CHAPTER : I

I N T R O D U C T I O N.

1.1 Introductory Remarks :-

The contents of the thesis are arranged under five chapters , Chapter - I is of review work and deals with the introduction of the total work. Chapter -II concerns with some problems of steady and unsteady flows of viscous stratified fluid over a porous bed under various natural conditions. The study of the stratified fluid through the porous medium has great importance in many engineering and technological fields. It is widely applicable to withdraw fluid from a region in which the fluid density and viscosity vary in the vertical direction. Such type of flow is of great importance to petroleum technology concerned with the movement of oil , gas and water through the reservoir of an oil and gas as the flow behaviour of the fluid in petroleum reservoir depends to a large extent on the viscous stratification and on the properties of the medium. The problems in this chapter have been divided into four parts , viz to study (i) unsteady laminar stratified flow over a porous bed (ii) the slip velocity for the flow of stratified fluid of variable viscosity past a porous bed under the action of pressure gradient (iii) unsteady laminar stratified flow over a porous bed under the action of body force (iv) stratified fluid of variable viscosity past a permeable circular pipe.

Chapter -III deals the motion of stratified fluid which largely depends on the magnitude of stratification factor , porosity factor , slip parameter and Hartmann number. They must have an effect on the boundary layer. So we have studied its effect on the motion of the stratified fluid. The problems of this chapter have been divided into two parts viz to study (i) the boundary layer thickness for the flow of viscous stratified fluid past a porous bed (ii) the boundary layer thickness for MHD stratified fluid through a porous medium.

In chapter - IV , we have discussed one dimensional flow problems through porous media. For , these types of problems have an important application in various discipline like petroleum engineering , geophysics , agricultural engineering and to study the under ground water in river beds. This chapter contains two problems , viz. to study (i) unsteady flow of viscous fluid through a straight long porous circular tube due to pressure gradient , (ii) unsteady flow of viscous fluid through a straight long porous circular tube due to time varying pressure gradient with an initial arbitrary velocity distribution.

Chapter - V deals with the study of viscous fluid over an inclined porous bed under the effect of gravity. This type of flow problem has wide application to draw fluid from region in which the fluid density and viscosity vary in the vertical direction. Such type of flow have an important application in various discipline like petroleum engineering, agricultural engineering , chemical engineering and so on. Stratified fluid flow problem have also great importance also to the recent advancement in drill - geothermal power process concerned with the movement of fluid through the reservoir of the fluid field.

1.2 STRATIFIED FLUID FLOWS

Chapter – II concerns with some problems of steady and unsteady flow of viscous stratified fluid over a porous bed under various natural conditions. It is seen that very little work has been done on the viscous stratified liquid through a porous pipe which has wide application in the field of engineering and chemical technology. We consider four problems on steady / unsteady flow of stratified fluid in order to make an entry into this field of study.

The study of the stratified fluid through the porous medium has a great importance in many engineering and technological fields. It is widely applicable to withdraw fluid from a region in which the fluid density and viscosity vary in vertical direction. Such type flow is of great importance to the petroleum technology concerned with the movement of oil , gas and water through reservoir of an oil and gas field as the flow behaviour of the fluids in a petroleum reservoir depends to a large extent on the viscous stratification and depends also on the properties of the medium.

The aim of this study is to investigate the flow of a viscous stratified fluid passed a permeable bed with a motivation that stratification may provide a technique for studying pore size in a porous medium. The physical reason is that the stratification may retard or accelarate the flow. The magnitude of the retardation or acceleration is related to the slip parameter (α), stratification (n), the porosity factor (σ) and the Reynolds Number R . Hence one would expect that these factors might provide a technique for studying pore size in a porous medium ,which is very useful in petroleum industry. Density,stratification play an important role on many atmospheric and oceanic geophysical phenomenon. Owing to the increasing geophysical applications the study of stratified fluid flows has received a considerable attention by a number of authors.

