CHAPTER 1

INTRODUCTION

1.1 GENERAL THEORY ON NEWTONIAN AND NON-NEWTONIAN FLUIDS

The classical theory of hydrodynamics of viscous or Newtonian fluids is based on the assumption of a linear law governing the relation between the components of stress $τ_{ij}$ at a point of the fluid and the rate of strain components $E_{ij}$ in the form

$$τ_{ij} = -pδ_{ij} + φ_1 E_{ij} \tag{1.1.1}$$

where $p$ is the hydrostatic pressure, $δ_{ij}$ are the Kronecker deltas and the third order symmetric tensor,

$$E_{ij} = \left[ \frac{∂u_i}{∂x_j} + \frac{∂u_j}{∂x_i} \right] \tag{1.1.2}$$

defines the rate of tensor. All the fluids obeying the above linear law (1.1.1) are called Newtonian fluids and the co-efficient of viscosity $φ_1$ is in general a function of the material properties like temperature, density and molecular structure.

Because of its linearity and because of the fact that the stress of the rate of strain components do not enter through their time derivatives, this linear law provides, from a mathematical point of view, a great simplicity in analysis. Besides, it cannot be called a hypothetical constitutive equation as it provides a fairly good description of the properties of a very large class of real fluids namely Newtonian fluids. The class of Newtonian fluids has been studied very extensively both theoretically and experimentally by many researchers. Most of the gases like air and fluids like water
and mercury which possess simple chemical structures fall under the category Newtonian fluids.

The experiments on thick fluids showed a considerable deviation from this simple constitutive equation (1.1.1) and all the fluids which do not obey this stress rate of strain relationship have been termed as non-Newtonian. The typical examples of this class of fluids are molasses, molten rubber, cake mixes, printers ink, condensed milk, pastes, plastics, colloids, macro/molecular materials, high polymers and so on. The technological importance of these fluids has given a great impetus to the study of this class of fluids. Recently P.L. Bhatnagar has given the following rough classification of the entire class of fluids by considering the nature of response of a fluid to applied shearing stress.
Visco-elastic fluids

As the name implies these fluids possess a certain degree of elasticity in addition to viscosity. Thus, when a visco-elastic fluid is in flow, a certain amount of energy is stored up in the material as strain energy in addition to viscous dissipation. In a normal inelastic viscous fluid we are only concerned with the rate of strain but in elastic fluids, we can not neglect the strain, however small it may be, as it is responsible for the recovery of the original state and for the removal of stress. These material strains determined by the history of the fluid and can not be specified kinematically in terms of the large over-all moments of the fluids. During the flow, the natural state of the fluid changes constantly and tries to attain the instantaneous state of deformation but it never succeed completely. The lag measures the elasticity or the so called "memory" of the fluid. In the "Relaxation theory" an account of this memory is taken by introducing "stress relaxation times" and "strain retardation times". A number of researchers like Rivlin-Erickson, Oldroyd, T.G., Walters, K. etc have adopted this attitude in developing a mathematical theory of visco-elastic fluids. The visco-elastic fluids also exhibit the Weissenberg and Merrington effects obscured by the classical theory.

In passing we record some of the constitutive equations

Oldroyd constitutive equation

The constitutive equation proposed by Oldroyd is of the following form.

\[ \tau_{ij} + T_i \frac{D}{Dt} \tau_{i} + \mu_1 \tau_{kk} e_{ij} - \mu_2 \left( \tau_{jk} e_{jk} + \tau_{kj} e_{jk} \right) \]

\[ + \nu \tau_{ik} e_{ik} \delta_{ij} = 2\mu \left( e_{ij} + T_i \frac{D}{Dt} e_{ij} - 2\mu_1 e_{ik} e_{ik} + \nu_2 e_{ik} e_{ik} \delta_{ij} \right) \]

