CHAPTER 1
INTRODUCTION

1.1. INTRODUCTION:

Figure 1.1. Diagram to explain part of relationships of fluid mechanics branches
1.2. Fluid Mechanics:

Fluid mechanics deals with the study of all fluids under static and dynamic situations. Fluid mechanics is a branch of continuous mechanics which deals with a relationship between forces, motions, and statically conditions in a continuous material. This study area deals with many and diversified problems such as surface tension, fluid statics, flow in enclose bodies, or flow round bodies (solid or otherwise), flow stability, etc. In fact, almost any action a person is doing involves some kind of a fluid mechanics problem. Furthermore, the boundary between the solid mechanics and fluid mechanics is some kind of gray shed and not a sharp distinction. For example, glass appears as a solid material, but a closer look reveals that the glass is a liquid with a large viscosity.

A proof of the glass “liquidity” is the change of the glass thickness in high windows in European Churches after hundred years. The bottom part of the glass is thicker than the top part. Materials like sand (some call it quick sand) and grains should be treated as liquids. It is known that these materials have the ability to drown people. Even material such as aluminium just below the mushy zone also behaves as a liquid similarly to butter. Furthermore, material particles that “behaves” as solid mixed with liquid creates a mixture that behaves as a complex liquid. After it was established that the boundaries of fluid mechanics aren’t sharp, most of the discussion in this book is limited to simple and (mostly) Newtonian (sometimes power fluids) fluids which will be defined later. The fluid mechanics study involves many fields that have no clear boundaries between them. Researchers distinguish between orderly flow and chaotic flow as the laminar flow and the turbulent flow. The fluid mechanics can also be distinguished between a single phase flow and multiphase flow (flow made more than one phase or single distinguishable material). The last boundary (as all the boundaries in fluid mechanics) isn’t sharp because fluid can go through a phase change (condensation or evaporation) in the middle or during the flow and switch from a single phase flow to a multiphase flow. Moreover, flow with two phases (or materials) can be treated as a single phase (for example, air with dust particle). After it was made clear that the boundaries of fluid mechanics aren’t sharp, the study must make arbitrary boundaries between fields. Then the dimensional analysis can be used explain why in certain cases one distinguish area/principle is more relevant than the
other and some effects can be neglected. For example, engineers in Software Company analyzed a flow of a complete still liquid assuming a complex turbulent flow model. Such absurd analyses are common among engineers who do not know which model can be applied. Thus, one of the main goals of this book is to explain what model should be applied. Before dealing with the boundaries, the simplified private cases must be explained. There are two main approaches of presenting an introduction of fluid mechanics materials. The first approach introduces the fluid kinematic and then the basic governing equations, to be followed by stability, turbulence, boundary layer and internal and external flow. The second approach deals with the Integral Analysis to be followed with Differential Analysis, and continue with Empirical Analysis.

1.3. Magnetohydrodynamics (MHD):

We can describe scientifically the interaction of electromagnetic fields and fluids by the proper application of the principles of the special theory of relativity. The practical applications of these principles, in Physical Engineering, Astro-Physics, Geo-Physics etc…, have become an important in recent years. The study of three applications to continuum is known as Magnetohydrodynamics (MHD) or Magneto fluid dynamics. The study of Magnetohydrodynamics (MHD) plays an important role in agriculture, engineering and petroleum industries. MHD has won practical applications, for instance, it may be used to deal with problems such as cooling of nuclear reactors by liquid sodium and induction flow water which depends on the potential differencing the fluid direction perpendicular to the motion and goes to the magnetic field. The study of Magnetohydrodynamics (MHD) of viscous conducting fluids playing a significant role, owing to its practical interest and abundant applications, in Astro-physical and Geo-physical phenomena. Astro-Physicsts and Geo-Physicsts realized the importance of MHD in stellar and planetary processes. The main impetus to the engineering approach to the electromagnetic fluid interaction studies has come from the concept of the magnetohydrodynamics, direct conversion generator, ion propulsion study of flow problems of electrically conducting fluid, particularly of ionized gasses is currently receiving considerable interest. Such studies have made for years in connection with Astro-Physical and Geo-Physical problems
such as sun spot theory, motion of the instellar gas etc… Recently, some engineering problems need the study of the flow of an electrically conducting fluid, in ionized gas is called plasma. Many names have been used in referring to the study of plasma phenomena. Hartmann called it mercury dynamics, as he worked with mercury. Astro-Physics called it comical electro dynamics and some called it magnetohydrodynamics. Physics and electrical engines commonly use the term plasma physics or plasma dynamics. The aerodynamist has spoken of magnetohydrodynamics.

