THE ROLE OF MATHEMATICAL SCIENCES IN SUSTAINABLE DEVELOPMENT GOALS

BOOK *of* PROCEEDINGS

International Conference on
Contemporary Developments in
Mathematical Sciences

in Honour of

Professor Kayode Rufus Adeboye

Department of Mathematics
Federal University of Technology, Minna

70th *Birthday & Retirement from Service*

Professor Kayode Rufus Adeboye

B.Sc. (Lagos), M.Phil. (Reading), Ph.D. (Ilorin), FMAN, FNMS, FAC

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PROFESSOR Kayode Rufus Adeboye

B.Sc. (Lagos), M.Phil. (Reading), Ph.D. (Ilorin), FMAN, FNMS, FAC

PROFILE

EARLY LIFE AND EDUCATION

Professor Kayode Rufus Adeboye was born in Egbe-Ekiti on April 12th, 1949 to Chief and Mrs. Daniel O. Adeboye. He attended Ekiti Parapo College, Ido-Ekiti, for his Secondary School Education. For his tertiary education, he attended Oluloyo College of Education, Ibadan, Nigeria from 1964 to 1966. He commenced his undergraduate degree programme in 1968 at the University of Lagos and got Western State University scholarship in 1969. He graduated with a B.Sc. with Honours (Second Class Upper Division) in Mathematics in 1971 and following his brilliant performance in his undergraduate course, he was awarded a University of Lagos Postgraduate Scholarship in 1972 and 1973, AFGRAD Scholarship, USA in 1974, Federal Government Postgraduate Scholarship in 1974 and University of Ife fellowship in 1976 to continue his studies at University of Reading, Reading, England. From 1973 to 1975 he worked as a Tutor at the University of Ife now Obafemi Awolowo University.

Professor Kayode Rufus Adeboye left Nigeria in 1975 at the age of 26 on scholarship to pursue postgraduate studies in Mathematics at the University of Reading, Reading, England. On successfully completing this course in 1978, he returned to Nigeria and continued his academic work as Assistant Lecturer (1978 - 1980) and Lecturer II (1980 - 1982) at the University of Ife and Research Officer (1982 - 1989) at the National Teacher Institute, Kaduna, Nigeria. He embarked on his PhD degree in Mathematics at the University of Ilorin, Nigeria in 1988 supervised by Prof. M. A. Ibiejugba of blessed memory.

Kayode Rufus Adeboye was awarded the PhD degree in Mathematics by the University of Ilorin in 1991 at the age of 42.

He later joined the service of Federal University of Technology, Minna in 1989 as Senior Lecturer in the Department of Mathematics/Computer Science and rose to the rank of a Professor of Mathematics in 1997. He taught mathematics at the Federal University of Technology, Minna for more than 30 years.

AT THE FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA

At the Federal University of Technology, Minna, he has been the thesis advisor for twelve Ph.D. students and the joint thesis advisor of many Ph.D. students with Professor N. I. Akinwande, Prof. Y. M. Aiyesimi, Prof. Y. A. Yahaya, Prof. U. Y. Abubakar and Prof. R. O. Olayiwola. He has supervised the studies of 31 M.Tech. Students, 120 postgraduate diploma students between 1994 and 2010 and more than 250 undergraduate students' projects between 1991 and 2019.

The numerous roles he has had at the Federal University of Technology, Minna include but are not limited to the following: School Time-Table Officer (1992 - 1999); Head of Department (1993 - 1999); Member, University Senate (1992 - 2019); Chairman, Computer Centre Service Board (1997 - 2002); Chairman, School Examination Malpractices Committee (1990 - 1999); Member, University Students' Disciplinary and Examination Malpractices Committee (1990 - 2007); Member, School Research Committee (1993 - 2006); Chairman, University Ceremonies Committee (1993 - 2003); Chairman, University Fees Review Committee (1998 - 2003); Member, Appointments and Promotion Committee (1997 - 2000); Chairman, Students' Crisis Investigation Committee, Federal University of Technology, Minna, Nigeria (2001); Chairman, University Staff School Management Board, Federal University of Technology, Minna, Nigeria (1999 - 2003); Chairman, Millenium Bug Committee, Federal University of Technology, Minna, Nigeria (1998 - 2002);Dean, School of Science and Science Education (1999 - 2003); Member, Committee of Deans (1993 - 2003); and Chairman, Senate Committee on Senate Standing Orders (2008).

ACADEMIC AND PROFESSIONAL QUALIFICATIONS

1. Nigeria Certificate in Education (NCE), Oluloyo College of Education, Ibadan, Nigeria. 1967
2. B.Sc. (Hons) Second Class Upper (Mathematics), University of Lagos, Nigeria. 1971
3. M.Phil. (Numerical Analysis), University of Reading, Reading, England. 1979
4. Ph.D. (Mathematics), University of Ilorin, Ilorin, Nigeria. 1991

UNIVERSITY EDUCATION (WITH DATES)

(a) University of Lagos (1968-1971)
(b) University of Reading, Reading, England (1975-1978)
(c) University of Ilorin (1988-1991)

SCHOLARSHIPS AND FELLOWSHIPS AWARDS

(a) Western State University Scholarship (1969)
(b) University of Lagos Postgraduate Scholarship (1972 and 1973)
(c) AFGRAD Scholarship, USA (1974)
(d) Federal Government Postgraduate Scholarship (1975)
(e) University of Ife Fellowship (1976)

AWARDS, HONOURS AND DISTINCTIONS

1. Fellow of Mathematical Association of Nigeria (FMAN), 1999.
2. Fellow of Nigerian Academy of Control (FAC), 2000.

3. Best Practices in University Teaching Project (BESTPUT), Mathematics National University Commission (NUC), Abuja, Nigeria, 2002.
4. IBC's 21st Century Award for Achievement, International Biographical Centre (IBC), Cambridge, UK, 2002.
5. Outstanding Intellectuals of the 21st Century Award, International Biographical Centre (IBC), Cambridge, UK, 2002.
6. Who's Who in the 21st Century Order of Excellence, International Biographical Centre (IBC), Cambridge, UK, 2002.
7. IBC Living Legends Award, International Biographical Centre (IBC), Cambridge, UK, 2003.
8. Contemporary Who's Who Award, American Biographical Institute (ABI), Raleigh, NC, USA, 2003.
9. Man of the Year, American Biographical Institute (ABI), Raleigh, NC, USA, 2003.
10. American Medal of Honour, American Biographical Institute (ABI), Raleigh, NC, USA, 2004.
11. Man of the Year Representing Nigeria, American Biographical Institute (ABI), Raleigh, NC, USA, 2009.
12. Fellow of Nigerian Mathematical Society (FNMS), 2016.

OTHER ACADEMIC ACTIVITIES AND RESPONSIBILITIES

Professor Kayode Rufus Adeboye was an External Examiner and External Assessor to many Nigeria Universities and Polytechnics. He was also the Chairman and Member, NUC Accreditation Team to many Nigeria Universities. The numerous roles he has had outside the Federal University of Technology, Minna include but are not limited to the following:

(i) Sabbatical leave, Ibrahim Badamasi Babangida University, Lapai, Nigeria (2006 - 2007) and University of Abuja, Abuja (2014 - 2015).

(ii) Course writer, National Teachers' Institute (NTI), Kaduna, Nigeria (1988 -1994).

(iii) Supervisor, NTI-NCE by DLS, Niger state, (1990-1996).

(iv) Supervisor, University of Ibadan External Degree Programme, Niger State, (1990-997).

(v) External Moderator, Niger State College of Education, Minna, (1990- 1998).

(vi) Chief Examiner, JSS (Mathematics), National Examinations Council (NECO), (1999 - To date)

(vii) Chief Examiner, SSCE (Further Mathematics), National Examinations Council (NECO) (2012- To date).

(viii) Resource Person, Postgraduate Course on Computer Science, National Mathematical Centre (NMC), Abuja, Nigeria (1996).

(ix) Coordinator, National Mathematical Centre (NMC), Abuja Internal Conference on Computational Mathematics (1999).

(x) Resource Person, National Mathematical Centre (NMC), Abuja Research programme in Computational Mathematics (1999).

(xi) Chairman, NUC Minimum Academic Standard Curriculum Development for Basic Sciences and Computer Science (1999).

(xii) Coordinator (Mathematics Group), National Open University of Nigeria (NOUN) Course Development Workshop (2002).

(xiii) Member, NUC Minimum Academic Standard Final Year Syllabus for General Studies (2004).
(xiv) Resource Person, National Mathematical Centre (NMC), Abuja Higher Degree Programme (2004, 2007).
(xv) Editor-in-Chief, National Mathematical Centre (NMC), Abuja Seminar Proceedings (2006).
(xvi) Associate Editor, AMSE Journal, France (2005 – 2008)
(xvii) External Examiner, Master's Degree Programme, National Mathematical Centre (NMC), Abuja (2010 - 2016)
(xviii) Associate Editor, Nigerian Mathematical Society (JNMS) (2013 – To date)
(xix) External Assessor, Professorial Appointment, NDA, Kaduna (2019).
(xx) External Assessor for 2 Professorial Appointments, National Mathematical Centre, Abuja (2019)
(xxi) Dean, Faculty of Applied and Natural Sciences, Ibrahim Badamasi Babangida University, Lapai, Nigeria (2006 - 2007).