... (1.1.3)
Where

\[ \tau_{ij}^* = \tau_{ij} + p \delta_{ij} \quad \ldots (1.1.4) \]

\[ e_{ij} = \frac{1}{2} (v_{ij} + v_{ji}) \quad \ldots (1.1.5) \]

and

\[ \frac{D}{Dt} b_i = \frac{\partial}{\partial t} b_i + v_k \frac{\partial b_i}{\partial x_k} + w_{ik} b_k + w_{ik} b_k \quad \ldots (1.1.6) \]

with \( w_{ij} = v_{ij} - v_{ji} \) (verticity vector) \( \quad (1.1.7) \)

Here \( \mu, T_1, T_2 (\ll T_1) \) are the co-efficient of viscosity, stress relaxation time and rate of stress retardation time respectively and the constants \( \mu_1, \mu_2, \mu_3, v_1 \) and \( v_2 \) have dimensions of time. The elasticity or the memory of the fluid has been taken into account by relaxation times \( T_1 \) and \( T_2 \) and the linearity of the Newtonian constitutive equation has been broken by introducing quadratic terms in the rate of strain components and the products of stress and the rate of strain components.

**Walters' model**

A detailed theoretical investigation has begun for the incompressible elasto-viscous prototype designated as liquid B' by K. Walters [109]. The equations of state for liquid B' can be written in the form.

\[ \tau_{ij} = -p g_{ij} + \tau_{ij}^* \quad \ldots (1.1.8) \]

\[ \tau^{*\alpha}(x, t) = 2 \int_0^1 \Psi(t - t') \frac{\partial x^\alpha}{\partial x^\beta} e^{i \omega t'} (x', t') dt' \quad \ldots (1.1.9) \]

where

\[ \Psi(t - t') = \int_0^\infty [N(\tau)/\tau] e^{-(t - t')/\tau} d\tau \quad \ldots (1.1.10) \]
\[ \tau_{ij}(x,t) = 2 \int_{-\infty}^{t} \psi(t-t') \frac{\partial \hat{x}_m}{\partial x'_i} \frac{\partial \hat{x}_n}{\partial x'_j} e^{0_{mn}}(x', t') \, dt' \]  \hspace{1cm} (1.1.11)

\( N(\tau) \) being the distribution function of relaxation times \( \tau^{(t)} \). In these equations \( \tau_{ij} \) is the stress tensor, \( p \) an arbitrary hydrostatic pressure, \( g_{ij} \) the metric tensor of a fixed co-ordinate system at time \( t' \) of the element that is instantaneous at the point \( x' \) at time \( t \), and \( \varepsilon_{ij} \) is the rate of strain tensor. The liquid designated as liquid B by Oldroyd [111],

\[ \frac{\partial}{\partial t} \left( 1 + \lambda_i \frac{\partial}{\partial t} \right) \tau^{(t)} = 2\eta_0 \left( 1 + \lambda_i \frac{\partial}{\partial t} \right) \varepsilon^{(0)} \]  \hspace{1cm} (1.1.12)

is a special case of liquid B' obtained by writing

\[ N(\tau) = \eta_0 \left( \frac{\lambda_i}{\lambda_1} \right) \delta(\tau) + \eta_0 \frac{\lambda_i - \lambda_2}{\lambda_1} \delta(\tau - \lambda_i) \]  \hspace{1cm} (1.1.13)

in equations (1.1.9) and (1.1.10) and \( \delta \) denotes a Dirac delta function, defined in such a way that

\[ \delta(x) = 0(x \neq 0), \quad \int_{-\infty}^{\infty} \delta(x) \, dx = \int_{0}^{\infty} \delta(x) \, dx = 1 \]

in equations (1.1.12) \( \frac{\partial}{\partial t} \) denotes convected differentiation of a tensor quantity in relation to the material in motion, as defined by Oldroyd, for a contra variant tensor \( h^k \),

\[ \frac{\partial}{\partial t}(h^k) = \frac{\partial h^{ik}}{\partial t} + v^m \frac{\partial h^{ik}}{\partial x^m} - \frac{\partial v^i}{\partial x^m} h^{im} - \frac{\partial v^i}{\partial x^m} h^{mk} \]  \hspace{1cm} (1.1.14)

where \( v^i \) is the velocity vector. The Newtonian liquid of constant viscosity \( \eta_0 \) is given by

\[ N(\tau) = \eta_0 \delta(\tau) \]  \hspace{1cm} (1.1.15)
For mathematical convenience, it is necessary to restrict the discussion to liquids with short memories (i.e. short relaxation times) in the simplified form.

