Department of Geology, B.Sc. Sem. V – (PMG/ZBG)

Paper I, Unit I

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Flow Dynamics

The transportation and deposition of sediments are governed by the laws of physics. This topic introduces some of the fundamental concepts of sedimentation as a means to understanding the fabric and structures of the deposits which they generate. **Sedimentation** is, literally, the settling out of solid matter in a liquid. In geology however, sedimentary processes are generally understood as those which both transport and deposit sediment. They include the work of water, wind, ice, and gravity.

Variables

Two of the most important physical properties of fluids are density and viscosity.

The **density** of a fluid, denoted by ρ, is the mass of fluid per unit volume of fluid. The density of water is very close to one gram per cubic centimeter (1 g/cm3) or one thousand kilograms per cubic meter (103 kg/m3). The density of air at sea level and room temperature is far smaller, by a factor of about 800.

The **viscosity** of a fluid, usually denoted by μ, is a measure of the resistance of the fluid to deformation.

One more fluid property, the **specific weight**, usually denoted by γ , is important when the fluid is in a gravitational field, as on the Earth's surface. The specific weight is the weight of the fluid per unit volume of fluid.

Reynolds number

The Reynolds number is the ratio of **inertial forces** to **viscous forces** and is a convenient parameter for predicting if a flow condition will be **laminar or turbulent**. It can be interpreted that when the **viscous forces** are dominant (slow flow, low Re) they are sufficient enough to keep all the fluid particles in line, then the flow is laminar. Even very low Re indicates viscous creeping motion, where inertia effects are negligible. When the **inertial forces dominate** over the viscous forces (when the fluid is flowing faster and Re is larger) then the flow is turbulent.

It is a dimensionless number comprised of the physical characteristics of the flow. An increasing Reynolds number indicates an increasing turbulence of flow.

It is defined as:

$$\mathrm{Re}_D = \frac{\rho V D}{\mu} = \frac{V D}{\nu}$$

where:

V is the flow velocity,

D is a **characteristic linear dimension**, (travelled length of the fluid; hydraulic diameter etc.)

ρ fluid density (kg/m^3),

μ dynamic viscosity (Pa.s),

ν kinematic viscosity (m^2/s); $\nu = \mu / \rho$.

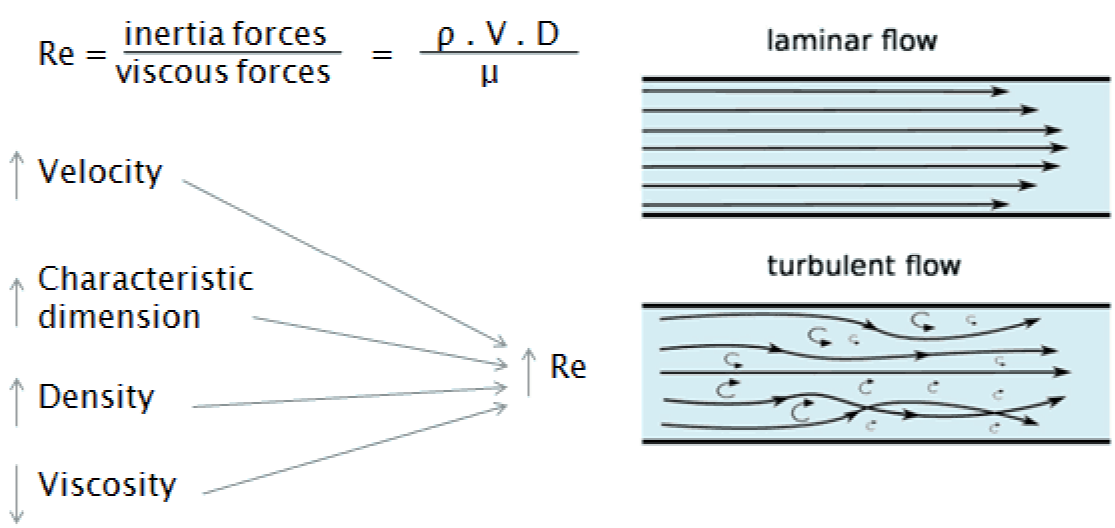

Figure 1Laminar vs. Turbulent Flow

Laminar flow:

- **Re < 2000**
- 'low' velocity
- Fluid particles move in **straight lines**
- Layers of water flow over one another at different speeds with **virtually no mixing** between layers.
- The flow velocity profile for laminar flow in circular pipes is parabolic in shape, with a maximum flow in the center of the pipe and a minimum flow at the pipe walls.
- The average flow velocity is approximately one half of the maximum velocity.
- Simple mathematical analysis is possible.
- **Rare in practice in water systems**.

