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EXAMINATION OF FLUID MECHANICS FLOWS THROUGH POROUS MEDIUM

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ABSTRACT

Fluid mechanics can be divided into fluid statics, the study of fluids at rest; fluid kinematics, the study of fluids in motion; and fluid dynamics, the study of the effect of forces on fluid motion. Fluid mechanics concerns itself with the investigation of motion and equilibrium of fluids. We normally recognize three states of matter: solid, liquid and gas. However, liquid and gas are both fluids, in contrast to solids they lack the ability to resist deformation. Because a fluid cannot resist the deformation force, it moves, it flows under the action of the force. Its shape will change continuously as long as the force is applied. A solid can resist a deformation force while at rest, this force may cause some displacement but the solid does not continue to move indefinitely.

Key words : Fluid mechanics, fluid dynamics

INTRODUCTION

Thus, a fluid is a substance that does not has characteristic shape or extensive physical property such as crystalline structure. Also, a fluid is a substance changed by an amount, which is not so small as compared to suitable chosen forces, however small in magnitude. From a morning coffee to an evening bath, fluids are all around us. Water is a fluid and so is air. In space and inside stars there is also another kind of fluid called plasma.

Newtonian Fluids : According to their response to an applied shear rate or shear stress, fluids are again of two types "Newtonian" and "non-Newtonian" (2008) . A Newtonian fluid (named after Isaac Newton) is a fluid in which shear stress is proportional to the velocity gradient, perpendicular to the plane of shear. The constant of proportionality is known as the viscosity. A simple equation to describe Newtonian fluid behavior is

$$\tau=\mu\frac{d\mathbf{q}}{dy}, \quad (1.1)$$

where τ is the shear stress exerted by the fluid, μ is the fluid viscosity and $\frac{d\mathbf{q}}{dy}$ is the velocity gradient perpendicular to the direction of shear, or equivalently the strain rate

Non-Newtonian Fluids: Any fluid that does not obey the Newtonian relationship between the shear stress and shear rate is called non-Newtonian. High molecular weight liquids which include molten polymers and solutions of polymers, as well as liquids in which fine particles are suspended (slurries and pastes), are usually non-Newtonian. Liquid metals also exhibit non-Newtonian flow characteristics. The atomic mass and density of liquid metals is quite large compared with fluids that have simple Newtonian viscosity behavior. Common examples include mayonnaise, peanut butter, toothpaste, egg whites, liquid soaps and multi-grade engine oils.

In non-Newtonian fluids, the slope of the shear stress versus shear rate curve will not be constant as we change the shear rate. Thus, a non-Newtonian fluid is a fluid in which the viscosity changes with the applied shear force i.e. the effective viscosity does depend on that relative velocity. As a result, non-Newtonian fluids may not have a well-defined viscosity.

Time Independent Fluids: In simple unidirectional shear, the flow behavior of this class of materials may be described by a constitutive relation of the form

$$T_{ij}=f\left(e_{ij}\right), \quad (1.3)$$

or, its inverse form

$$e_{ij}=f^{-1}\left(T_{ij}\right), \quad (1.4)$$

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this equation implies that the value of the shear rate $\left(e_{ij}\right)$ at any point within the sheared fluid is determined only by the current value of shear stress $\left(T_{ij}\right)$ at that point or vice versa. Also, we can say that such fluids have no memory of their past history. These fluids may be further subdivided into three types

i. shear thinning or pseudoplastic
ii. shear thickening or dilatant
iii. viscoplastic behavior with or without shear thinning behavior

SHEAR THINNING FLUIDS : For such fluids the apparent viscosity decreases with increased shear rate. Shear thinning fluids without yield stresses typically obey a power law model

$$\tau=\mu\left(\frac{d\mathbf{q}}{dy}\right)^n \qquad (1.5)$$

over a range of shear rates.
Shear thinning power law fluids with yield stresses are sometimes called Herschel-Buckley fluids. Numerous other rheological
model equations for shear-thinning fluids are in common use. Many shear-thinning fluids exhibit Newtonian behavior at extreme shear rates, both low and high i.e. shear stress-shear rate plots becomes straight line. Some examples of this fluid include colloids, clay, milk, gelatin, blood, liquid cement, paper pulp in water, latex paint, ice, syrup, molasses, shampoo, ketchup, fruit juice concentrates and styling gel.