\[
\tau^{ii} = 2\eta_0 e^{0(\eta)} - 2k_o \frac{\partial}{\partial t} e^{0(\eta)}
\]  

...(1.1.16)

where \(\eta_0 = \int_0^\infty N(\tau) d\tau\) is the limiting viscosity at small rates of shear

\[
k_o = \int_0^\infty N(\tau) d\tau \text{ and the terms involving } \int_0^\infty \tau^n N(\tau) d\tau (n \geq 2) \text{ have been neglected.}
\]

The liquid with equations of state (1.1.8) and (1.1.16) will be referred to as Walters’ liquid B' and the liquid with equations (1.1.8) and (1.1.11) are called Walters’ liquid A. In the case of Oldroyd’s liquid B, equations (1.1.12) and (1.1.13) become

\[
k_o = \eta_0 (\lambda_1 - \lambda_2) \text{ and equation (1.1.16) become}
\]

\[
\tau^{ii} = 2\eta_0 \left[ 1 - (\lambda_1 - \lambda_2) \frac{\partial}{\partial t} \right] e^{0(\eta)}
\]  

...(1.1.17)

In this case the approximation is equivalent to neglecting second order terms in \(\lambda_1\) and \(\lambda_2\).

**Basic equations**

**Continuity equation**

\[
\nabla \cdot \mathbf{u} = 0
\]  

...(1.1.18)

(\(\mathbf{u}\)) is the velocity vector

**Momentum equation**

\[
\mathbf{u}_{i, j} + \mathbf{u} \cdot \mathbf{u}_{j, i} = \frac{1}{\rho} T_{i, j}
\]  

...(1.1.19)

In the absence of external forces and \(\rho\) is the density of the fluid.
Energy equation

\[ pC_p \left[ T_{ij} + v^j T_{ij} \right] = k g^{ij} \cdot T_{ij} + T^k \cdot E_{kj} \]  

...(1.1.20)

Where \( C_p \) is the specific heat and \( k \) is the thermal conductivity of the fluid.

Equations of motion for two-dimensional flow: (Cartesian co-ordinate system).

Continuity equation

\[ \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \]  

...(1.1.21)

Momentum equations (Unsteady case)

\[ \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = -\frac{1}{\rho} \frac{\partial p}{\partial x} + u \nabla^2 u - k \left[ \left( \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} \right) \right] \]  

\[ -2 \left[ \frac{\partial u}{\partial x} \frac{\partial^2 u}{\partial x^2} + \frac{\partial u}{\partial y} \frac{\partial^2 u}{\partial y^2} \right] \]  

...(1.1.22)

\[ \frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} = -\frac{1}{\rho} \frac{\partial p}{\partial y} + v \nabla^2 v - k \left[ \left( \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} \right) \right] \]  

\[ -2 \left[ \frac{\partial v}{\partial x} \frac{\partial^2 v}{\partial x^2} + \frac{\partial v}{\partial y} \frac{\partial^2 v}{\partial y^2} \right] \]  

...(1.1.23)

where \( \nu = \frac{\mu}{\rho} \) = kinematic viscosity

\( \nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} \)

Making the usual boundary layer assumptions, equations of motion of visco-elastic fluid for unsteady flow are

\[ \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = -\frac{1}{\rho} \frac{\partial p}{\partial x} + \frac{\partial^2 u}{\partial y^2} - k \left[ \frac{\partial^2 u}{\partial y^2} + u \frac{\partial^3 u}{\partial x \partial y^2} + v \frac{\partial^3 u}{\partial y^3} + \frac{\partial u}{\partial x} \frac{\partial^2 u}{\partial y \partial x} - \frac{\partial u}{\partial x} \frac{\partial^2 u}{\partial y \partial x} \right] \]  

...(1.1.24)
For steady flow the equations of motion are

\[ u \frac{∂u}{∂x} + v \frac{∂u}{∂y} = \frac{1}{ρ} \frac{∂p}{∂x} + v \frac{∂^2u}{∂y^2} - k_0 \left[ u \frac{∂^2u}{∂x∂y} + v \frac{∂^2u}{∂y^2} + \frac{∂u}{∂x} \cdot \frac{∂^2u}{∂y^2} - \frac{∂u}{∂y} \cdot \frac{∂^2u}{∂x∂y} \right] \]

...(1.1.25)

where \( k_0 \) is the co-efficient of elastic velocity.