1.4. Applications of Magnetohydrodynamics (MHD):

Some details about the applications of MHD are mentioned below.

1.4.1. The Earth:

The molten iron is one of the major components of the outer core of the earth. The earth’s magnetic field is generated in this outer core. The gradual change of the field over time and the reversals which are not so frequent or regular, need to be explained. The study of magnetohydrodynamics allows us to explain this phenomenon which is an area of current research. Ionosphere can also be studied using MHD.

1.4.2. The Sun:

The major composition of sun is ionised hydrogen. In this regard MHD has two major areas which are of prime interest. One is the convection zone which generates the solar magnetic field. The moving electrically conducting fluid interacting with a magnetic field is the basic mechanism that is akin to the earth’s core operation. But gives rise to a different magnetic field. A periodical phenomenon of 22 years is taken for the solar field to reverse. The atmosphere of the convective zone is denser than the solar atmosphere in which an observation can be made of features like prominences and flares. A phenomenon that needs explanation is the corona heating to a temperature upto 10⁶ K. Even as the region separating the chromospheres from the convection zone that is the photospheres maintains at a few thousand degrees.
1.4.3. **Industry:**

There are many applications in industry speaking of few, pumping liquid metals make use of electromagnetic force and there is no need for moving parts (Example in cooling systems of nuclear power stations). The shaping of molten metal and the control of its shape after solidification, the levitation and heating of a metal sample which prevents contact with a container can also be achieved.

1.4.4. **Fusion:**

The release of huge quantities of energy, like from the sun which fuses hydrogen and helium has remained a mystery and has evaded mankind. The huge temperatures required cannot be withstood by any material. However a method to solve this issue is by ensuring that hydrogen and any material container used should not come into contact, thereby controlling the ionized hydrogen in a magnetic container and the subsequent contamination. Though there is progress, the containment times and temperature do not attain break even and the energy given out from fusion equals the energy put into the system.

1.5. **Porous Medium:**

A porous medium can be defined as a substance with a solid matrix and an interconnected vacuum. The recovery of crude oil from the pores of reservoir rocks has lead in recent times to the examination of fluid flow through porous media and has become a major area of research. Also the flow through porous medium is of interest in Chemical Engineering (absorption, filtration), Petroleum Engineering, Hydrology, Soil Physics, Bio-Physics and Geo-Physics. The role of Non-Newtonian fluids in industries and modern technology the thermal instability, thermal solution instability and Rayleigh-Taylor instability, problems of Walters (model B) fluid and stress fluid is growing. The definition of porosity of the porous medium can be given as the ratio of pore volume to the total volume of a given sample of material. A complete gradation exists from large forces to easily accessible fluids of very small openings in minerals that are caused by minor lattice imperfection. Moisture equivalent, effective porosity, specific retention, drainage coefficient of storage such as degree of saturation, forces applied to the sample, length of test, degree of
interconnection of pores and fluid chemistry. Permeability of the porous medium is a measure of ease with which fluids pass through a porous material. The intrinsic permeability is an important property of the solid material and it is not dependent upon the density or viscosity of the fluid.