MEMBERSHIP OF LEARNED SOCIETIES

(i) Member, Nigerian Mathematical Society (NMS).
(ii) Member, Mathematical Association of Nigeria (MAN).
(iii) Member, Nigerian Computer Society (NCS).
(iv) Member, American Mathematical Society (AMS), USA.
(v) Member, International Association of Survey Statistians (IASS), Geneva, Austria.

BOARD MEMBERSHIP

(i) Member, Board of Directors, Internet Exchange Point of Nigeria (IXPN), (2007 – To date).
(ii) Member, Ministerial Committee on Privatization, Federal Ministry of Solid Minerals, Abuja,
Nigeria, (2004 - 2005).
(iii) Member, Advisory Committee, American Biographical Institute (ABI), NC, USA, (2004).
(iv) Member, University Governing Council, Federal University of Technology, Minna, Nigeria,
(2000 - 2002).
(v) Member, Management Board, National Mathematical Centre (NMC), Abuja, Nigeria, (2000 -
2004).

PUBLICATIONS

Professor Kayode Rufus Adeboye has 2 completed University funded Research projects, Inaugural lecture, 12 Book publications and over 60 Journal publications and these publications are as follows:

Completed University Funded Research Projects:

1. Adeboye, K. R. and Ayeni, R. O. (2000). Hybrid-Collocation-Galerkin Method for Differential Equations with Application to Petroleum Reservoir Mechanics.
2. Adeboye, *K.* R. and Bolarin, O. A., (2009), Application of Numerical Methods to Petroleum Reservoir Mechanics.

Inaugural Lecture:

K. R. Adeboye (2014). Mathematics, Mathematicians and Numerical Analysis: the Bridge and Bridgehead View of Nigeria with Mathematical Prism.

Book Publications:

1. K. R. Adeboye, (2006). Mathematical Methods for Science and Engineering Students, Moonlight publishers, Abuja, Nigeria.

2. K, R. Adeboye, (2006), ICT Policies Development and Applications in Nigerian Educational System, A chapter in a book written to honour Prof Okebukola, former NUC, Abuja Executive Secretary.

3. Adeboye, K. R., (1990), Nigerian Certificate in Education Course Book on Mathematics, Cycle 2, Module 1, Units 1 - 5 (Chapters on Differential Calculus), vol. 1, Published by National Teachers' Institute, Kaduna.

4. Adeboye, K. R., (1990), Nigerian Certificate in Education Course Book on Mathematics, Cycle 2, Module 5, Units 1 - 5 (Chapters on Numerical Analysis), vol. II, 71 - 95, Published by National Teachers' Institute, Kaduna.

5. Adeboye, K. R., (1991), Nigerian Certificate in Education Course Book on Mathematics, Cycle 3, Module 1, Units 6 - 10 (5 Chapters on Introductory Theory of Numbers and Polynomials), vol. 1, 23 - 53, Published by National Teachers' Institute, Kaduna.

6. Adeboye, K. R., (1992), Nigerian Certificate in Education Course Book on Mathematics, Cycle 3, Module 5, Units 6 - 10 (5 Chapters on Real Analysis), vol. II, Published by National Teachers' Institute, Kaduna.

7. Adeboye, K. R., (1993), Nigerian Certificate in Education Course Book on Mathematics, Cycle 4, Module 1, Units 1 - 3 (3 Chapters on Vector Spaces), vol. 1, 1 - 18, Published by National Teachers' Institute, Kaduna.

8. Adeboye, K. R., (1993), Nigerian Certificate in Education Course Book on Mathematics, Cycle 4, Module 2, Units 1 - 5 (5 Chapters on Linear Algebra), vol. I. 71 - 116, Published by National Teachers" Institute, Kaduna.

9. Adeboye, K. R., (1997), CO-Author, MAN Textbook of Mathematics for Science Students in Nigerian Universities, Cornerstone Publications, Ilorin.

10. Adeboye, K. R., (1998), CO-Author, Question and Answer Scries for SSCE by MAN, Cornerstone Publications, Ilorin 11. Adeboye, K. R., (1999), CO-Author, MAN Question and Answer Series for JAMB candidates, Cornerstone Publications, Ilorin.

12. Adeboye, K. R., (2005), Chairman, Editorial Board, Published Conference Proceedings, National Mathematical Centre, Abuja.

Journal Publications:

1. Adeboye, K.R. and Salisu A. (2017). A Re-definition of the Stability Condition for the Parabolic Scheme. *International Journal of Science and Technology (IJST) Uk Publication,* (Accepted for Publication).
2. Adeboye, K.R. and Salisu A. (2017), An H^2-Galerkin Method for the Solution of Parabolic Boundary Value Problems. *Journal of the Nigerian Association of Mathematical Physics,* Vol.41, Pp 453 - 456.
3. Adeboye, K.R., Abiodun A.P. and Salisu A. (2017) A Nonhydrostatic Atmospheric Model for Numerical Weather Prediction, Using Minna, Nigeria as aCase Study. *NMC Journal* (Presented for Publication).
4. Etuk, Stella Oluyemi and Adeboye, K.R. (2017), Refinements of the Egyptian Fraction Finite Difference Scheme for First and Second Initial Value Problems. *Journal of Science, Technology and Mathematics Education (JOSTMED).* Vol. II
5. K. A Al-Mustapha and Adeboye, K. R. (2017),Variational-Composite Hybrid Fixed Point Iterative Method for the Solution of three-point Boundary Value Problems of Fourth Order Differential Equations. *Journal of the Nigerian Association of Mathematical Physics,* Vol.39, Pp 111-118.
6. Kilicman, Adeboye, K.R. and Wadai, M. (2016), A Variational Fixed Point Iterative Technique for the Solution of Second Order Differential Equations. Malaysian *Journal of Sciences* Vol.35(1), Pp 29 - 36.
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47. Adeboye, K. R. (2001). A Convergent Explicit One-step Integrator for Initial Value Problems with Singular Solutions, *JOSTMED,*
48. Adeboye, K R. (2000). A Super Convergent H^2 - Galerkin Method for the Solutions of Boundary Value Problems, NMC Proceedings
49. Adeboye, K. R. (1999). A Cubic Order Predictor-Corrector Iterative Method for the Solution of Non-Linear Algebraic Equations. *Journal of Science, Technology and Mathematics Education (JOSTMED),* 2(1), 111-118.
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51. Adeboye, K. R. (1997). H^1 - Galerkin - Collocation and Quasi - iterative Method for Boundary Value Problems, *Abacus,* 26, 490-497.
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England.

CONCLUSION

We'll end this biography quoting from his inaugural lecture about the lack of knowledge of mathematics on the part of students –

Mathematics is needed for the development, maintenance, understanding, quantification and record keeping of our society. Since no society is static and the desire for higher heights in science and technology will continue to increase, the demand on mathematics will ever be on the increase. In view of the universal importance of mathematics to man on earth, it becomes compulsory that those charged with education should find ways of involving more of the younger generation of our days in the study of mathematics. Any nation that cannot get school children involved and be interested in mathematics, will never attain true social, economic, scientific and technological independence. Such a nation will continue to look up to those other nations of the world which through sound mathematics education have become world powers, with sound economic, scientific and technological bases, for her needs, even in matters of political guidance.

The educational system in Nigeria as at now is in a state of comma as a result of neglect. The rule then was "acquire now, neglect or even abandon later". The government acquired all the educational institutions from primary to tertiary level in the late 1970's only to neglect or even abandon them in the early 1980's. Some states established universities only to boost their egos. They never considered the cost of running a university before establishing one. They would want to hire lecturers at the rate of two for a kobo! I wish to advise the NUC to add to the conditions to be satisfied before establishing a university that the minimum conditions of service acceptable are those obtainable at the federal universities and this will put paid to the unbridled histrionics often engaged in by the owners.

REFERENCES

K. R. Adeboye (2014). *Mathematics, Mathematicians and Numerical Analysis: the Bridge and Bridgehead View of Nigeria with Mathematical Prism*. 27th Inaugural Lecture series, Federal University of Technology, Minna, Nigeria.

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provides more accurate model of the moving load problems as the loads are actually distributed over a small segment or the entire length of the non-uniform Rayleigh beam they traverse..

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C07: Unsteady MHD Couette Flow Through a Parallel Plate with Constant Pressure Gradient

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Abstarct

In this paper, the unsteady MHD Couette flow through a porous medium of a viscous incompressible fluid bounded by two parallel porous plates under the influence of thermal radiation and chemical reaction is investigated. A uniform suction and injection are applied perpendicular to the plates while the fluid motion is subjected to constant pressure gradient. The transformed conservation equations are solved analytically subject to physically appropriate boundary conditions by using Eigenfunction expansion technique. The influence of a number of emerging non-dimensional parameters namely, pressure gradient, suction parameter, radiation parameter and Hartman number are examined in detail. It is observed that the primary velocity is increased with increasing pressure gradient while increase in radiation parameter leads to decrease in the thermal profile of the flow.