**Equation of energy**

The relevant two dimensional equation of energy is

\[ ρC_p \left( \frac{∂T}{∂t} + u \frac{∂T}{∂x} + v \frac{∂T}{∂y} \right) = k \left( \frac{∂^2T}{∂x^2} + \frac{∂^2T}{∂y^2} \right) + \phi \]

...(1.1.26)

Boundary layer energy equation for two-dimensional steady incompressible fluid is derived as

\[ ρC_p \left( u \frac{∂T}{∂x} + v \frac{∂T}{∂y} \right) = k \frac{∂^2T}{∂y^2} + \phi \]

...(1.1.27)

and boundary layer energy equation for unsteady incompressible flow is given by

\[ ρC_p \left( \frac{∂T}{∂t} + u \frac{∂T}{∂x} + v \frac{∂T}{∂y} \right) = k \frac{∂^2T}{∂y^2} + \phi \]

...(1.1.28)

### 1.2 MAGNETOHYDRODYNAMICS

Magnetohydrodynamics is the study of motion of electrically conducting media in the presence of magnetic field. It is the fusion of two branches of physics viz., hydrodynamics and electromagnetism. The dictionary meaning of hydro may be water but hydrodynamics includes the study of all liquids as well as gases. Hence MHD assumes an electrically conducting medium which may be a liquid or an ionised gas (plasma) in the presence of magnetic field. Both plasma and conducting fluids are treated in common theory by assuming plasma as a continuous fluid for which the kinetic theory of gases still hold true. Electric currents induced as the mechanical
forces produced which modify the motion in the fluid, as a result the flow of electrically conducting fluid in the presence of a transverse magnetic field are the major interactions which contribute the study of MHD.

The following information about the early development of MHD is worth mentioning. Hartmann in 1937 studied the motion of electrically conducting fluids in the presence of magnetic field. Champon and Ferraro developed the theory of magnetic storms during 1930-35. The systematic study of MHD dates from 3rd October 1942, the date of issue of "Nature" in which Hannes Alfven of the Royal institute of Technology at Stocklem, Sweden, Published an article describing the prediction of new type of wave. By combining, Maxwell's equations with fundamental equations of hydrodynamics, Alfven predicted new type of wave motion which are called by his name. At the same time, Alfven established the theorem of frozen fluids i.e., in a highly conducting fluids, the magnetic lines of force are frozen into the fluid. The motion along the lines of force of magnetic field does not effect the flow but when the fluid moves transverse to the lines of force it carries them with it.

The subject of MHD had its origin in the study of magnetism of cosmic problems -like problems of earth's interior, of the sun, the stars, the inter stellar space etc. MHD has many practical applications also. It is used in problems such as cooling of nuclear reactor by liquid sodium in the extraction of electrical energy directly from a hot plasma through a powerful magnetic field.

Because of these engineering and practical applications, many engineers and scientists are joining geophysics and astrophysists to study extensively the dynamics
of electrically conducting fluids. The study of MHD flow of non-Newtonian fluids is of much importance in constructing electromagnetic flow meters and its application to blood flow measurements.

**Basic equations**

The basic equations of MHD when the displacement currents and free charges neglected are,

Maxwell’s equations:

\[
\text{Curl } \vec{\mathbf{H}} = \vec{j} \tag{1.2.1}
\]

\[
\text{div } \vec{E} = 0 \tag{1.2.2}
\]

\[
\text{Curl } \vec{\mathbf{E}} = -\mu_0 \frac{\partial \vec{\mathbf{H}}}{\partial t} \tag{1.2.3}
\]

\[
\text{div } \vec{\mathbf{H}} = 0 \tag{1.2.4}
\]

\[
\text{div } \vec{j} = 0 \tag{1.2.5}
\]