Shear Thickening Fluids : For such fluids the apparent viscosity increases with increased shear rate. They too obey the power law except that n is always >1. Since these fluids vary exponentially, it is possible for them to be dilatant over one range of shear rates and pseudo plastic over a different range of shear rates. They are rarely encountered, but some common examples include concentrated solution of sugar in water, suspensions of rice starch or corn starch and clay slurries.

Viscoplastic Fluids: The behavior of viscoplastic fluids is characterized by the existence of a threshold stress (called yield stress or apparent yield stress), which must be exceeded for the fluid to deform (shear) or flow. This is a fluid that will not flow when only a small shear stress is applied. Conversely, such a substance will behave like an elastic solid (or flow like a rigid body) when the externally applied stress is less than the yield stress. Of course, once the magnitude of the external yield stress exceeds the value of yield stress, the fluid may exhibit Newtonian behavior or shear-thinning characteristics

Concept of Porous Medium: A porous medium is a material containing pores (voids). The skeletal portion of the material is often called the "matrix" or "frame" which is usually a solid, but structures like foams are often usefully analyzed using the concept of porous media. It is however much more difficult to give an exact geometrical definition of what is meant by the notion of a pore. Intuitively pores are void spaces, imbedded in a material, may be either connected or isolated (non-connected), distributed more or less frequently in either a regular or random manner in a material. These pores may be effective or ineffective. Effective pore mean the pores through which the fluid can actually pass. These pores contribute towards the porosity of the material. By ineffective pores we mean the pores through which the fluid can't pass. This may be either due to surface-tension caused by fine holes or the pores may not be interconnected, so that they do not affect the flow directly but may affect the compressibility of a medium.

Permeability: Permeability measures quantitatively the ability of a porous medium to conduct fluid flow, typically measured in decries or milidarcies. It is a number used to indicate the relative ability of a substance to allow a fluid to permeate its surface. This permeability constant was first demonstrated by Darcy (1856). An empirical observation of Darcy known as Darcy's law introduces permeability in terms of measurable quantities. The origin of this permeability constant is well discussed by Muskat (1937).

Darcy's Law And Its Generalization: The one-dimensional flow of an incompressible fluid through a non-consolidated, uniform, rigid and isotropic solid matrix was first measured by Darcy (1856), which relates the movement of fluid to the pressure gradients acting on a parcel of fluid. Darcy's law is a phenomenological law generated by experimental data. While experimenting with flow of water through sand filter, Darcy concluded that the rate of percolation of water through that filter bed is directly proportional to the cross sectional area of the filter bed and total force impressed on it and inversely proportional to the thickness of the bed i.e. Darcy's law shows that the volumetric flow rate is a function of the flow area, elevation, fluid pressure and proportionality constant. It may be stated in several different forms depending on the flow conditions. Darcy's law is a foundation stone for several fields of study including ground-water hydrology, soil physics and petroleum engineering. Also, it can help answer important questions such as what direction an aquifer pollution plume is moving in, and how fast it is travelling.

Limitations and Validity of Darcy's Law: Darcy's law was established in certain circumstances: laminar flow in saturated granular media, under steady-state flow conditions, considering the homogenous, isotherm and incompressible fluid and neglecting the kinetic energy.
It is difficult to predict the exact range of the validity of Darcy's law. The best method to ascertain the range is to conduct experiments and determine the actual relationship between the velocity and the hydraulic gradient. The linear Darcy's law holds for flows at low Reynolds number in which the driving forces are small and balanced only by viscous forces i.e. at low Reynold's numbers, viscous forces dominate, and Darcy's law is valid. Reynolds number increases with increase in characteristics length, which represents the geometry of the passage of fluid and the deviation from Darcy's law increases with decrease in characteristics length with polynomial equation of second order i.e. for high Reynolds number, the situation when inertia forces rather than the viscous forces become high, Darcy's law loses its applicability. The linear Darcy's law breaks down also if the flow becomes too slow. In this case, interactions between the fluid and the pore walls become important. Examples occur during the slow movement of polar liquids or electrolytes in finitely porous materials with high specific internal surface.

Stability Theory: The concept of stability of a state of a physical or mathematical system was understood in the eighteenth century and Clerk Maxwell [Campbell & Garnett, (1882) expressed the qualitative concept clearly in the nineteenth century:
"When…an infinitely small variations of the present state will alter by an infinitely small quantity in the state at some future time, the condition of the system, whether at rest or in motion, is said to be stable; but when an infinitely small variation in the present state may bring about a finite difference in the state of the system in a finite time, the condition of the system is said to be unstable."

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