CHAPTER 1

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1.1. GENERAL

The movement of gravitational water through soils is called percolation or seepage. The property of soil which permits such percolation is called permeability. The problem of percolation through porous material is of great importance in different branches of science and engineering.

The flow of water was first observed in streams, canals and ditches and later in pipes. The laws governing movement of fluids through capillary tubes which predominate in alluvial and sedimentary formations were first studied experimentally by Hagen 1839 and Poisuille 1840 Tolman (112). Their observation was that, the rate of flow in capillary tubes varies directly as the hydraulic gradient and this has been called Hagen-Poiseuille law. Hagen also observed the effect of temperature on the viscosity of water.

The law of percolation of water through sand was first deduced experimentally by Darcy (26). His well known formula was published in 1856. Darcy’s law governs the relation between velocity of percolation, permeability of water-bearing materials and water table slope of free water or hydraulic gradient of confined water. It is used mainly in calculating yield of water moving under a known hydraulic gradient.

After the publication of Darcy’s law a great deal of experimental work has been reported in this field, by many
research workers. So far as the validity of Darcy's law at very low and very high gradients is concerned, it has been questioned by many investigators. Some of them have tried to give theoretical justification of Darcy's empirical equation and others an experimental verification of this law. Some realising that in certain situation the flow deviates from Darcy's linear law, have studied the problem within and beyond this limit.

Though a great deal of publication has been reported in different branches of science and engineering but the problem still remains unanswered to a great extent. The experimental results by many research workers have been reported in various journals as in the fields of Geology, Geophysics, Chemistry, Civil Engineering, Petroleum Production, Hydraulics, Hydrodynamics, Physics, Soil Mechanics, Mechanical Engineering, Chemical Engineering, Sanitary Engineering, Nuclear Science, Agriculture Science and Food Technology etc. The application of seepage study can be discussed in detail in each field mentioned above, but a brief mention of only the important fields of its application will be given here in the following headings.

1.2. APPLICATIONS OF SEEPAGE STUDIES IN SCIENCE AND ENGINEERING

The important fields of the application of seepage studies are given below:

(i) Geology
(ii) Civil Engineering
(iii) Agriculture Science
(iv) Chemical Engineering
(v) Earth Science
(vi) Mining Engineering
(vii) Mechanical Engineering and
(viii) Other fields

(1) GEOLOGY

Of all the sciences geology is of greatest importance where the study of subsurface water and the laws of percolation find their applications. This is because the great water bodies are accumulated in the geological formations, known as ground water reservoirs. The water holding capacity of a rock is controlled by its porosity, and the freedom of water to flow in any formation depends mainly upon the size, shape and arrangements of the interstices in the formation.

The interstices of the porous material as a whole are considered a conduit, through which the seepage of water (or other fluids) takes place. These interconnected pore spaces in any geological formations are of great importance in the study of ground water percolation.

Under a given hydraulic gradient the velocity of percolation varies directly as the square of the size of the pore spaces of water bearing formations. There are two main kinds of flow of water through interstices of water bearing geological formations known as laminar and turbulent flow.

A rapid movement of water occurs generally in coarse sorted materials such as coarse sand, gravel, uncedanted sandstone, open fractures, solution channels and possibly in

※ Under geology specific issues are dealt with, whereas earth science covers the general ones.
by canals, rivers and streams for irrigation and drainage purposes. Drainage is required for many engineering purposes i.e. for lowering of ground water to facilitate subsurface excavation and construction works, for increasing the stability of soil against seepage etc. The protective filters of fine and coarse particles are used for filtration. The study of seepage water through the soil also holds good for the following engineering problems.

(a) The rate of settlement of saturated compressible soil layer can be determined.

(b) Determination of seepage of water through the body of earth dams and stability of slopes.

(c) Determination of uplift pressure and pressure distribution under hydraulic structure and their safety against piping.

(d) Ground water flow towards wells and drainage of soils can be determined.

The recharge and discharge of ground water reservoir is of great practical significance from civil engineering point of view. A list of important factors that may be measured and used in the inventory of ground water reservoir is therefore given below:

1. **FACTORS RESPONSIBLE FOR GROUND-WATER INCREMENT**

   (a) Penetration of rainfall water to the water table.