Ohm’s law

\[
\vec{j} = \sigma \left( \vec{E} + \vec{q} \times \vec{B} \right) \tag{1.2.7}
\]

The generalised Navier - Stoke’s equation of motion is

\[
\frac{\partial \vec{q}}{\partial t} = -\frac{1}{\rho} \text{ grad } p + \nu \nabla^2 \vec{q} + \frac{\vec{j} \times \vec{B}}{\rho} \tag{1.2.8}
\]

where \( \vec{q} \) is the velocity of the fluid, \( p \) the pressure, \( \rho \) the density, \( \vec{B} = \mu_0 \vec{H} \), \( \vec{B} \) being the electromagnetic induction, \( \vec{E} \) the electric field and \( \frac{\partial}{\partial t} \) is the mobile operator, \( \vec{j} \times \vec{B} \) is the Lorentz’s force.
Equation of Energy:

\[
\rho C_v \frac{dT}{dt} = k \nabla^2 T + \phi + \frac{J^2}{\sigma} \quad \text{(1.2.9)}
\]

where \[
\frac{d}{dt} = \frac{\partial}{\partial t} + u \frac{\partial}{\partial x} + v \frac{\partial}{\partial y}
\]

\[
\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}
\]

Two-dimensional form of Lorentz's force

When the conduction current \( \sigma \vec{E} \) is negligible compared to the induction current \( \sigma (\vec{q} \times \vec{B}) \), Ohm's law gives

\[
\vec{J} = (\vec{q} \times \vec{B})
\]

if \( q = q_1 + q_j \); \( \vec{H} = \vec{H}_0 = \pm H_{0i} \)

then \( \vec{B} = B_n = \pm B_{nj} \)

\[
\vec{q} \times \vec{B} = \pm B_0 q_k, \; \vec{J} = \pm \sigma B_0 q_k
\]

So the Lorentz's force

\[
\vec{J} \times \vec{B} = -\sigma B_0^2 q_i
\]

where \( \vec{H}_0 \) is the applied magnetic field and i, j, k are the three orthogonal vectors.

1.3 POROUS MEDIA

A porous medium is a continuous solid phase with many pores in it. Examples are sponges, clothes, wicks, paper sand gravel, filters, concrete, bricks, plaster walls, many naturally occurring rocks, packed beds used for distillation, absorption etc. The study of porous media has gained appreciable importance in many scientific and engineering applications. Such of these flow problems are of
great importance to the petroleum engineer in concern with the flow of oil, gas and water through the reservoir of oil or gas field add to the hydrologist in his study of migration of underground water and to the chemical engineer in connection with filtration processes.

These problems are also of much interest in geophysics in the study of interaction of the geomagnetic field and the fluid in the geothermal region.

Studies of flow through porous media first engaged the attention of several engineers of the famous crops - desponts at Caunettes during the second half of the 19th century. Henry P.G. Darcy (1803-1858) as a director of Public Works in Dijon has worked in the design and execution of a municipal water supply system. This system functioned admirably and gave rise to a series of researchers, which he conducted on the flow of water through sand bed filters. He published the results of these studies along with much other information of the development of water supply systems in 1856. The law which Darcy discovered known as “Darcy’s law” - stated as the rate of flow is proportional to the pressure drop through a bed of fine particles. It is mathematically expressed as