The pioneer works of Holton (1965) , Barcilon and Pedlosky (1967) , Graebel , Long and Wu (1968) , Dore (1969), Sakurai (1969) , Buzyua and Veronis (1971), Joseph (1967) , Beavers et al (1970) , Saffman (1971) , Beavers , Sparrow and Magnuson (1970) may be regarded as the origin of the modern research on the above subject .

Debnath (1974), Rajasekhara , Rudraiahand Ramaiah (1975) considered the couette flow over a naturally permeable bed . Channabassappa and Ranganna (1976) considered the flow of viscous stratified fluid past a porous bed with the anticipation that stratification may provide a technique for studying the pore size in a porous medium.Gupta and Sharma (1978) discussed the stratified viscous flow of variable viscosity between a bed and moving impermeable plate under the action of a body force. Bhattacharya (1980)considered the unsteady flow of a viscous fluid in the channel under time dependent pressure gradient of exponentially decaying and periodic type. Kishan and Sharma (1980) studied the stratified viscous flow of variable viscosity between a porous bed and moving impermeable plate under the action of body force. Mukherjee .S , Mukherjee . S and Maiti M (1986), Kamal Kumar , Mahabir Prasad and Gupta (1990) considered both density and viscosity stratification exponentially decaying functions of vertical co-ordinates. Recently , Raghava-Charyhu (1985) considered the combined force and forced convection in vertical circular porous channel. More recently , Sanyal and Jash (1992) considered the combined force and force convection of a conducting fluid in a vertical circular tube.

In Chapter - II first part deals with the problem of unsteady laminar stratified flow over a porous bed. In this paper we have studied the effect of stratification (n) and porosity factor (σ) on the flow of viscous stratified fluid under the presence of pressure gradient. Flow due to the time dependent exponential pressure gradient has been studied. For small values of R (Reynolds Number) it is seen that effect of σ on average velocity is very insignificant while that of n has a significant effect on average velocity.

Second part of this chapter is meant to study the slip velocity for the flow of stratified fluid of variable viscosity past a porous bed under the action of pressure gradient. The motion of viscous stratified fluid largely depend on the magnitude of stratification factor , porosity factor and slip parameter. So naturally they must have an effect on the slip velocity also.

In this paper we have studied the effect of stratification factor , porosity factor and slip parameter on the slip velocity of the flow of viscous stratified fluid.

The third part of chapter-II deals with the solution of the problem of unsteady laminar stratified flow over a porous bed under the action of body force. The quantitative effects of porosity factor and stratification factor , the fractional increase in mass flow rate $|\phi|$ has been numerically evaluated for different sets of values of α, σ and n .

In the fourth part of this chapter , we have considered the stratified fluid of variable viscosity past a permeable circular tube. In the present paper we have studied the effects of stratification factor (n) , slip parameter (α) and porosity factor (σ) on the slip velocity and velocity profile of the flow of viscous stratified fluid under the influence of pressure gradient. It has been observed that if $\sigma = 2\alpha$,slip velocity (W_*) vanishes and if $\sigma < 2\alpha$ then the slip velocity increases with the decrease of σ and in case $\sigma > 2\alpha$ back slip flow appears to generate in motion.

1.3 Boundary layer effects on stratified fluid flow

The concept of boundary layer owes its existence to Ludwig Prandtl , a German aeronautic engineer , who in 1904 conceived and brought forward the idea of a layer characteristic of fluid (even of very low viscosity) in the vicinity of a solid. The flow of a viscous fluid no matter how small is the viscosity , must satisfied the no - slip condition at the solid boundary . The no - slip condition implies that the velocity of fluid at a solid boundary must be the same as that of the boundary itself. For a boundary at rest , the fluid velocity must reduce to zero at the boundary surface. As soon as a flowing fluid comes in contact with a stationary solid body , its velocity reduces to zero in accordance with the no- slip condition. The fluid velocity increases in the direction normal to the boundary. The fluid layer in the neighbourhood of the solid boundary where the effects of fluid friction (viscous effects) are predominant ,is known as the boundary layer .