   (b) Natural seepage of water from streams, rivers, canals, lakes and ponds etc.

   (c) The rise of ground water by artificial seepage from
irrigation, reservoirs, spreading operations and feeding water down wells.

(d) The flow of free or confined ground water from outside the area under investigation.

(2) **FACTORS RESPONSIBLE FOR GROUND-WATER DECREMENT**

(a) Effluent seepage, spring flow of free ground water, discharge by surface flow, artificial removal by drainage works, evaporation and transpiration.

(b) The loss of ground water reservoir by effluent seepage and spring discharge of confined water along faults or slow leakage from the lower portions of aquifers holding confined water.

(c) Determination of artificial discharge by pumping.

(d) Subsurface discharge of free water from underneath the area investigated.

Only some of the above mentioned factors may be important in any one area and occasionally can be determined in several different ways.

The flow system under conditions discussed above may be linear or non-linear depending upon the shape, size and arrangement of the materials constituting the formations and the head causing flow. The laws governing the linear flow regime are well defined, but in the non-linear regime the laws governing the flow are not yet well defined and one has to depend upon empirical results.

(iii) **AGRICULTURE**

The seepage study is of great significance and finds its
applications in the solution and analysis of many agricultural problems. The soil moisture is a natural reservoir abundantly supplied by surface water and consumed by plants continuously. Through the controlled seepage the soil moisture in the rootzone should be maintained at the lowest feasible level, by frequent rains or by a practical system of irrigation in order to support a vigorous growth of crops.

The salinity and alkali are the two important and effective factors in agriculture which control the growth of plants. These in turn are controlled by the quantity of seepage water, irrigation practices and drainage conditions. A knowledge of source and direction of flow of ground water is especially required to solve these problems. The salt balance in the soil as generally affected by the quantity and quality of irrigation water and the effectiveness of seepage and drainage is of paramount importance to control the salinity in the soil to retain successful growth of plants.

RELATIVE IMPORTANCE OF IRRIGATION AND SEEPAGE TO SALINITY CONTROL

The application of agriculture water to soil, is for the purpose of providing a favourable environment for the growth of plants. Seepage of water through agricultural soils is a process by which the soluble salts are dissolved and transported by the downward movement of water through the soil. The seepage process can be used for controlling the salt contents of soil. This can be achieved by maintaining an appreciable depth of water on the soil surface by means of dikes or ridges and then establishing downward movement through the soil. Therefore it
is most effective procedure that can be used for removing excess soluble salts from the soil.

(iv) **CHEMICAL ENGINEERING**

The study of percolation through porous media is of great importance from chemical engineering point of view. The removal of substances in the form of solution, form insoluble, permeable solid is known as leaching or percolation. For example, if the soluble constituent is in the solid form as the metal leached from ores and in the liquid form the oil leached from soyabeans and other oil seeds. On the basis of its number of applications and its importance to many ancient industries percolation is known by a number of other names e.g. solid/liquid extraction, liquid/liquid extraction, lixiviation, leaching, diffusion, washing and decantation - settling, etc. The process of percolation may involve simple physical solution or dissolution and the rate of percolation may be affected by the rate of chemical reaction. All such simple processes depend chiefly upon empirical methods.

A very useful application is in removal of atmospheric air pollution e.g. the ventilation is used in the rooms, air pollution of the gallaries of coal mines controlled by ventilation shaft and the reduction of industrial toxic fumes from chemical or from other operations. The very fine particles are separated from liquid or gases in many industries e.g. spray-drying of milk, soap and manufacture of carbon black etc. In all these conditions the laws of slow viscous flow may be applied, because of the very fine particles involved.
The separation of one or more components by simple solution is known as liquid/solid extraction. Now a days the largest use of this process is in extractive metallurgical, vegetable oil and in sugar industries and simply the preparation of tea or coffee in a percolator or a drip pot. The separation of the components of a homogeneous mixture on the basis of differing solubility in another liquid phase is known as liquid/liquid extraction. It’s largest use is in the petroleum industry for the separation of aromatic from aliphatic compound for lubricating oil manufacture. In coal tar acid industries, the recovery of tar acid from crudetar oil by washing with an aqueous solution of alkali, is another example of liquid/liquid extraction. In the farmaceutical industries for recovery of antibiotic from fermentation process pencilline is obtained by extraction. Other examples in this field are the recovery and separation of vitamins and the production of alkaloids from natural products. In washing extraction the solid is crushed to break the cellwalls permitting the valuable soluble product to be washed from the matrix. Sugar recovery from cane is a unique example of this process. Some leach tanks operate under pressure to contain volatile solution or increase the rate of percolation.