Keywords: constant pressure gradient, eigenfunction expansion, hall current, magnetohydrodynamics MHD, suction.

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1. Introduction

The dynamics of fluids through porous channel has been a popular area of research regarding to numerous increasing applications in chemical, mechanical and material process engineering.

Examples of such fluid includes clay coating, coal, oil slurries, shampoo, paints cosmetic products, grease, custard and physiological liquids (blood, bile, and synovial fluid). Over the years, considerable interest has been observed on the effect of MHD in viscous, incompressible, non-Newtonian fluid flow with heat transfer. These interests on non-Newtonian fluids are owed to its important applications in various branches of science, engineering and technology, particularly in chemical and nuclear industries, material processing, geophysics and bio-engineering. In view of these applications, an extensive range of mathematical models have been developed to simulate the diverse hydrodynamic behavior of these non-Newtonian fluids. However, different non-Newtonian fluid models have been presented by researchers and solved using various types of analytical and computational schemes Bhattacharyya *et al.* (2013).

2. Literature Review

Sayed-Ahmed *et al.* (2011) investigated time dependent pressure gradient effect on unsteady MHD Couette flow of an electrically conducting, viscous, incompressible fluid bounded by two parallel non-conducting porous plates with heat transfer under exponential decaying pressure gradient. Olayiwola (2015) investigated the modeling and simulation of combustion fronts in porous media. Jana and Jana (2012) examined Couette flow through a porous medium in a rotating system. In another related work, Seth *et al.* (2011) studied the effects of rotation and magnetic field on unsteady Couette flow in a porous channel. Seth *et al.* (2011) studied the unsteady hydromagnetic Couette flow within porous plates in a rotating system. Recently, Sharma & Yadav (2015) considered Heat transfer through three dimensional Couette flow between a stationary porous plate bounded by porous medium and moving porous plates. Sharma *et al.* (2015) investigated the steady laminar flow and heat transfer of a non-Newtonian fluid through a straight horizontal porous channel in the presence of heat source. Olayiwola & Ayeni

(2012) examined a mathematical model and simulation of In-situ combustion in porous media. In another related work, the mathematical model of solid fuel Arrhenius combustion in a fixed-bed was analyzed by Olayiwola (2011). Bhattacharyya *et al.* (2013) studied analytically the solution for magnetohydrodynamic boundary layer flow of Casson fluid over a stretching/shrinking sheet with wall mass transfer. The unsteady boundary layer flow of a Casson fluid due to an impulsively started moving plate was considered by Mustafa *et al.* (2011). Recently, Mukhopadhyay *et al.* (2012) investigated the steady boundary layer flow and heat transfer over a porous moving plate in the presence of thermal radiation. Makinde & Mhone (2005) studied the heat transfer to MHD flow in a channel filled with porous medium. Malapati & Polarapu (2015) analyzed unsteady MHD free convective heat and mass transfer in a boundary layer flow past a vertical permeable plate with thermal radiation and chemical reaction. Chamkha and Ahmed (2012) examined unsteady MHD heat and mass transfer by mixed convection flow in the forward stagnation region of a rotating sphere at different wall conditions. The effects of thermal radiation and magnetic field on unsteady mixed convection flow and heat transfer over a stretching in the presence of internal heat generation/absorption was studied by Elbashbeshy & Aldawody (2011). Talukdar (2010) investigated the buoyancy and chemical reaction effects on MHD mixed convection heat and mass transfer in a porous medium with thermal radiation and ohmic heating. Mohammed *et al.* (2015) analyzed radiation and mass transfer effects on MHD oscillatory flow in a channel filled with porous medium in the presence of chemical reaction. The aim of the research is to establish an analytical solution capable of describing the concentration, temperature and velocity in the process of MHD Couette flow through a parallel plate.

3. Methodology

3.1 Mathematical Formulation

Following Sayed-Ahmed *et al.* (2011), the unsteady flow of a viscous, incompressible, non-conducting fluid through a channel with chemical reaction, thermal radiation, constant and variable pressure gradient in the presence of magnetic field is investigated. The flow is assumed to be laminar, incompressible and flows between two infinite horizontal plates located at $y = \pm h$ which extends from $x = -\infty$ to ∞ and from $z = -\infty$ to ∞.

The upper plate is suddenly set into motion and moves with a uniform velocity U_0 while the lower plate is kept stationary as shown in the diagram below. The upper plate is simultaneously subjected to a step change in temperature from T_1 to T_2. The upper and lower plates are kept at two constant temperatures T_2 and T_1 respectively with $T_2 > T_1$. The fluid flows between the two plates under the influence of an exponential decaying with time pressure gradient in the x-direction which is a generalization of a constant pressure gradient. A uniform suction from above and injection from below with constant velocity v_0 which are all applied at $t = 0$. The system is subjected to a uniform magnetic field B_0 in the positive y-direction and is assumed undisturbed as the induced magnetic field is neglected by assuming a small magnetic Reynolds number. The Hall effect is taken into consideration and consequently a z-component of the velocity is expected to arise.

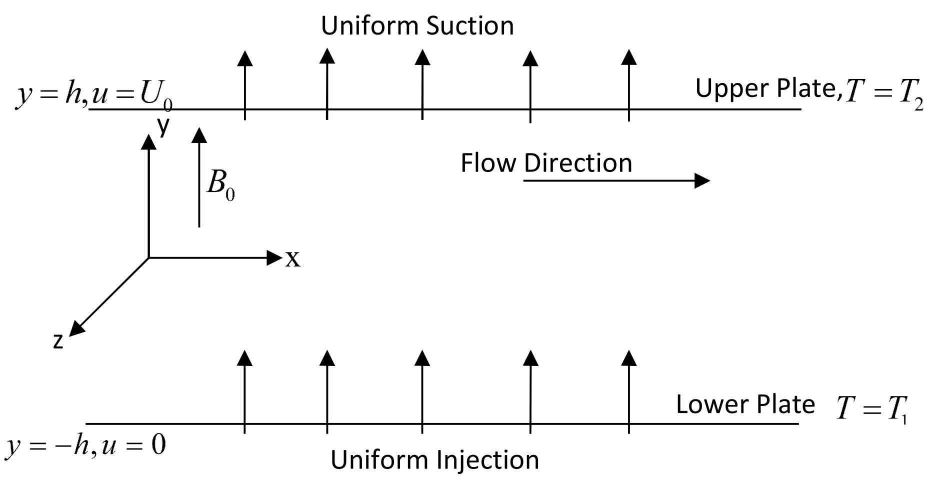

Figure 1: Schematic diagram of the problem

Based on the above assumptions,

$$v = ui + v_0 j + wk \tag{1}$$

Introducing a Chapman-Rubesin viscosity law, with $w = 1$ as shown in Olayiwola (2016) and using the condition at the lower plate, results in:

$$\mu = \frac{c\mu_1 T}{T_1} \tag{2}$$

Where μ_1 is the Casson coefficient of viscosity.

Thus, the two components of the governing momentum equation in dimensional form are as follows:

$$\rho\frac{\partial u}{\partial t}+\rho v_0\frac{\partial u}{\partial y}=-\frac{\partial p}{\partial x}+\frac{\partial}{\partial y}\left(\mu\frac{\partial u}{\partial y}\right)-\frac{\sigma B_0^2}{(1+BiBe)^2+Be^2}\left[(1+BiBe)u+Bew\right]-$$

$$\mu\frac{u}{k}+g\beta_T\left(T-T_1\right)+g\beta_C\left(C-C_1\right) \tag{3}$$

$$\rho\frac{\partial w}{\partial t}+\rho v_0\frac{\partial w}{\partial y}=\frac{\partial}{\partial y}\left(\mu\frac{\partial w}{\partial y}\right)-\frac{\sigma B_0^2}{(1+BiBe)^2+Be^2}\left[(1+BiBe)w-Beu\right]-\mu\frac{w}{k} \tag{4}$$

The energy equation in dimensional form is given as

$$\left.\begin{aligned}&\rho C_P\frac{\partial T}{\partial t}+\rho C_P v_0\frac{\partial T}{\partial y}=\frac{1}{\Pr}\frac{\partial}{\partial y}\left(\mu\frac{\partial T}{\partial y}\right)+\mu\left[\left(\frac{\partial u}{\partial y}\right)^2+\left(\frac{\partial w}{\partial y}\right)^2\right]+\\&\frac{\sigma B_0^2}{(1+BiBe)^2+Be^2}\left[u^2+w^2\right]-\frac{1}{\rho C_P}\frac{\partial q}{\partial y}\end{aligned}\right\} \tag{5}$$

The concentration equation in dimensional form is given as:

$$\rho\frac{\partial C}{\partial t}+\rho v_0\frac{\partial C}{\partial y}=\frac{1}{Sc}\frac{\partial}{\partial y}\left(\mu\frac{\partial C}{\partial y}\right)+D_1\frac{\partial^2 T}{\partial y^2}-D_2\left(C_2-C_1\right) \tag{6}$$

