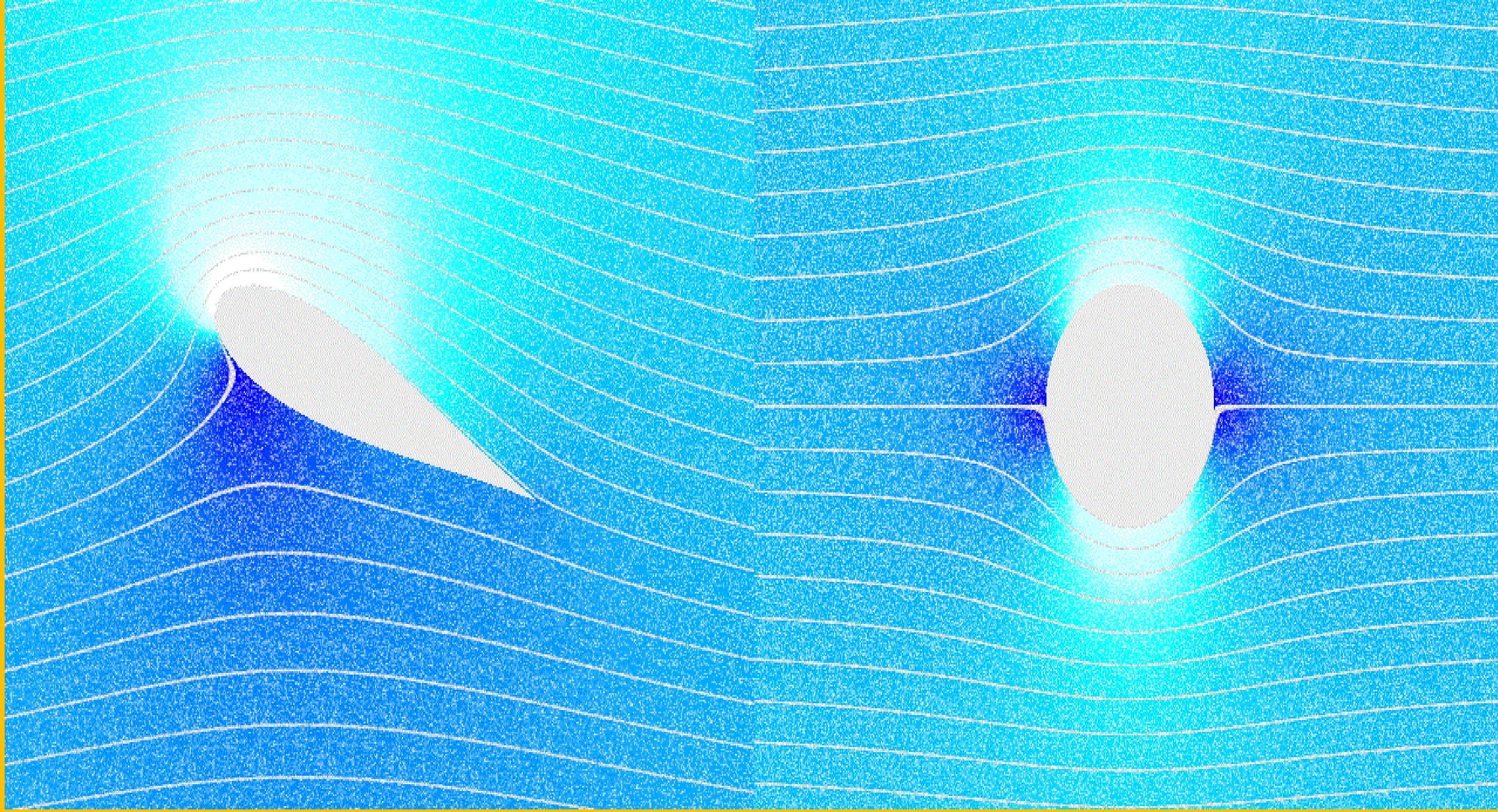


FLOW OF FLUIDS

FLOW OF FLUIDS

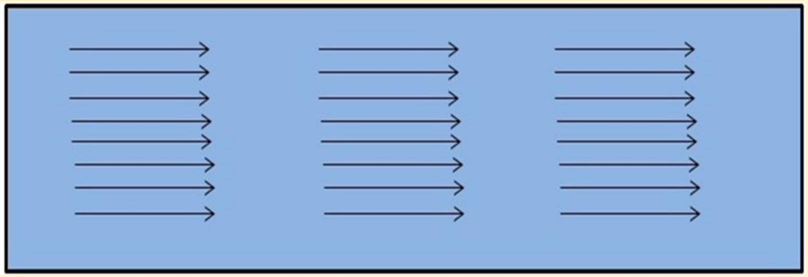
Flow of fluids can be divided into 2 different types, laminar and turbulent.

Laminar Flow

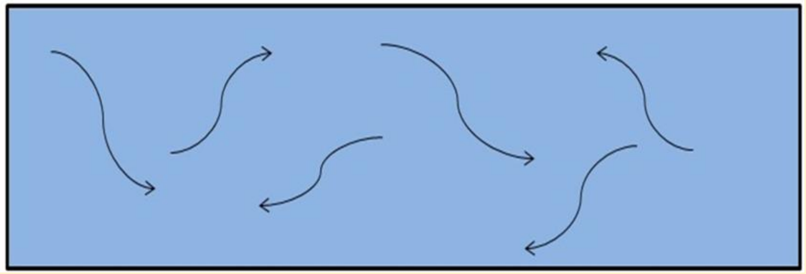
- The fluid flow in which the adjacent layers of the fluid do not mix with each other and moves parallel to each other is called laminar flow.
- In the laminar flow, the fluid layer moves in straight line.
- The laminar flow always occurs when the fluid flow with low velocity .
- The fluid flow is very orderly i.e. there is no mixing of adjacent layers of the fluid and they move parallel to each other and also with the walls of the pipe.