Percolation study finds a wide application in the flow of gases and liquids through porous materials such as sand and rock formation to their connected openings. The flow of gases, lava and ashes from the volcanoes of hills and mountains is an excellent case in this point. In all these conditions the
flow nature can be presumed on the basis of empirical equations.

(v) EARTH SCIENCE

The percolation laws also hold good in the study and analysis of various problems related to earth. In geology, movement of turbid water known as turbidity currents, is a process in which the sediment dispersion or suspension is generally governed by the laws of sedimentation and fluid turbulence. The concept of turbidity currents as agents for transportation and deposition for sandy (or coarse) sediments was introduced and developed mainly by P.H. Kuenen in 1950(41).

The suspension of sediment by turbidity currents in an under water flow produced by the movement of a turbid mass of water down slope due to gravitational attraction. The main role played by this current is generally considered the agent responsible for erosion and construction of various formations. The excellent examples are, the deposition of turbidites, flych (Turbidite-shales), the erosion of submarine canyons, the building of mid ocean canyons and the smoothing of abyssal planes etc.

The transportation of sediments by winds, follows essentially the same law as does transportation by water. Another important application of seepage study is that, it is considered as the principal cause of land sliding. A considerable quantity of water is percolated through the pores or cracks in the formations supplied by the different agencies, such as rainfall or surface flow, increases the weight of the mass and
develops sufficient slipperiness so that equilibrium conditions are overbalanced and then land sliding takes place due to gravitational attraction.

Dune formation, ripple and quick sand conditions in different water bodies are other best examples related to percolation studies. The field of meteorology is of great importance where laws of percolation find their application. A simple example in this regard is the formation and motion of rain drops. On the basis of above discussion one can say that an idea about laws of seepage is very important in all the above mentioned fields and also helpful in the study of many problems related to the earth.

(vi) MINING ENGINEERING

The laws of percolation are also very much useful in the study of problems related to mining. In this context leaching process is divided in two ways.

(a) In the first place leaching is carried out through percolation (seeping of solvents through a bed of solids).

(b) In the second place particulate solids are dispersed into the extracting liquids and ultimately subjected to separation from it.

In addition to its application to ores, obtained through mines from different rock formations (and crushed in prescribed sizes), by the simple technique of heap leaching percolation is carried out in batch tanks and in several designs of continuous extractors for the settlement and separation of different
particles from ores.

Percolation of water also poses great damages to mines, such as damage to tunnel buildings and lives as happened in Chas Nala in Bihar in which thousands of people lost their lives.

(vii) MECHANICAL ENGINEERING

The study of percolation also plays an important role in the study of several practical problems concerning mechanical engineering. The flow of oil in the bearings for lubrication is laminar and thus governed by the law of percolation. The theory of laminar flow shows that under great normal pressure the oil in the bearing has only slight frictional resistance.

The flow on the surface of modern aircraft and missiles flying at extremely high altitude may also be laminar. The Reynolds number for this case is usually moderate, and viscous effect is confined to the boundary layers region of the body. The laminar boundary layer flow determines the skin friction and the aerodynamics of these bodies.

(viii) OTHER FIELDS

The relevance of percolation law cannot be ignored or minimised in the study of organism which is considered to be a minor agent of transportation, e.g. blood circulation which contains various cells in suspension, shows close resemblance to the flow of liquid with various solids in suspension in it.

The law of percolation is also functional in food technology especially during the dehydration process in which
the rate of flow of air through a tower packed with some kinds of food stuff is affected by this law.

Apart from this, the laws of percolation can also be put into use in various other studies such as physical properties of solids and liquids. For example the viscosity determination of a fluid is based on liquid – solid extraction dynamics.