Subject to the initial and boundary conditions;

$$\left.\begin{array}{lll} u(y,0)=0, & u(-h,t)=0, & u(h,t)=U_0 \\ w(y,0)=U_0 y(1-y), & w(-h,t)=0, & w(h,t)=0 \\ T(y,0)=0, & T(-h,t)=T_1, & T(h,t)=T_2 \\ C(y,0)=0, & C(-h,t)=C_1, & C(h,t)=C_2 \end{array}\right\} \quad (7)$$

Where ρ and μ are respectively the density and apparent viscosity of the fluid, σ is electric conductivity, β is Hall factor, Bi is ion slip parameter, $Be=\sigma\beta B_0$ is Hall parameter, c and k are respectively the specific heat capacity and thermal conductivity of the fluid. Where u and w are components of velocities along and perpendicular to the plate in x and y directions respectively, σ is the electrical conductivity, β_T is the coefficient of volume expansion of the moving fluid, β_C is the coefficient of volumetric expansion with concentration, v is the kinematic viscosity, T is the temperature of the fluid, C is the concentration of the fluid, C_1 is concentration at infinity, D_1 the thermal diffusivity, D_2 the chemical reaction rate constant, C_P is the specific heat capacity at constant pressure. t is time, g is gravitational force, μ_e is magnetic permeability of the fluid, K is the porous media permeability coefficient, q is radiative heat flux, H_0 is intensity of magnetic field, $B_0=\mu_e H_0$ is electromagnetic induction, τ_0 is yield stress, β is coefficient of volume expansion due to temperature and α is mean radiation absorption coefficient.

To write the governing dimensional equations (3)-(6) with their corresponding boundary conditions (7) in non-dimensional form, we use the following dimensionless variables:

$$\bar{u}=\frac{u}{U_0},\quad \bar{w}=\frac{w}{U_0},\quad \bar{y}=\frac{y}{h},\quad \bar{x}=\frac{x}{h},\quad \bar{t}=\frac{tU_0}{h},\quad \theta=\frac{T-T_1}{T_2-T_1}$$
$$\phi=\frac{C-C_1}{C_2-C_1},\quad \bar{P}=\frac{P}{\rho U_0^2},\quad \bar{\mu}=\frac{c\mu_1 T}{T_1} \tag{8}$$

we obtain

$$\frac{\partial u}{\partial t}+S\frac{\partial u}{\partial y}=-\frac{\partial \bar{P}}{\partial x}+\frac{c}{\mathrm{Re}}\frac{\partial}{\partial y}\left((a\theta+1)\frac{\partial u}{\partial y}\right)-\frac{Ha^2}{\mathrm{Re}(1+BiBe)^2+Be^2}\left[(1+BiBe)u+Bew\right]-$$
$$\frac{Pc}{\mathrm{Re}}\left((a\theta+1)u\right)+Gr_\theta\theta+Gr_\phi\phi \tag{9}$$

$$\frac{\partial w}{\partial t}+S\frac{\partial w}{\partial y}=\frac{c}{\mathrm{Re}}\frac{\partial}{\partial y}\left((a\theta+1)\frac{\partial w}{\partial y}\right)-\frac{Ha^2}{\mathrm{Re}(1+BiBe)^2+Be^2}\left[(1+BiBe)w-Beu\right]-$$
$$\frac{Pc}{\mathrm{Re}}\left((a\theta+1)w\right) \tag{10}$$

$$\frac{\partial \theta}{\partial t}+S\frac{\partial \theta}{\partial y}=\frac{c}{\mathrm{Re}\,\mathrm{Pr}}\frac{\partial}{\partial y}\left[(a\theta+1)\frac{\partial \theta}{\partial y}\right]+\frac{cEc}{\mathrm{Re}}(a\theta+1)\left[\left(\frac{\partial u}{\partial y}\right)^2+\left(\frac{\partial w}{\partial y}\right)^2\right]+$$
$$\frac{EcHa^2}{\mathrm{Re}\left[(1+BiBe)^2+Be^2\right]}\left[u^2+w^2\right]-Ra^2\theta \tag{11}$$

$$\frac{\partial \phi}{\partial t}+S\frac{\partial \phi}{\partial \bar{y}}=\frac{c}{Sc\,\mathrm{Re}}\frac{\partial}{\partial y}\left[(a\theta+1)\frac{\partial \phi}{\partial y}\right]+T_D\frac{\partial^2\theta}{\partial \bar{y}^2}-K_r\phi \tag{12}$$

Subject to the initial and boundary conditions

$$\left.\begin{array}{lll} u(y,0)=0, & u(-1,t)=0, & u(1,t)=1 \\ w(y,0)=y(1-y), & w(-1,t)=0, & w(1,t)=0 \\ \theta(y,0)=0, & \theta(-1,t)=0, & \theta(1,t)=1 \\ \phi(y,0)=0, & \phi(-1,t)=0, & \phi(1,t)=1 \end{array}\right\} \quad (13)$$

Where

$$\left.\begin{array}{l} \mathrm{Re}=\frac{\rho U_0 h}{\mu_1}, \quad S=\frac{\nu_0}{U_0}, \quad P=\frac{h^2\mu_1}{k}, \quad Ha^2=\frac{\sigma B_0^2 h^2}{\mu_1}, \quad Gr_\theta=\frac{g\beta_T(T_2-T_1)h}{\rho U_0^2}, \\ Gr_\phi=\frac{g\beta_C(C_2-C_1)h}{\rho U_0^2}, \quad \mathrm{Pr}=\frac{\mu_1 c_p}{k}, \quad Ec=\frac{U_0^2}{c_p(T_2-T_1)}, \quad Ra^2=\frac{4\alpha^2 h}{\rho^2 C_p^2 U_0}, \\ Sc=\frac{U_0 h}{D}, \quad T_D=\frac{D(T_2-T_1)}{h(C_2-C_1)U_0}, \quad a=\frac{T_2-T_1}{T_1}, \quad K_r=\frac{D_2 h}{\rho U_0} \end{array}\right\} \quad (14)$$

a. Method of Solution

Since the boundary conditions are from -1 to 1, we first transform the boundary conditions to 0 to 1 using the transformation:

$$z=\frac{y+1}{2} \quad (15)$$

Let $0<S<<1$ and $Ec=bS, a=eS,\ Be=fS, Gr_\theta=gS, Gr_\phi=hS$ such that

$$\left.\begin{aligned}
u(z,t) &= u_0(z,t) + Su_1(z,t) + \ldots \\
w(z,t) &= w_0(z,t) + Sw_1(z,t) + \ldots \\
\theta(z,t) &= \theta_0(z,t) + S\theta_1(z,t) + \ldots \\
\phi(z,t) &= \phi_0(z,t) + S\phi_1(z,t) + \ldots
\end{aligned}\right\} \tag{16}$$

Collecting like powers of S, we have for:

S^0 :

$$\left.\begin{aligned}
&\frac{\partial\theta_0}{\partial t} = \frac{c}{4\,\mathrm{Re}\,\mathrm{Pr}}\frac{\partial}{\partial z}\left[\frac{\partial\theta_0}{\partial z}\right] - Ra^2\theta_0 \\
&\theta_0(z,0) = 0, \quad \theta_0(0,t) = 0, \quad \theta_0(1,t) = 1
\end{aligned}\right\} \tag{17}$$

$$\left.\begin{aligned}
&\frac{\partial\phi_0}{\partial t} = \frac{c}{4Sc\,\mathrm{Re}}\frac{\partial}{\partial z}\left[\frac{\partial\phi_0}{\partial z}\right] + T_D\frac{\partial^2\theta_0}{\partial z^2} - Kr\phi_0 \\
&\phi_0(z,0) = 0, \quad \phi_0(0,t) = 0, \quad \phi_0(1,t) = 1
\end{aligned}\right\} \tag{18}$$

$$\left.\begin{aligned}
&\frac{\partial w_0}{\partial t} = \frac{c}{4\,\mathrm{Re}}\frac{\partial}{\partial z}\left(\frac{\partial w_0}{\partial z}\right) - \frac{Ha^2}{\mathrm{Re}}[w_0] - \frac{Pc}{\mathrm{Re}}[w_0] \\
&w_0(z,0) = (2z-1)(2-2z), \quad w_0(0,t) = 0, \quad w_0(1,t) = 0
\end{aligned}\right\} \tag{19}$$

$$\left.\begin{aligned}
&\frac{\partial u_0}{\partial t} = \frac{c}{4\,\mathrm{Re}}\frac{\partial}{\partial z}\left(\frac{\partial u_0}{\partial z}\right) - \frac{Ha^2}{\mathrm{Re}}[u_0] - \frac{Pc}{\mathrm{Re}}(u_0) + \sigma \\
&u_0(z,0) = 0, \quad u_0(0,t) = 0, \quad u_0(1,t) = 1
\end{aligned}\right\} \tag{20}$$

