion

This work has modeled the impacts which an induced magnetic field has on clay-loam soil's temperature using an exponentiated boundary condition. It is evidently seen that the induced magnetic field relatively increases the soil temperature. Thus, though man may not have control on some physical factors like solar radiation and internal heat that influence soil's temperature, yet, an induced magnetic field can be used to manipulate the surface temperature of clay-loam soil.

Further research can be conducted to examine the impacts of these fields on the soil properties and to devise effective strategies for their use in agriculture.

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