The theory of boundary layer flow constitutes the back - bone of modern fluid dynamics specially the flow of low viscous fluids such as air and water which are encountered everyday in engineering and technological problems. The development of the knowlegde of boundary layer flow in the works of prandtl , Karman Schlichting and many others has enabled the world to get such sophisticated flying machines as modern supersonic aircrafts, rockets , missiles and the like. With the aid of the boundary layer theory , the science of aeronautical engineering has made rapid progress in the last few decades. The other beneficials as a result of development in the theory of boundary layer flow , are the fields of gas dynamics and aerofoil theory.

Prandtl succeeded in 1904 showing that the flow of a low viscosity fluids (like water and air which are most important fluids from their inexpensively , abundent availability in nature) is amenable to mathematical consideration. This was acheived by taking into account the viscous effects within the narrow region situated in the vicinity of a solid boundary. This region within which the effects of viscosity are confined is the boundary layer. From the knowlegde of classical hydrodynamics,the drag force experienced by a solid body immersed in a flowing fluids could not be theoretically explained until the emergence of the boundary layer concept.

In the flow of air over the earth surface and about large buildings , the motion of aeroplane in the air mass , in all these and such other cases where a flowing fluid comes in contact with a solid boundary , we do have the existence of boundary layer.

However , the motion of viscous stratified fluid largely depends on the magnitude of stratification factor , porosity factor , slip parameter and Hartmann Number. So they must have an effect on the boundary layer also.

Among many other aspects of stratified fluid flow problems , the most important aspect is the consideration of boundary layer problems. Many research scholars have made considerable contributions in this field. The fluid flow in porous channel , porous pipe has been investigated by a number of workers in the recent past , Sellers (1955) , Lighthill (1954) , Berman (1958) Wong (1971) , Chiu (1962) , Soo (1961) and Singleton (1965) investigated the problems of boundary layer flow of dusty fluid over a semifinite flat plate. Gupta and Pop (1975) analysed the boundary growth in a rotating liquid with suspended particles. Kapur and Gupta (1963 a) considered the steady boundary layer equation for a power law fluid flowing between parallel plates. Mathur and Nandanan (1972) have studied the laminar boundary layer flow of an oldroyed fluid under the influence of pressure gradient with and without suction through a wedge. Srivastava and Maiti (1966) have solved the boundary layer equations for two dimensional flow of a second order fluid.

Bathaiah (1980) has discussed the flow of a viscous incompressible slightly conducting fluid through a porous straight channel under a uniform transverse magnetic field. Bathaiah and K . Srinivasan (1993) considered the flow of a viscous conducting fluid between two parallel plates of uniform length , lower plate being stationary and upper plate moving with constant velocity. Manju Gupta and Sharma (1993) considered the unsteady flow of electrically conducting elasto – viscous dusty liquid through a recti-linear pipe having its cross – section as a hyperbolic sector in the presence of a tranwverse magnetic field under the influence of an arbitrary time varying pressure gradient.

Kumar , Prasad and Gupta (1990) considered the MHD flow of stratified through a porous medium between two oscillating plates. Chawla (1972) investigated the boundary flow of a micropolar fluid along an infinite plate when the plate performs impulsive motion in its own plane. Gersten and Gross (1974) have studied the three dimensional incompressible boundary layer flow past a porous flate plate. Jain and Singh (1992) considered the unsteady magnetrohydynamics boundary layer flow past a porous flate plate with sudden change in suction. Rath and Parida (1982) considered the oscillating free convection boundary layer flow of a viscous fluid near an infinite vertical wall and investigated that (1) by increasing injection velocity the fluid layer very near the wall may be made to oscillate with an amplitude larger than that of wall velocity (2) the boundary layer temperature fluctuates with a phase which change only with the magnitude but not the sign of fluid influx parameter.

The study of the flow of the viscous fluid past a porous medium without stratification has been studied by Beavers and Joseph (1967) Channabassappa and Ranganna (1976) considered the flow of viscous stratified fluid past a porous bed with the anticipation that stratification may provide a technique for studying the pore size in a porous medium. The boundary layer thickness just beneath the permeable interface and the friction factor are also obtained.