S^1:

$$\left.\begin{array}{l}\frac{\partial u_1}{\partial t}+\frac{1}{2}\frac{\partial u_0}{\partial z}=\frac{c}{4\operatorname{Re}}\frac{\partial}{\partial z}\left(\frac{e\theta_0\partial u_0}{\partial z}+\frac{\partial u_1}{\partial z}\right)-\frac{Ha^2}{\operatorname{Re}}\left[u_0 Bif+u_1+fw_0\right]-\\ \frac{Pc}{\operatorname{Re}}\left(e\theta_0 u_0+u_1\right)+g\theta_0+h\phi_0\\ u_1(z,0)=0,\qquad u_1(0,t)=0,\qquad u_1(1,t)=0\end{array}\right\} \tag{21}$$

$$\left.\begin{array}{l}\frac{\partial \theta_1}{\partial t}+\frac{1}{2}\frac{\partial \theta_0}{\partial z}=\frac{c}{4\operatorname{Re}\operatorname{Pr}}\frac{\partial}{\partial y}\left[e\theta_0\frac{\partial \theta_0}{\partial z}+\frac{\partial \theta_1}{\partial z}\right]+\frac{bc}{4\operatorname{Re}}\left[\left(\frac{\partial u_0}{\partial y}\right)^2+\left(\frac{\partial w_0}{\partial y}\right)^2\right]-\\ \frac{bHa^2}{\operatorname{Re}}\left[\left(u_0\right)^2+\left(w_0\right)^2\right]-Ra^2\theta_1\\ \theta_1(z,0)=0,\qquad \theta_1(0,t)=0,\qquad \theta_1(1,t)=0\end{array}\right\} \tag{22}$$

$$\left.\begin{array}{l}\frac{\partial w_1}{\partial t}+\frac{1}{2}\frac{\partial w_0}{\partial z}=\frac{c}{4\operatorname{Re}}\frac{\partial}{\partial z}\left(e\theta_0\frac{\partial w_0}{\partial z}+\frac{\partial w_1}{\partial z}\right)-\frac{Ha^2}{\operatorname{Re}}\left[w_0 Bif+w_1-fu_0\right]-\frac{Pc}{\operatorname{Re}}\left(e\theta_0 w_0+w_1\right)\\ w_1(z,0)=0,\qquad w_1(0,t)=0,\qquad w_1(1,t)=0\end{array}\right\} \tag{23}$$

$$\left.\begin{array}{l}\frac{\partial \phi_1}{\partial t}+\frac{1}{2}\frac{\partial \phi_0}{\partial z}=\frac{c}{4Sc\operatorname{Re}}\frac{\partial}{\partial z}\left[e\theta_0\frac{\partial \phi_0}{\partial z}+\frac{\partial \phi_1}{\partial z}\right]+T_D\frac{\partial^2\theta_1}{\partial z^2}-Kr\phi_1\\ \phi_1(z,0)=0,\qquad \phi_1(0,t)=0,\qquad \phi_1(1,t)=0\end{array}\right\} \tag{24}$$

3.2.1 Eigenfunction Expansion Technique

Now, consider the problem (see Myint-U and Debnath, (1987))

$$\left.\begin{array}{l}\dfrac{\partial u}{\partial t}=k\dfrac{\partial^2 u}{\partial x^2}+\alpha u+F(x,t)\\ u(x,0)=f(x),\qquad u(0,t)=0,\qquad u(L,t)=0\end{array}\right\} \tag{25}$$

For the solution of problem (24), we assume a solution of the form

$$u(x,t)=\sum_{n=1}^{\infty}u_n(t)\sin\frac{n\pi}{L}x \tag{26}$$

Where

$$u_n(t)=\int_0^t e^{\left(\alpha-k\left(\frac{n\pi}{L}\right)^2\right)(t-\tau)}F_n(\tau)d\tau+b_n e^{\left(\alpha-k\left(\frac{n\pi}{L}\right)^2\right)t} \tag{27}$$

$$F_n(t)=\frac{2}{L}\int_0^L F(x,t)\sin\frac{n\pi}{L}xdx \tag{28}$$

$$b_n(t)=\frac{2}{L}\int_0^L F(x)\sin\frac{n\pi}{L}xdx \tag{29}$$

Comparing equation (17) – (24) with the (25) we obtain the solutions to the velocity (primary and secondary), temperature, and concentration distributions as

$$\theta_0(\mathrm{z},\mathrm{t})=\mathrm{z}+\sum_{n=1}^{\infty}q_1\left(1-e^{-q_0 t}\right)\sin n\pi z \tag{30}$$

$$\phi_0(\mathrm{z},\mathrm{t})=z-\sum_{n=1}^{\infty}\left(q_4\left(1-e^{-q_2 t}\right)+q_5\sum_{n=1}^{\infty}\left(\frac{1}{q_2}\left(1-e^{-q_2 t}\right)-\frac{1}{q_2-q_0}\left(e^{-q_0 t}-e^{-q_2 t}\right)\right)\right)Sinn\pi z \tag{31}$$

$$w_0(z,t)=\sum_{n=1}^{\infty} q_{10}e^{-q_{11}t}Sinn\pi z \tag{32}$$

$$u_0\left(z,t\right)=z+\sum_{n=1}^{\infty}\frac{q_{12}}{q_{11}}\left(1-e^{-q_{11}t}\right)Sinn\pi z \tag{33}$$

$$u_1(z,t)=\sum_{n=1}^{\infty}u_5\left(t\right)Sinn\pi z \tag{34}$$

Where

$$\begin{aligned}
u_5(t)=&\,q_{16}\left(\frac{1}{q_{11}}\left(1-e^{-q_{11}t}\right)\right)+\sum_{n=1}^{\infty}q_{27}P_4\left(\frac{1}{q_{11}}\left(1-e^{-q_{11}t}\right)-te^{-q_{11}t}\right)+\\
&\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_{28}q_1P_4\left(\frac{1}{q_{11}}\left(1-e^{-q_{11}t}\right)-te^{-q_{11}t}-\frac{1}{q_{11}-q_0}\left(e^{-q_0t}-e^{-q_{11}t}\right)-\frac{1}{q_0}\left(e^{(q_{11}-q_0)t}-e^{-q_{11}t}\right)\right)+\\
&\sum_{n=1}^{\infty}q_{29}q_1\left(\frac{1}{q_{11}}\left(1-e^{-q_{11}t}\right)-\frac{1}{q_{11}-q_0}\left(e^{-q_0t}-e^{-q_{11}t}\right)\right)+\\
&q_{26}\left(\begin{aligned}&\sum_{n=1}^{\infty}q_4\left(\frac{1}{q_{11}}\left(1-e^{-q_{11}t}\right)-\frac{1}{q_{11}-q_2}\left(e^{-q_2t}-e^{-q_{11}t}\right)\right)+\\
&\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_5P_1\left(\frac{1}{q_{11}}\left(1-e^{-q_{11}t}\right)-te^{-q_{11}t}-\frac{1}{q_{11}-q_2}\left(e^{-q_2t}-e^{-q_{11}t}\right)\right)-\\
&\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_5P_2\left(\frac{1}{q_{11}-q_0}\left(e^{-q_0t}-e^{-q_{11}t}\right)-\frac{1}{q_{11}-q_2}\left(e^{-q_2t}-e^{-q_{11}t}\right)\right)\end{aligned}\right)
\end{aligned} \tag{35}$$

$$\theta_1\left(z,t\right)=\sum_{n=1}^{\infty}u_6\left(t\right)Sinn\pi z \tag{36}$$

Where

$$u_6(t)=\begin{pmatrix} \sum_{n=1}^{\infty} q_1 q_{30}\left(\frac{1}{q_0}\left(1-e^{-q_0 t}\right)-te^{-q_0 t}\right)+\sum_{n=1}^{\infty}\sum_{n=1}^{\infty} q_1^2 q_{31}\left(\frac{1}{q_0}\left(1-e^{-q_0 t}\right)-2te^{-q_0 t}-\frac{1}{q_0}\left(e^{-2q_0 t}-e^{-q_0 t}\right)\right)+ \\ q_{32}\frac{1}{q_0}\left(1-e^{-q_0 t}\right)+\sum_{n=1}^{\infty}\sum_{n=1}^{\infty} q_{10}^2 q_{33}\left(\frac{1}{q_0-2q_{11}}\left(e^{-2q_{11}t}-e^{-q_0 t}\right)\right)+ \\ \sum_{n=1}^{\infty} q_{34}P_4\left(\frac{1}{q_0}\left(1-e^{-q_0 t}\right)-\frac{1}{q_0-q_{11}}\left(e^{-q_{11}t}-e^{-q_0 t}\right)\right)+ \\ \sum_{n=1}^{\infty}\sum_{n=1}^{\infty} q_{35}P_4^2\left(\frac{1}{q_0}\left(1-e^{-q_0 t}\right)-\frac{2}{q_0-q_{11}}\left(e^{-q_{11}t}-e^{-q_0 t}\right)+\frac{1}{q_0-2q_{11}}\left(e^{-2q_{11}t}-e^{-q_0 t}\right)\right) \end{pmatrix}$$

$$w_1(z,t)=\sum_{n=1}^{\infty} u_7(t)\,Sinn\pi z \tag{37}$$

Where

$$u_7(t)=\begin{pmatrix} q_{10}q_{36}\left(te^{-q_{11}t}\right)+\sum_{n=1}^{\infty}\sum_{n=1}^{\infty} q_{37}q_1 q_{10}\left(te^{-q_{11}t}+\frac{1}{q_0}\left(e^{-(q_{11}-q_0)t}-e^{-q_{11}t}\right)\right)+q_{38}\left(\frac{1}{q_{11}}\left(1-e^{-q_{11}t}\right)\right)+ \\ \sum_{n=1}^{\infty} q_{14}P_4\left(\frac{1}{q_{11}}\left(1-e^{-q_{11}t}\right)+te^{-q_{11}t}\right) \end{pmatrix}$$