At last it can be summed up that the phenomenon known as seepage is of great significance and any deficiency in its knowledge may make many designs and operations uneconomical and even impossible. A thorough knowledge of the laws of percolation is therefore indispensable, the lack of which may cause great loss to human lives and property.

1.3. TYPES OF FLOW THROUGH POROUS MEDIA

The flow through porous media may be categorised into the following parts:

1. Linear or Laminar flow regime.
2. Non-linear or turbulent flow regime.

1. LINEAR FLOW REGIME

The laminar flow regime is also called streamline flow or Darcy flow regime. In laminar flow the particles move along smooth path in layer without large irregular fluctuations and one layer slides over the adjacent layer. In this flow the viscous forces are sufficiently large as compared to the inertial forces. The flow is satisfied by the Navier-Stokes equation of motion and governed by the Newton’s law of viscosity.
It may be considered as flow in which all turbulence and other effects have been damped out by the action of viscosity. The flow occurs at low value of Reynolds number. If we draw a plot between dimensionless quantities i.e. Reynolds number, ‘Re’ and friction factor ‘f’ as adopted for flow through straight pipes, it will show a straight line relationship. The limits of validity of linear flow regime have been reported variously by various investigators. A detailed discussion related to its validity will be given in the next chapter.

2. NON-LINEAR FLOW REGIME

It can further be subdivided into two regions.

Region 1: In this region the presence of inertial forces make Darcy’s law insignificant and if the graph is drawn between ‘Re’ and ‘f’ it will show great deviation from the linear law. The viscous forces are also important in this flow.

Region 2: The flow is considered to be completely turbulent, when the viscous force is of insignificant magnitude in comparison to inertial forces. The turbulent flow occurs when the Reynolds numbers are high and is characterised by rapid movement and continuous fluctuations in the velocity components, which cause transfer of momentum and consequently give rise to additional shear and normal stress of large magnitudes Garde (39).

In contrast to the flow through straight pipes, the transition from laminar to turbulent flow is gradual in porous media flow.
1.4. ANALOGIES TO POROUS MEDIA FLOW PROBLEMS

The analogical solution of flow problem through porous media has been divided into two categories viz:

(1) some have regarded it as an internal problem, in which the flow through pores between the particles has been assumed to be similar to the flow through continuous pipe system.

When using internal analogy, one should keep in mind that all the pipe system intercommunicate, combining to form a single overall system, with special transverse agitation of the flowing fluid, which is not identical with simple turbulent mixing. Further, the points of contacts of various particles are the sources of turbulence. The shape of systems will depend upon the type of packing of the particles.

(2) others have treated it as an external problem i.e. one of flow around the particles. The treatment of fluid permeation as an external problem, would at first glance appears to be more easily justified, since it is not unusual to have unstabilized flows in external situations. However, when one has to deal with other than individual widely separated particles, the following factors add to the complexities of the problem.

(i) Stream expansion and contraction.

(ii) Promotion of turbulence by adjacent particles; and finally

(iii) By the different resistance coefficient of the particles which in any case depend not only on the local porosities in the bed, (i.e. non-uniform
porosity) but also on the arrangement of the particles as well.

Some authors (18,19) are of the view that the main contribution to the resistance is due to periodic contraction and expansion of fluid jets passing through the packed beds.

Analogical approaches are helpful only in the study of qualitative analysis of the phenomenon. For analytical design equations, all approaches involve many simplifying assumptions, which, in turn reduce the practical significance of the resulting formulae. Thus to solve a practical problem, one has to depend upon empirical or semi-empirical equations.

1.5. OBJECTS OF THE PRESENT INVESTIGATION

The main objectives of the present investigation are given below:

1. A review of various analogical approaches used by the research workers for solving the problem of percolation through porous materials.

2. A critical study of flow through pipes and its comparison with porous media flow. Extension of the laws governing flow through pipes to flow through the pore channels in a porous media.

3. An investigation into the causes of early departure from linear law in porous media flow as compared to flow through straight capillary tubes.

4. An experimental study of the effect of curvature of flow paths on critical Reynolds number, (Reynolds number at which the flow no more remains linear).

5. An experimental investigation into the effect of change in the direction of flow along a curved path on critical Reynolds number.