52.1: Introduction to Fluid Dynamics

Fluid dynamics, also termed fluid mechanics, is a very important and broad study of fluids in motion, impacting most engineering disciplines, weather and climate modeling, city and home water distribution systems, etc. Here we will focus on internal flows in piping, tubing, hoses, and fittings transporting a single gas or liquid phase, thereby excluding multi-phase flows such as gas-liquid, gas-solid, and liquid-solid mixtures. Also outside the scope of this material is high-speed gas flow (sonic and supersonic), hydraulic hammer (liquids), and open channel flow (culverts).

Fluid dynamics is a complex subject; in fact it's probably the most complex of the physical sciences. Even fairly simple physical systems can have very complicated solutions, and some subjects, such as fluid turbulence, are a long way from being well understood. The study of fluid flow is of great importance in fields like chemical engineering and meteorology.

The flow of fluids can be characterized by a number of properties:

- Steadiness. Fluid flow may be steady (laminar) or full of irregular eddies (turbulent).
- Compressibility. Fluids generally change density with changing pressure; such fluids are called compressible. A fluid that does not change density with changing pressure is called incompressible; this is sometimes used as an approximation for real fluids.
- Viscosity. Real fluids exhibit a kind of internal friction called viscosity that measures how "thick" the liquid is. Honey and molasses, for example, are fluids with a high viscosity, while water and gasoline have relatively low viscosity. Viscosity is discussed in detail in section 49.5 .
- Rotation. A fluid is rotational if it exhibits angular momentum about some point (so that a small paddle inserted at that point would begin to rotate). A fluid with no such points is called irrotational.

In many cases the fluid can be treated as though it had no viscosity, resulting in frictionless flow. Such a fluid is called an ideal fluid. The flow of an ideal fluid can be incompressible or compressible; it is neither laminar nor turbulent.

Flow in piping may be laminar, transitional, or turbulent. Laminar flow is characterized by a parabolic velocity profile having a centerline velocity equal to two times the average (Figure $52.1.1$). Flow is very orderly and there is no radial or tangential movement. Behavior is predictable with little uncertainly as long as the fluid viscosity is Newtonian: i.e., constant, and independent of sheer rate. Most low-viscosity fluids, such as air, water, alcohol, and gasoline are Newtonian. Laminar flow is usually associated with low velocities, small equipment and/or viscous liquids.

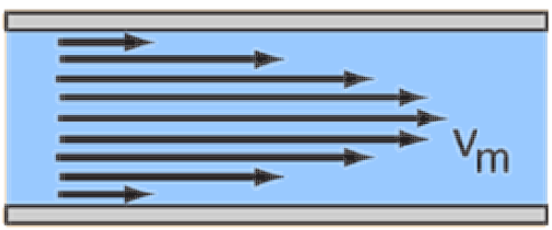

Figure $52.1.1$: Laminar fluid flow through a pipe. The maximum flow velocity v_m is at the centerline and is equal to twice the average flow velocity. (Figure from Georgia State University, http://hyperphysics.phyastr.gsu.edu/hbase/pfric2.html

Unlike laminar flow, turbulent flow is chaotic, and the technology relies on empirical correlations to predict physical behavior. Wall friction produces eddies, some as large as the pipe, which produce smaller eddies that ultimately dissipate as heat. British physicist Lewis Fry Richardson said it best:

> *Large whirls have little whirls*
>
> *That feed on their velocity;*
>
> *And little whirls have lesser whirls,*
>
> *And so on to viscosity.*

Also unlike laminar flow, turbulent flow depends on the surface roughness of the containing pipe.

It is also possible to have transitional flow which switches between laminar and turbulent flow in an irregular manner.