$$\phi_1(z,t)=\sum_{n=1}^{\infty} u_8(t)\,Sinn\pi z \tag{38}$$

Where

$$u_8(t)=\left(\begin{array}{l}q_{39}\left(\begin{array}{l}\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_{43}\frac{\left(1-e^{-q_2t}\right)}{q_2}-\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_{44}\frac{\left(e^{-q_0t}-e^{-q_2t}\right)}{q_2-q_0}-\\ \sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_{45}\frac{t\left(e^{-q_0t}-e^{-q_2t}\right)}{q_2-q_0}+\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_{46}\frac{\left(1-e^{-q_2t}\right)}{q_2}-\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_{47}\frac{\left(e^{-q_0t}-e^{-q_2t}\right)}{q_2-q_0}-\\ 2\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_{48}\frac{t\left(e^{-q_0t}-e^{-q_2t}\right)}{q_2-q_0}-\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_{49}\frac{\left(e^{-q_0t}-e^{-q_2t}\right)}{q_2-q_0}+\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_{50}\frac{\left(e^{-q_0t}-e^{-q_2t}\right)}{q_2-q_0}+\\ \sum_{n=1}^{\infty}q_{51}\left(\frac{\left(1-e^{-q_2t}\right)}{q_2}-\frac{\left(e^{-q_0t}-e^{-q_2t}\right)}{q_2-q_0}\right)+\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_{52}\frac{\left(e^{-2q_{11}t}-e^{-q_2t}\right)}{q_2-q_0}-\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_{53}\frac{\left(e^{-2q_{11}t}-e^{-q_2t}\right)}{q_2-q_0}+\\ \sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_{54}\frac{\left(1-e^{-q_2t}\right)}{q_2}-\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_{55}\frac{\left(e^{-q_0t}-e^{-q_2t}\right)}{q_2-q_0}-\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_{56}\frac{\left(e^{-q_{11}t}-e^{-q_2t}\right)}{q_2-q_{11}}+\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_{57}\frac{\left(e^{-q_0t}-e^{-q_2t}\right)}{q_2-q_0}+\\ \sum_{n=1}^{\infty}\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_{58}\left(\frac{\left(1-e^{-q_2t}\right)}{q_2}-\frac{\left(e^{-q_0t}-e^{-q_2t}\right)}{q_2-q_0}\right)-2\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_{59}\frac{\left(e^{-q_{11}t}-e^{-q_2t}\right)}{q_2-q_{11}}+2\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_{60}\frac{\left(e^{-q_0t}-e^{-q_2t}\right)}{q_2-q_0}+\\ \sum_{n=1}^{\infty}\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_{61}\frac{\left(e^{-2q_{11}t}-e^{-q_2t}\right)}{q_2-2q_{11}}+\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_{62}\frac{\left(e^{-q_0t}-e^{-q_2t}\right)}{q_2-q_0}\end{array}\right)\\ q_{40}\frac{\left(1-e^{-q_2t}\right)}{q_2}+\\ q_{41}\left(\begin{array}{l}-\sum_{n=1}^{\infty}q_4\frac{\left(1-e^{-q_2t}\right)}{q_2}+\sum_{n=1}^{\infty}q_4te^{-q_2t}+\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_5P_1\frac{\left(1-e^{-q_2t}\right)}{q_2}-\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_5P_1te^{-q_2t}-\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_5P_2\frac{\left(e^{-q_0t}-e^{-q_2t}\right)}{q_2-q_0}\\ \sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_5P_2te^{-q_2t}\end{array}\right)\\ q_{42}\left(\begin{array}{l}-\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_1q_4\left(\frac{\left(1-e^{-q_2t}\right)}{q_2}-te^{-q_2t}\right)+\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_5q_1P_1\left(\frac{\left(1-e^{-q_2t}\right)}{q_2}-te^{-q_2t}\right)-\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_5q_1P_2\left(\frac{\left(e^{-q_0t}-e^{-q_2t}\right)}{q_2-q_0}-te^{-q_2t}\right)+\\ \sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_1q_4\left(\frac{\left(e^{-q_0t}-e^{-q_2t}\right)}{q_2-q_0}-\frac{\left(e^{-(q_2+q_0)t}-e^{-q_2t}\right)}{q_0}\right)+\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_5q_1P_1\left(\frac{\left(e^{-q_0t}-e^{-q_2t}\right)}{q_2-q_0}-\frac{\left(e^{-(q_2+q_0)t}-e^{-q_2t}\right)}{q_0}\right)+\\ \sum_{n=1}^{\infty}\sum_{n=1}^{\infty}\sum_{n=1}^{\infty}q_5q_1P_2\left(\frac{\left(e^{-q_0t}-e^{-q_2t}\right)}{q_2-q_0}-\frac{\left(e^{-(q_2+q_0)t}-e^{-q_2t}\right)}{q_0}\right)\end{array}\right)\end{array}\right)$$

Therefore the solutions to the governing equations are given as:

$$\theta(\mathrm{z,t}) = \mathrm{z} + \sum_{n=1}^{\infty} q_1 \left(1 - e^{-q_0 t}\right) \sin n\pi z + S\sum_{n=1}^{\infty} u_6\left(t\right) Sinn\pi z \tag{39}$$

$$\phi(\mathrm{z,t}) = z + v_2(\mathrm{z,t}) + S\sum_{n=1}^{\infty} u_8\left(t\right) Sinn\pi z \tag{40}$$

$$w(\mathrm{z},t) = \sum_{n=1}^{\infty} q_{10} e^{-q_{11}t} Sinn\pi z + S\sum_{n=1}^{\infty} u_7\left(t\right) Sinn\pi z \tag{41}$$

$$u\left(z,t\right) = z + \sum_{n=1}^{\infty} \frac{q_{12}}{q_{11}} \left(1 - e^{-q_{11}t}\right) Sinn\pi z + S\sum_{n=1}^{\infty} u_5\left(t\right) Sinn\pi z \tag{42}$$

4 Results and Discussions

The system of partial differential equations describing unsteady couette flow of an electrically conducting incompressible fluid bounded by two parallel non conducting porous plates are solved analytically using eigenfunction expansion method. The analytical solutions of the governing equations are computed and presented graphically with the aid of a computer symbolic algebraic package MAPLE 17 for the values of the following parameters:

$\mathrm{Re} = 1,$	$Ra^2 = 1,$	$s = 0.1,$	$\mathrm{Pr} = 0.71,$	$Ha^2 = 1,$	$K_r = 0.5,$	$Sc = 0.22,$
$Bi = 1,$	$Be = 1,$	$a = 0.1,$	$c = 0.2,$	$P = 1,$	$T_D = 0,$	$Ec = 0.01,$
$\mathrm{Gr}_\theta = 0.2,$	$Gr_\phi = 0.2,$	$\sigma = 2$				

The figures 2-12 Explains the graphs of primary and secondary velocities, temperature and concentration against different dimensionless parameters.

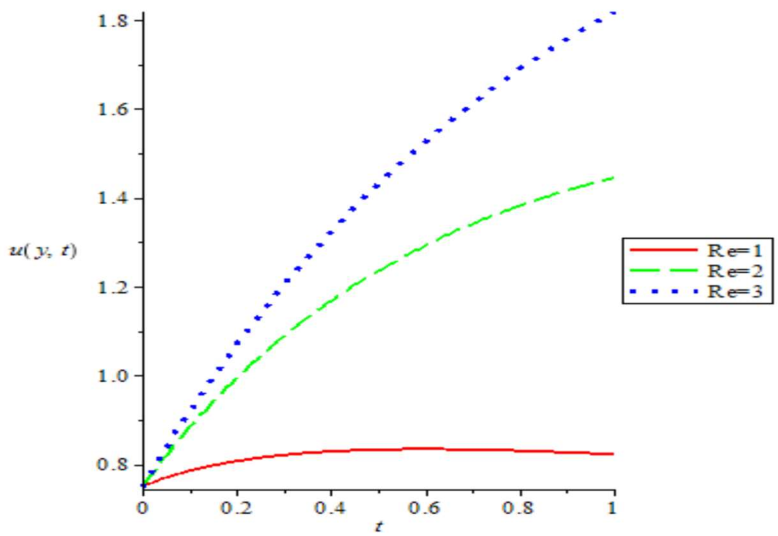

Figure 2 Relationship between Primary velocity and time for different values of Re

Figure 2 presents the graph of primary velocity with time for different values Reynolds number (Re). it is observed that primary velocity increases with time and also increases as Reynolds number increases.