Chapter-III contains two papers. In the first paper we have studied the problem of boundary layer thickness for the flow of viscous stratified fluid past a porous bed.In the present note , we have studied the effects of stratification (n) and porosity factor (σ) on the boundary layer thickness of the flow of viscous stratified fluid between a moving rigid impermeable bed and a fixed permeable bed .

The second paper of this chapter , we have studied the boundary layer thickness for MHD stratified fluid through a porous medium. In this part , we have considered the effect of stratification factor (n),porosity factor (σ) and slip parameter (α) on the boundary layer thickness of the flow of viscous stratified fluid under the influence of transverse magnetic field.The effects of various parameters on the boundary layer have been shown with the aid of graph.

1.4 Motion of viscous fluid through a porous pipe.

One dimensional flow problem involving porous media have important application in various discipline like petroleum engineering ,Geophysics , Agricultural engineering and so on. The study of flow through porous media is of principle interest due to its importance in chemical engineering for filtration and water purification purposes , petroleum engineering for studying the movement of natural gas , oil and water through the oil reservoir and to study the under-ground water in river beds.

Many authors like Gersten and Gross (1974) , Varshney and Johri (1992) , Gupta (1983) , Chawla (1972) , Soundalgekar (1972) , Rao (1961) , Sellers (1955), Yuan (1956) , Bermen (1958) , Wong (1971) , Radhakrishnamacharya and Maiti (1977) , Singha (1964) , Chin Fan (1963) , Mithal (1960) , Bathaiah (1980) , Ahmadi and Manvi(1971), Yamanoto and Iwamura (1976) made significant contributions in this field. Rao (1961) considered the periodic flow through an annulus of two porous concentric cylinders for ordinary viscous fluid . Sigha.G . S (1967) solved the problem of flow of viscoelastic Maxwell fluid through two porous concentric cylinders. Das (1977) considered the flow of viscous incompressible fluid through two porous concentric circular cylinders under the influence of pressure gradient which is a function of time alone. Again , Das (1977) considered the problem of unsteady flow of viscous incompressible fluid in the annulus of two porous concentric cylinders subjected to suction or injection. Recently , Usha Singh and Sharma (1992) considered three dimensional magnet-fluid dynamic of an incompressible fluid over an semifinite plate in porous medium with pressure gradient Raja (1984) investigated the run - up flow of a viscous incompressible fluid in a generalised porous medium. Dutta and Arvind Kumar Sharma (1993) investigated the run - up flow of an electro - viscous liquid in a porous medium. Sharma and Harish Kumar (1993) considered unsteady flow of walters fluid past and infinite porous vertical plate with constant suction in the presence of constant heat flux. Pandey (1969) considered slow steady flow of a viscous incompressible fluid between two porous walls at slightly variable distance from each other with distributed suction.

More recently , Kulshrestha and Singh (1993) considered the MHD flow of viscous incompressible fluid between two co – axial rotating porous cylinders and discussed the effects of injection , suction parameter and electro – magnetic field on velocity distribution.

The first part of Chapter – IV is concerned with the solution of the problem of unsteady flow of viscous fluid through a straight porous circular tube due to pressure gradient. In the present paper , pressure gradient is a function of time but it is independent of space co-ordinates.The general solution is obtained by using finite Hankel transform. Velocity distribution for some particular types of pressure gradient are discussed.

In the second paper of this chapter , we have studied the unsteady motion of viscous fluid through a straight porous channel due to pressure gradient with an initial arbitrary velocity distribution. The fluid is assumed to be Newtonian and incompressible. The general solution is obtained in terms of Bessel function of order n by applying finite Hankel transform. Velocity profile for some particular types of pressure gradients namely (i) impulsive (ii) ~~constant~~ ~~(iii)~~ periodic are discussed.