The permeability $K$ can be defined as

$$K = \frac{-Q \mu}{A \rho g \left( \frac{\partial h}{\partial S} \right)^{-1}} \quad (1.1)$$

where $Q$ is the total discharge of the fluid, $A$ refers to the cross-sectional area, $\mu$ refers to the viscosity, $\rho$ denotes the density, $g$ denotes the acceleration due to gravity and $\frac{\partial h}{\partial S}$ indicates the hydraulic gradient in the direction of the flow. The dimension of the permeability is $L^2$. The unit of permeability is named as Darcy who is extensively used in petroleum industry. The value of one Darcy is $0.987 \times 10^{-8} \, Cm^2$. Permeability is very high with air and other non-polar fluids.

![Figure 1.2. Thermal radiation](image)

1.6. **Thermal Radiation:**

The third mode of heat transmission due to electromagnetic wave propagation, which can occur in a total vacuum as well as in a medium. Thermal radiation is an important factor in the thermo dynamic analysis of many high temperature systems like solar connectors, boilers and furnaces. The simultaneous effects of heat and mass transfer in the presence of thermal radiation play an important role in manufacturing industries. For the design of fins, steel rolling, nuclear power plants, cooling of towers, gas turbines and various propulsion devices for aircraft, combustion and furnace design, materials processing, energy utilization, temperature measurements,
remote sensing for astronomy and space exploration, food processing and cryogenic engineering, as well as numerous agricultural, health and military applications. Experimental evidence indicates that radiant heat transfer is proportional to the fourth power of the absolute temperature, where as conduction and convection are proportional to a linear temperature difference. The fundamental Stefan-Boltzmann law is

\[ q = \sigma AT^4 \]  

(1.2)

When thermal radiation comes in contact with a body, it can be absorbed (Absorptivity- \( \alpha \)), reflected (reflectivity- \( \rho \)) or transmitted (Transmissivity- \( \tau^* \)) through it. The totality of all the three fractions must be unity, i.e. \( \alpha + \rho + \tau^* = 1 \).

1.7.  Free or Natural convection:

Free or Natural convection is a mechanism, or type of heat transport, in which the fluid motion is not generated by any external source (like a pump, fan, suction device, etc.) but only by density differences in the fluid occurring due to temperature gradients. In natural convection, fluid surrounding a heat source receives heat, becomes less dense and rises. The surrounding, cooler fluid then moves to replace it. This cooler fluid is then heated and the process continues, forming convection current; this process transfers heat energy from the bottom of the convection cell to top. The driving force for natural convection is buoyancy, a result of differences in fluid density. Because of this, the presence of a proper acceleration such as arises from resistance to gravity, or an equivalent force (arising from acceleration, centrifugal force or Coriolis effect), is essential for natural convection. For example, natural convection essentially does not operate in free fall (inertial) environments, such as that of the orbiting International Space Station, where other heat transfer mechanisms are required to prevent electronic components from overheating. Natural convection has attracted a great deal of attention from researchers because of its presence both in nature and engineering applications. In nature, convection cells formed from air raising above sunlight-warmed land or water are a major feature of all weather systems. Convection is also seen in the rising plume of hot air from fire, oceanic currents, and sea-wind formation (where upward convection is also modified.
by Coriolis forces). In engineering applications, convection is commonly visualized in the formation of microstructures during the cooling of molten metals, and fluid flows around shrouded heat-dissipation fins, and solar ponds. A very common industrial application of natural convection is free air cooling without the aid of fans: this can happen on small scales (computer chips) to large scale process equipment.