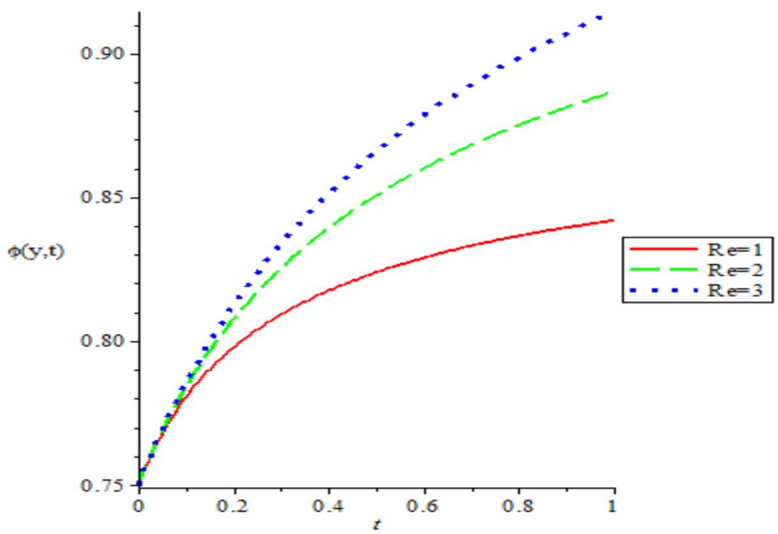

Figure 3 Relationship between concentration and time for different values of Re

Figure 3 presents the graph of concentration profile with time t for different values of Reynolds number. It is observed that the concentration profile increases with time and also, increases as Reynolds number increases

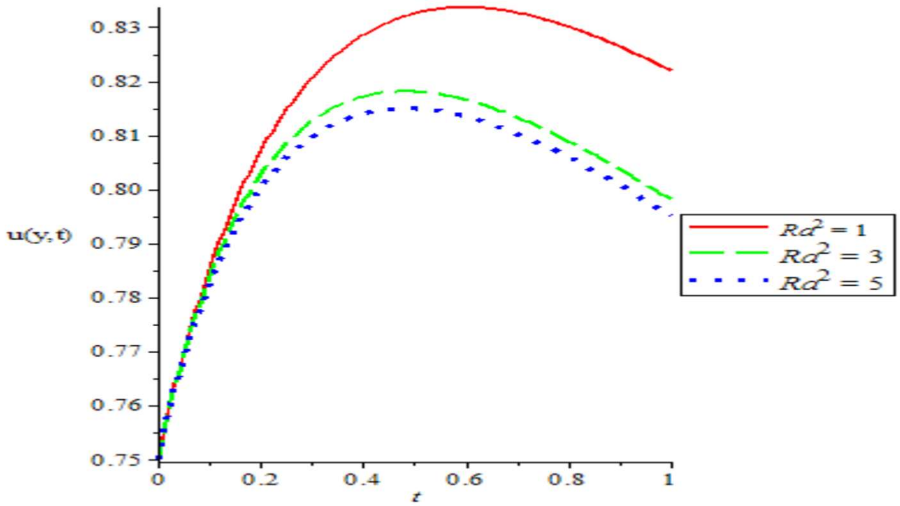

Figure 4 Relationship between primary velocity and time for different values of Ra

Figure 4 shows the influence of radiation on the primary velocity profile. It is evident that the primary velocity increases with time. Also, increase in the radiation parameter is found to decelerate the primary velocity of the flow.

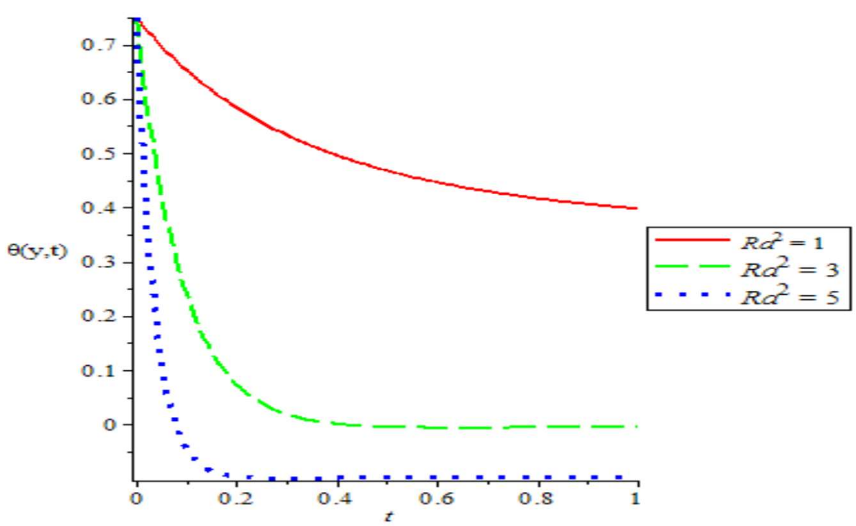

Figure 5 Relationship between temperature and time for different values of Ra^2

Figure 5 displays the effect of thermal radiation parameter on the thermal profile of the flow with time t. It is observed that the flow field suffers a decrease in temperature as radiation parameter increases while as radiation parameter the temperature decreases with time t.

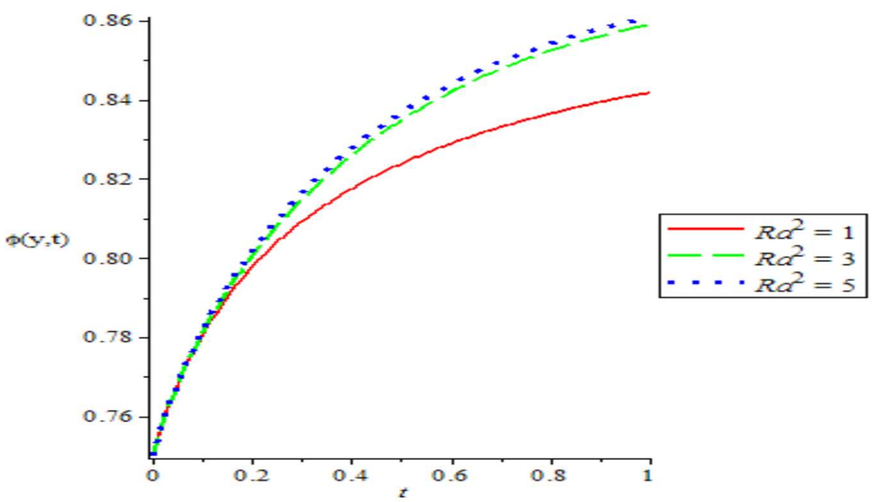

Figure 6 Relationship between concentration and time for different values of Ra^2

Figure 6 depicts the graph of concentration with time t for different values of radiation parameter. It is evident that concentration increases with time and also increases as radiation increases.

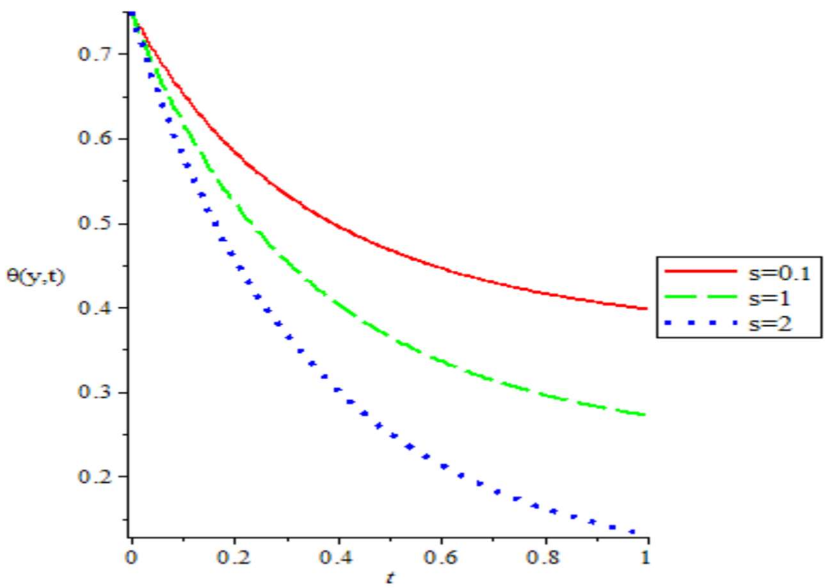

Figure 7 Relationship between temperature and time for different values of S

Figure 7 illustrates the graph of temperature with time for different values of suction parameter. It is seen that temperature decreases with time and also decreases as suction parameter increases.

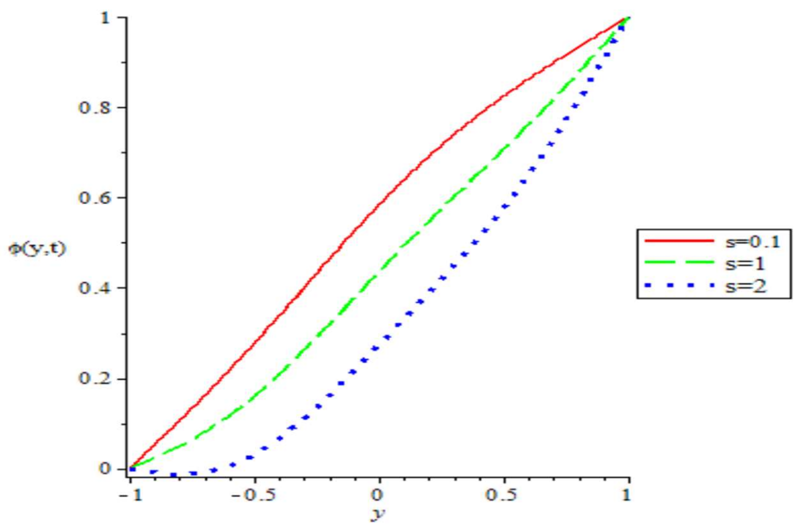

Figure 8 Relationship between concentration and distance for different values of S

Figure 8 presents the effect of suction parameter on concentration along distance y. it is observed that increase in suction parameter leads to decrease in concentration along distance while concentration is observed to increase along distance y.

