3.3 DIMENSIONLESS NUMBERS

In fluid mechanics, Dimensionless numbers or non-dimensional numbers are those which are useful to determine the flow characteristics of a fluid. Inertia force always exists if there is any mass in motion. Dividing this inertia force with other forces like viscous force, gravity force, surface tension, elastic force, or pressure force, gives us the dimensionless numbers.

Dimensionless Numbers in Fluid Mechanics

Some important dimensionless numbers used in fluid mechanics and their importance is explained below.

1. Reynolds Number

2. Froude Number

3. Weber Number

4. Mach Number

5. Euler's Number

1. Reynolds number

Reynolds number is the ratio of inertia force to the viscous force. It describes the predominance of inertia forces to the viscous forces occurring in the flow systems.

$$R_e = \frac{\rho.v.d}{\mu}$$

Where,

ρ = Density of fluid (kg/m³)

μ = viscosity of fluid (kg/m.s)

d = diameter of pipe (m)

v = velocity of flow (m/s)

Importance

Reynolds number is applicable for closed surface flows as well as for free surface flows. Some applications where Reynolds number is significant for finding the flow behavior are incompressible flow through small pipes, the motion of a submarine completely under water, flow through low-speed turbomachines, etc.

2. Froude number

Froude number is the ratio of inertia force to the gravitational force. Froude number is significant in case of free surface flows where the gravitational force is predominant compared to other forces.

$$F_r = \frac{v}{\sqrt{g.L}}$$

Where,

L = length of flow (m)

v = velocity of flow (m/s)

g = acceleration due to gravity (m/s^2)

Importance

Froude number is useful to describe the flow in open channels, flow over notches and weirs, the motion of a ship in turbulent sea conditions (ship resistance), flow over spillways, etc.

3. Weber number

Weber number is the ratio of inertia force to the surface tension. The formation of droplets or water bubbles in a fluid is normally due to surface tension. If Weber number is small, surface tension is larger and vice versa.

$$W_e = \frac{\rho.d.v^2}{\sigma}$$

Applications

Weber number is less than 1 when surface tension is predominant. It happens when the curvature of the liquid surface is small compared to its depth. This can be seen in different situations such as the flow of blood in veins and arteries, atomization of liquids, capillary flow of water in soils, thin layers of fluid passing over surface, etc.

4. Mach number

Mach number is the ratio of inertia force to the elastic force. If the Mach number is one, then the flow velocity is equal to the velocity of sound in the fluid. If it is less than one, then the flow is called subsonic flow, and if it is greater than one the flow is called supersonic flow.

$$M_a = \frac{v}{c}$$

Where,

v = Velocity of flow (m/s)

c = Velocity of sound in fluid (m/s)

Applications

Mach number is useful to describe problems in high flow velocities. It is also used in aerodynamics to describe the speed of jet plane or missile in terms of speed of sound.

5. Euler's number

Euler number is the ratio of pressure force to the inertia force.

$$E_u = \frac{F}{\rho . v^2 . L^2}$$

Where,

F = pressure force

ρ = Density of fluid (kg/m³)

L = Characteristic length of flow (m)

v = velocity of flow (m/s)

Applications

Euler's number is significant in cases where pressure gradient exists such as flow through pipes, water hammer pressure in penstocks, discharge through orifices and mouthpieces, etc.