$$Q = -\frac{k'}{\mu} \frac{dp}{dx} \quad \ldots(1.3.1)$$

where $k'$ represents the permeability of the material. $Q$ is a volumetric flow rate per unit cross-sectional area. It is extensively applied for investigating the behaviour of all types of water flow through porous media, such as underground flow to wells, flow in soils being irrigated and the permeability of dam foundations. The flow of oil in underground substructures has been found to follow Darcy’s law and a unit of
permeability designated as Darcy is generally used in the soil industry to day. Literally hundreds of studies have been devoted to experimental determination of the Darcy's permeability when the fluid permeates a porous material, the actual path of an individual fluid particle cannot be followed analytically. The gross effect as the fluid slowly percolates through the pores of the medium, must be represented by a macroscopic law which is applicable to masses of fluid large compared with the dimensions of the porous structure of a medium (Lapwood, 1948), which is the basis to obtain Darcy's law. Darcy law is generally accepted as the macroscopic equation of motion of Newtonian fluids. The flow governed by this law, in the case of homogenous isotropic porous medium, is of potential type rather than boundary layer. In other words, Darcy model take into account only the frictional force offered by the solid particles to the fluid rather than the boundary and inertial effects. One of the approximate boundary layer type of equations in a porous medium is the Brinkman model. Brinkman model consists of viscous term \( \nu \nabla^2 \mathbf{q} \) in addition to the Darcy resistance term \( (\mu/k')_{\mathbf{q}} \) in the momentum equation. Brinkman model generalises the fact that when the permeability \( k' \rightarrow \infty \), we obtain the equations for pure MHD flow and when \( k' \rightarrow 0 \), they tends to usual Darcy flow through porous medium.

Under the following approximations the basic equations of motion and energy for this media are valid, namely

1. The saturated porous medium is homogeneous and isotropic so that the porosity and permeability are constant. The porous medium is assumed to consist of sparsely distributed particles so that viscous shear and inertial effects play an important role in addition to the Darcy resistance.
2. The usual MHD approximations are valid even in the flows through porous media.

Basic Equations:

\[ \nabla \cdot \vec{q} = 0 \]  
\[ \rho \left( \frac{\partial \vec{q}}{\partial t} + (\vec{q} \cdot \nabla)\vec{q} \right) = -\nabla p + \rho \vec{a} - \frac{\mu}{k} \vec{q} + \mu \nabla^2 \vec{q} \]  
\[ \rho C_p \left( \frac{\partial T}{\partial t} + (\vec{q} \cdot \nabla)T \right) = k \nabla^2 T \]

1.4 FEATURES OF IN-CYLINDER FLUID DYNAMICS

Internal combustion engine, the man made wonder, has revolutionized the world in the field of transport over the last ten decades, this simple machine was the subject of continuous research. The two conflicting requirements of meeting the emission standards and fuel economy put greater strain on the engine designers and researchers in optimizing many of the parameters in the design and development of an engine. A better understanding of the in-cylinder fluid motion will help in simplifying the above problem to a great extent.

The fluid motion inside the engine cylinder appears to become unstable, either during the intake or during the compression process and breaks down into three-dimensional turbulent motions. The molecular diffusion due to turbulence, results in local fluctuation in the flow field. Besides, this complex pre-combustion gas motion, a phase change is also involved due to the injected fuel mass. Further the combustion
process in a diesel engine is an exceedingly complex one. The complexity of combustion is compounded by non-uniform fuel distribution within the combustion chamber and fuel air mixing process.

1.5 MODELING TECHNIQUES

Because of the time consuming and expensive nature of the experimental techniques and the recent advancement of computers, researchers are attracted towards modeling techniques to predict the in-cylinder gas motion. According to Heywood’s definition, modeling is a process has come to mean developing and using appropriate combination of assumptions and equations that permit critical features of the process to be analyzed. The modeling of engine processes continues to develop as our basic understanding of the physics, mathematics and chemistry of the phenomena of interest steadily expands. Specially mathematical modeling activities can make major contributions to the engine engineering by developing a more complete understanding of the process under study from the discipline of formulation the model.

For the processes that govern engine performance and emissions, two basic types of models have been developed. They are thermodynamic and fluid dynamic depending on the equation, which give the model. If the equations are based on energy conservation the model is thermodynamic or if the analysis is based on fluid motion it is fluid dynamic.

1.5.1 Thermodynamic based models

Thermodynamic models can be further classified into zero-dimensional and quasi-dimensional models. Zero-dimensional models usually refer to a
thermodynamic analysis of the engine cycle and are ideal for investigating energy balances. Here the charge is assumed to be uniform. The fuel injected into the combustion chamber is assumed to vapourise and mix with the in-cylinder air instantaneously.