1.5 <u>Study of viscous fluid under an inclined porous bed</u>

The flow of a fluid of variable viscosity in an inclined channel tube bounded by two permeable layers has wide applications in various field of technology. The flow which the permeable layers is governed by Navier - Stoke's equations. The flow in the porous medium is governed by Darcy's Law. Convective flow problems involving porous medium have important applications in various discipline like petroleum engineering geo-physics , agricultural engineering and so on. The study of blood flow is in pulmonary alvelor sheet where the fluid is between two permeable layers is of considerable importance in biomechanics.

Stratified fluid flow problems of vis_ous fluid have also great importance to the present day advancement in drilled geothermal power process concerned with the movement of fluid through the underground reservoir.

Investigation in stratified fluid flow was started long back. An excellent review was given by Graebal et al (1968) , Burnside (1889) , Love (1891) , Rossby (1938). Lyra (1943) investigated the motion of obstacles in stratified fluids. Experimental works in the stratified liquids carried out by Long (1953). Martin and Long (1968) considered the flow past a horizontal flate plane while Janowitz (1971)investigated the two dimensional flow produced by the slow horizontal motion of a finite vertical flat plate through a vertically stratified non-diffusion viscous fluid. Debnath (1974) analysed initial value investigation of an axisymmetrical forced motion of an inviscid incompressible rotating stratified fluid inclosed in a finite circular cylinder. Later , Mukherjee et al (1986) analysed the rotating stratified fluid flows generated by a time dependent pressure gradient. The flow is considered in a channel bounded by two parallel plates where fluid density and viscosity vary in the vertical direction.

Flow in a porous medium is assumed to be governed by either Darcy Law or Non - Darcy Law. Beavers and Joseph (1967) posulated a slip boundary condition at the nomial surface of the porous bed. Further ,they discussed the poiseulle flow over a permeable bed and verified B - J condition experimentally. Rudraiah et al (1982) made extensive studies on problems of flows past through a porous media. Channabassappa and Raganna (1975) examined the flow of a fluid of variable viscosity over a permeable bed.

Sneddon , Rudraiah and Wilfred , Ramkrishna et al , Atul kr Singh , Ajay kr. Singha ,Choudhury and Singh et al (1951 , 1982 , 1988 , 1991 , 1993) put forward some novel ideas on the fundamental aspects of the flow under gravity of a viscous stratified fluid /viscous incompressible fluid through an inclined porous channel / circular tube.

Sneddon (1951) first discussed the unsteady flow of viscous fluid between between two parallel plates inclined at an angle α to the horizon. Rudraiah and V . Wilfred (1982) investigated the natural convection in an inclined channel bounded by a porous media. Ramkrishna et al (1988) considered stratified flow in an inclined channel bounded by porous media. Recently , Choudhury and Singh (1991) considered the flow of a dusty visco - elastic liquid down an inclined plane. More recently , Atual Singh , Ajoy Kumar and Singh (1993) discussed the magnetro - hydro - dynamic flow of a dusty visco - elastic down an inclined plane.

The last chapter is devoted to the solution of the problem of motion under gravity of a viscous stratified fluid of a variable viscosity through an inclined plane and motion of a viscous incompressible fluid down an inclined circular tube. This chapter contains two papers.

In the first paper , We have studied the problem of flow of a fluid of variable viscosity between two inclined porous beds. The flow is governed by Navier - Stoke's equation in the free flow region and is assumed to be described by Darcy's Law in the lower and upper porous beds. The velocity profile , the mass flow rate and its fractional increases in mass flow rate are obtained.

The second paper of this chapter -V is concerned with the study of (i) unsteady motion of a viscous incompressible fluid down an inclined circular tube and (ii) Steady motion of a viscous stratified fluid through an inclined permeable circular tube. In the first problem , the flow governed Navier - Stoke's equations. The technique of finite Hankel Transform has been used to solve this problem. We have discussed the nature of the flow pattern for time varying pressure gradient and in the second problem , the flow within the pipe is governed by Navier - Stoke's equations and outside the pipe the flow is governed by modified Darcy Law. In the absence of the stratification factor and porosity factor , this flow pattern resembles to that of the first problem of the paper for sufficiently large values of t.

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