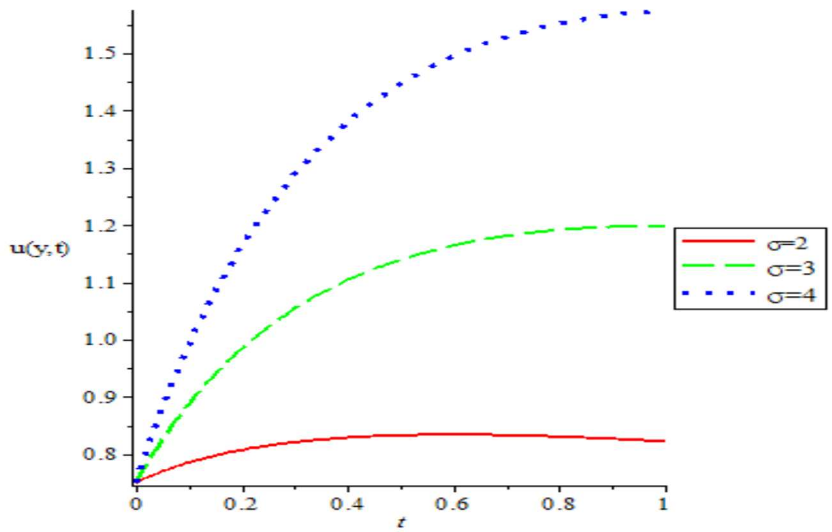

Figure 9 Relationship between primary velocity and time for different values of σ

Figure 9 shows the influence of pressure gradient on primary velocity with time. It is observed that increase in pressure gradient leads to increase in primary velocity. Also, primary velocity is found to increase with time.

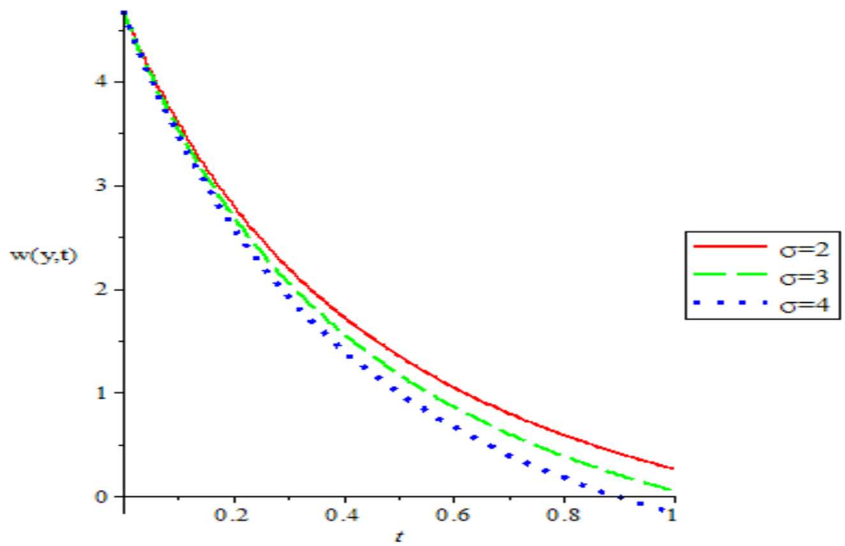

Figure 10 Relationship between secondary velocity and time for different values of σ

Figure 10 shows the effect of pressure gradient on secondary velocity with time t. It is observed that increase in pressure gradient leads to decrease in secondary velocity of the fluid while the secondary velocity is observed to decrease with time t.

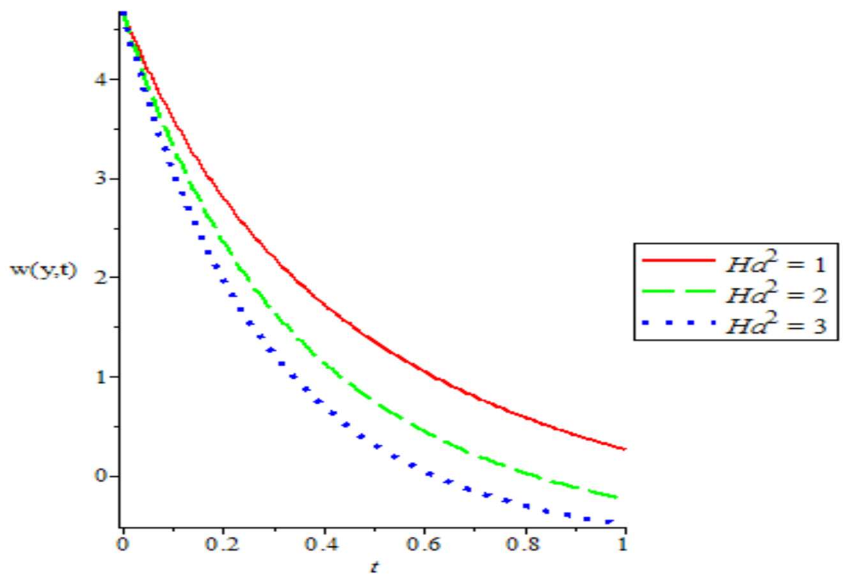

Figure 11 Relationship between secondary velocity and time for different values of Ha^2

Figure 11 presents the graph of secondary velocity with time t for different values of Hartman number. It is observed that increase in Hartman number leads to decrease in secondary velocity. This is due to the retarding Lorentz force which acts in opposite direction of the fluid flow when magnetic field is applied. This type of resisting force, slows down the velocity as shown in the figure.

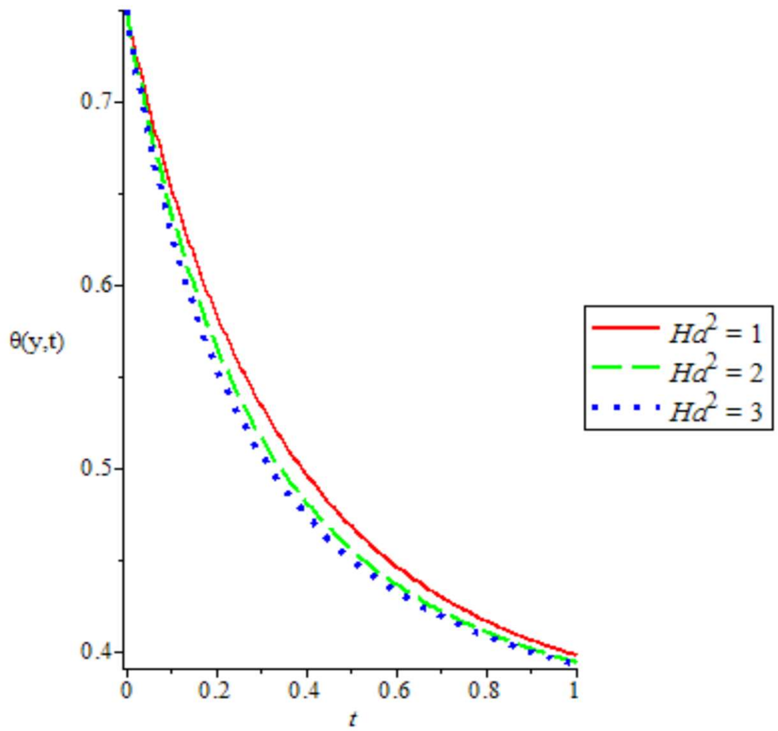

Figure 12 Relationship between temperature and time for different values of Ha^2

Figure 12 shows the effect of Hartman number with time t on temperature profile. It is observed that increase in Hartman number leads to decrease in temperature. Also, the temperature profile is observed to decrease with time.

5. Conclusion

For constant pressure gradient, the unsteady MHD Couette flow through a porous medium of a viscous incompressible fluid bounded by two parallel porous plates under the influence of thermal radiation and chemical reaction is investigated. A uniform suction and injection are applied perpendicular to the plate. The transformed conservation equations are solved analytically subject to physically appropriate boundary conditions by using Eigenfunction expansion technique. From the results obtained, we can conclude that:

1. Increase in Hartman number leads to decrease in velocity. This is due to the retarding Lorentz force which acts in opposite direction of the fluid flow when magnetic field is applied.
2. Concentration profile increases with time and also, increases as Reynolds number increases.
3. Increase in the radiation parameter is found to decelerate the velocity of the flow.
4. The flow field suffers a decrease in temperature as radiation parameter increases while as radiation parameter the temperature profile is observed to decreases with time t.

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