1.8. **Hall Effect:**

Upon pursuing doctorate degree at Johns Hopkins Campus, Maryland in 1879, E. Herbert discovered the Hall Effect. 18 years prior to the discovery of the electron, Hall accomplished measuring the minute effect in the equipment that he was using as an investigational tour-de-force. The effect of Hall currents cannot be neglected when the applied magnetic fields strength is very strong. The conduction parallel to the electric field is lessened so that the current is directed normally to the electric and magnetic fields because of gyration and drift of charged particles. This is what is called as the Hall Effect. It is the generation of an electric potential difference across the conducting unit and a magnetic field vertical to the current. It occurs based on the result of current nature in the conducting unit. Current includes the motion of several tiny charge carriers like electrons, holes, ions or the combination of all these. A moving charge experiences Lorentz force when the magnetic field is vertical to its movement. In the absence of this magnetic effect, the charge moves forward following the 'Line of Sight' (LoS) routes within collisions with impurities, quasi-particle and so on. A moving charge accumulates over a material surface when a vertical magnetic field is fed and routes within collisions are curved. Whenever there is a scarcity of mobile charges, these moving charges which have accumulated over the material surface generates equivalent and opposite charges over the other surface. A non-identical circulation of charge density will result transversely at the Hall component which is vertical to the LoS route and the applied magnetic effect. The migration of further charges is obstructed by an electric field that has risen out of the separation of charge. Thus, whenever there is charge flow, a steady electrical potential builds up. What is of significance is that only the electrons are directed in the similar way during the conductivity of electron or hole. This Hall Effect’s opposite sign cannot be explained. The variance existing with the non-fixed upper bounded
electrons of the valence band having opposite group speed and wave vector path could be efficiently dealt when the holes are directed oppositely unlike the electrons. For any metallic element with just one charge carrier type (electrons), the voltage difference (Hall voltage), \( V_H \) is defined as,

\[
V_H = -\frac{IB}{ned}
\]  

The value of conductor’s building up element is dependent on the type, number and charge carrier attributes that make up the current. This is its main characteristic. The Hall coefficient \( (R_H) \) is defined as,

\[
R_H = -\frac{E_y}{J_x B}
\]

where \( E_y \) is the induced electric field, \( J_x \) refers to the current density and B denotes the applied magnetic field.

In SI units, this becomes

\[
R_H = -\frac{E_y}{J_x B} = \frac{dV_H}{IB} = -\frac{1}{ne}
\]

Hence, the Hall Effect becomes beneficial in measuring both the carrier density and the magnetic field. One of the significant properties is that it distinguishes between the positively charged particles directing in one path and the negatively charged ones in the opposite. Hall Effect is the first to confirm that the moving electrons carry the current in metallic components, and not the protons. It also substantiated that in certain things (particularly p-type semi-conductors), it is likely to consider the current as positively charged holes that move than to consider the electrons. Sometimes confusion arises that it is the hole moves left but actually the electrons to the right. This is a major source of confusion in expecting the same sign of the Hall coefficient for both positive and negative charge carriers. It is understood by present quantum mechanical concept of transport in solids. The homogeneity model often results in misled Hall Effect’s polarity, even in optimal vander-Pauw electrode model. For instance, positive Hall Effect was clearly detected in \( n \)-type semiconductors. It is a conduction scenario that varies according to charge carriers.
Generally typical current is employed partially in common electrical applications since there occurs no change when either holes or electrons are considered to be moving. However the sign of Hall voltage differs for holes and electrons and it is being applied in the field of conductivity in semiconductors and other substances involving both holes and electrons. It is employed to determine the average drift speed of holes and electrons by mechanical movement of the Hall probe by changing velocities till when the Hall voltage gets disappear, indicating that the charge carriers are presently not moving based on magnetic effect. Further studies of carrier behaviours are described in the quantum Hall Effect. The impact of hall currents on the varying concentrated fluid is applied in MHD power generators and astrophysical and meteorological analyses.

![Figure 1.3. Hall Effect](image)

In view of applications, the Hall Effect may be considered within the range of MHD approximation. Magnetometers that use the principles of magnetic flux leakage to determine magnetic field or examine substances like tubes or pipes can be replaced by Hall probes. Instruments with very low signal level requiring amplification like Hall Effect devices might suit for laboratory equipment. However vacuum tube amplifiers that were in role at the beginning of the 20th century were not reliable for everyday applications on account of being very expensive and consuming too much power. The mass application of the Hall Effect became viable when the low
cost integrated circuit came into existence. Most devices now sold in the market that passes off for Hall Effect sensors are in fact a single package that contains a sensor and a high gain IC amplifier. Further advancement to the single package is the addition of an ADC and inter-IC communication system which enables direct connection to micro controllers input/output port.