Turbulent Flow:

- **Re > 4000**
- 'high' velocity
- The flow is characterized by the **irregular movement** of particles of the fluid.
- Average motion is in the direction of the flow
- The flow velocity profile for turbulent flow is fairly flat across the center section of a pipe and drops rapidly extremely close to the walls.
- The average flow velocity is approximately equal to the velocity at the center of the pipe.
- Mathematical analysis is very difficult.
- **Most common type of flow**.

Reynolds Number Regimes

Laminar flow. For practical purposes, if the Reynolds number is less than 2000, the flow is laminar. The accepted transition Reynolds number for flow in a circular pipe is $Re_{d,crit}$ = 2300.

Transitional flow. At Reynolds numbers between about 2000 and 4000 the flow is unstable as a result of the onset of turbulence. These flows are sometimes referred to as transitional flows.

Turbulent flow. If the Reynolds number is greater than 3500, the flow is turbulent. Most fluid systems in nuclear facilities operate with turbulent flow.

Froude number

The Froude number is a dimensionless number proportional to the square root of the ratio of the inertial forces over the weight of fluid. For a horizontal rectangular channel, the Froude number is defined as:

$$Fr = \frac{V}{\sqrt{gD}}$$

Where:

V = Water velocity

D = Hydraulic depth (cross sectional area of flow / top width)

g = Gravity

When:

Fr = 1, critical flow,

Fr > 1, supercritical flow (fast rapid flow),

Fr < 1, subcritical flow (slow / tranquil flow)

The Froude number is a measurement of bulk flow characteristics such as waves, sand bed forms, and flow/depth interactions at a cross section or between boulders.

The denominator represents the speed of a small wave on the water surface relative to the speed of the water, called wave celerity. At critical flow celerity equals flow velocity. Any disturbance to the surface will remain stationary. In subcritical flow the flow is controlled from a downstream point and information is transmitted upstream. This condition leads to backwater effects. Supercritical flow is controlled upstream and disturbances are transmitted downstream.

Consequences:

- **F_r < 1** results in **tranquil flow**. The velocity of **gravity waves** is greater than the flow velocity (i.e. waves can move upstream).
- **F_r > 1** results in **rapid flow**. The velocity of **gravity waves** is less than the flow velocity, so no waves propagate upstream.

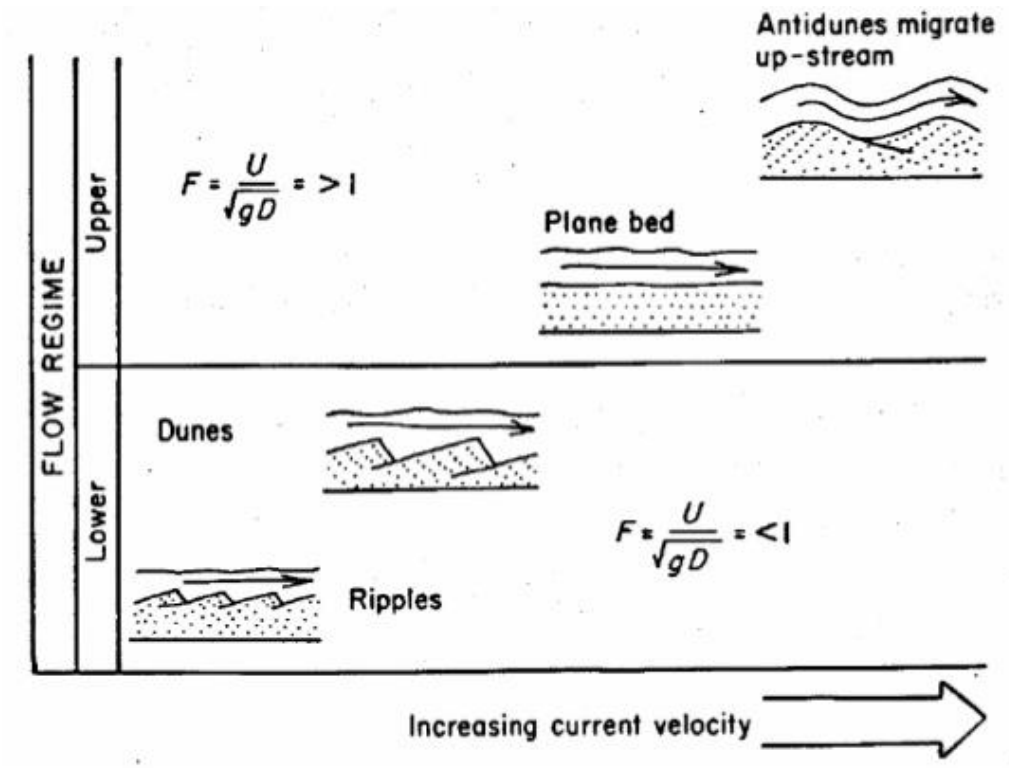

Figure 2 Bed forms and sedimentary structures for different flow regimes