Quasi-dimensional models are also referred to as entrainment models. They include the concept of space in addition to the basic thermodynamic approach. For example, a quasi-dimensional model can predict the SI engine flame or diesel fuel spray shape and penetration of fuel jet in a diesel engine. The thermodynamic based models are generally represented by means of ordinary differential equations and hence they can be solved mathematically either by analytical methods or by numerical methods and can yield results which have significantly less computational requirements. They are mainly useful for parametric studies.

Though useful to predict the engine processes to certain extent, the thermodynamic models have many drawbacks. Mainly, they are not realistic in nature. In spite of the simplified assumptions, they still require experimental validation. Also, this model does not have the complexity to accommodate variations in the geometry of combustion chamber and does not predict the exhaust flow characteristics.

1.52 Fluid dynamic based models

Over the past one and half decades fluid mechanics based 2- and 3-dimensional models, often called as multi-dimensional models, have become popular in the field of IC engines. These models have inherent ability to provide detailed information of the spatial distribution of the fluid flow, velocity and other
characteristics of the flow within the engine cylinder. Fluid dynamic models are realistic in nature and are able to take care of combustion chamber geometry. It further helps the designer to understand and identify the influence of various physical parameters on in-cylinder processes for improved engine performance and emission characteristics.

Multi-dimensional models are represented by partial differential equations mathematically for conservation of mass, momentum and energy.

Multi-dimensional models for engine applications demand huge computing resources. Most of these models are reported and to be developed on super computers. But the use and maintenance of super computers is expensive.

1.6 OBJECTIVE AND SCOPE OF THE PRESENT INVESTIGATION

It is evident from the foregoing discussion that useful multi-dimensional calculations for the in-cylinder flows are now feasible. However, due to the excessive reasons the current status of these models are limited mostly to two-dimensional and three-dimensional models of fluid flows.

In the present work the theoretical investigation and analysis of viscous and visco-elastic fluid flows with certain basic mathematical approaches for paving way to characterize in-cylinder flows and heat transfer is dealt. In this respect the present work consists of the boundary layer flow of viscous (Newtonian) and visco-elastic (non-Newtonian) fluids with the influence of magnetic field and porosity over continuous moving solid surfaces. Besides it is considered the study of heat and mass transfer analyses under two types of boundary conditions namely;
i) Prescribed power law surface temperature and prescribed power law mass concentration (PST) and

ii) Prescribed power law heat flux and prescribed power law mass flux (PHF).

The study of Newtonian and non-Newtonian flows have generated considerable interest in recent years, because of their enormous industrial applications particularly in fibre industries.

So in this thesis it is proposed to study the flow problems concerned to the boundary layer region. Various aspects regarding behaviour of fluid flow, heat transfer and mass transfer would be dealt through several mathematical problems which are of the nature of highly non-linear and of higher order. Depending upon the degree of higher order non-linearity we would like to use advanced innovative analytical methods for getting the non-linear behaviour of the physical phenomena. This ultimate results in the reduction of drag over solid bodies. Therefore it is of interest to study the suction or blowing on the flows of Newtonian and non-Newtonian fluids. Keeping this in view, it is of much interest to find out how the stresses on the bodies are affected by the suction/blowing and know the behaviour of non-Newtonian parameter to these in relation to the contribution of usual viscosity.

Besides perturbation technique is applied to solve the unsteady flow problems. This method represents the unsteady flow phenomena more realistically as it models the time varying properties of the flow and allows for mass accumulation between the engine system components.

The combined study of both the in-cylinder flow model and boundary layer concept over stretching bodies is an important tool in the analysis of engine system.
Thus in the present analysis cycle of calculations start from studying the viscous fluid flow characteristics with heat and mass transfer phenomena with PST and PHF cases to the study of visco-elastic fluid flow behaviours with heat and mass transfer phenomenas under various physical situations.

The present work highlights some important findings related to the parallel use of theoretical techniques for the study of the engine behaviour. With the advent of the fast computers, the formulation of the model can be as close to the actual problem as possible, enabling better understanding of the physics of the problem by which deficiencies can be overcome. These formulations will help an engineer to go into the details of investigation of in-cylinder flows for different engine operating conditions. This will enable the researchers to improve the performance and doing away with the intricate design complexities in the independent India in the days to come.