Turbulent Flow

- The fluid flow in which the adjacent layers of the fluid cross each other and do not move parallel to each other, is called turbulent flow.
- In turbulent flow the fluid layers do not moves in straight line. They move randomly in zigzag manner.
- The turbulent flow occurs when the velocity of the fluid is high .
- The fluid does not flow in definite order. There is a mixing of different layers and they do not move parallel to each other but crosses each other.



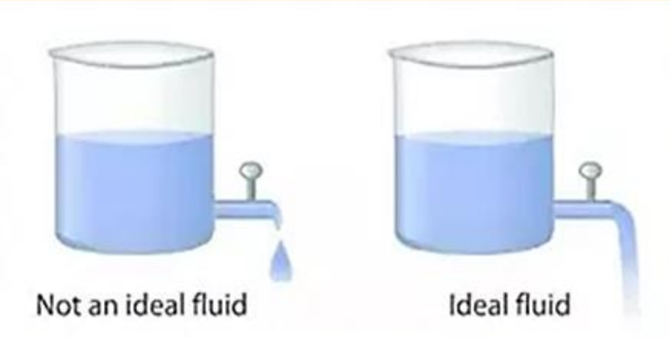
Laminar flow



Turbulent flow

Many features of fluid motion can be understood by considering the behavior of an **ideal fluid**, which satisfies the following conditions:

1. The fluid is nonviscous, which means there is no internal friction force between adjacent layers.
2. The fluid is incompressible, (the volume remains the same). which means its density is constant.
3. The fluid motion is steady, meaning that the velocity, density, and pressure at each point in the fluid don't change with time.
4. The fluid moves without turbulence. This implies that each element of the fluid has zero angular velocity about its center, so there can't be any eddy currents present in the moving fluid. A small wheel placed in the fluid would translate but not rotate.



picture 1

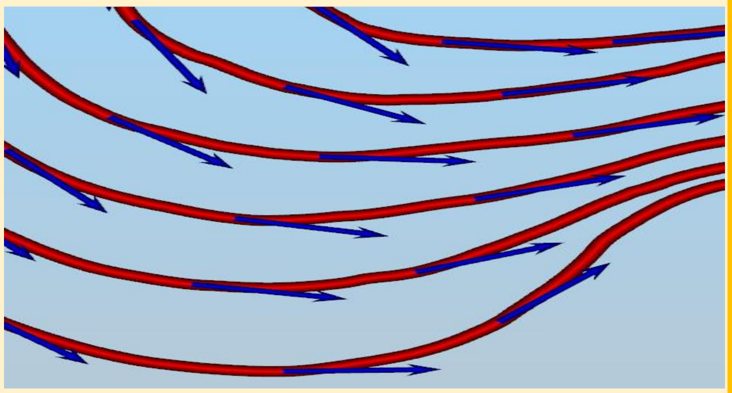
Ideal fluid does not exist in nature however, fluids with low viscosity such as air, water may however be treated as an ideal fluid (picture 1), which is a reasonable and well accepted assumption.

The movement of an ideal fluid is characterized by three basic parameters:
Density, pressure and velocity of a particle of the fluid.

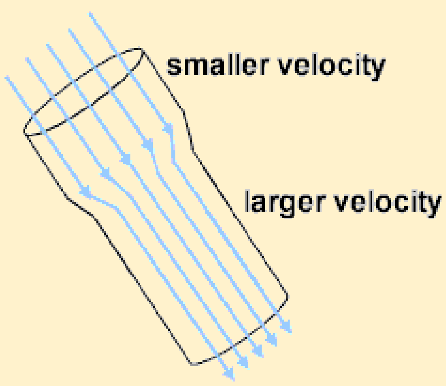
CONCEPTS AND QUANTITIES THAT DESCRIBE THE FLOW OF LIQUIDS

• Line of flow and flow tube •

The state of motion of a liquid can be determined by indicating the velocity vector as a function of time for each point of space. The combination of the vectors $\vec{v}$ given for all the points of space forms the so-called velocity vector field that can be depicted as follows. Let us draw lines in a flowing liquid so that a tangent to them at each point coincides in direction with the vector $\vec{v}$ {picture 2). These lines are called streamlines.



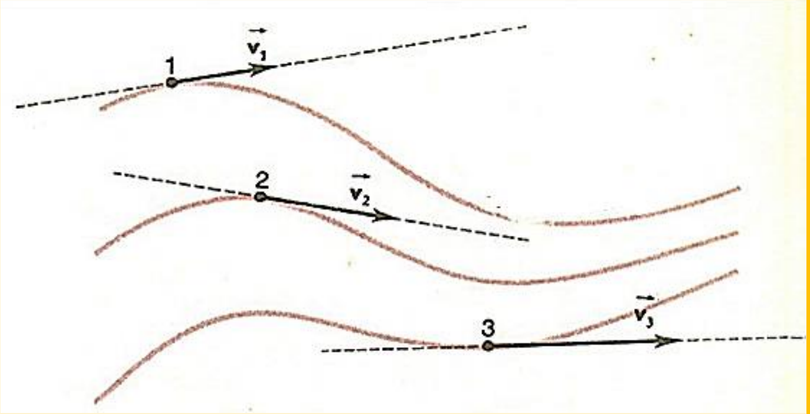
picture 2 - the streamlines are shown in red lines and the blue line represents the fluid velocity



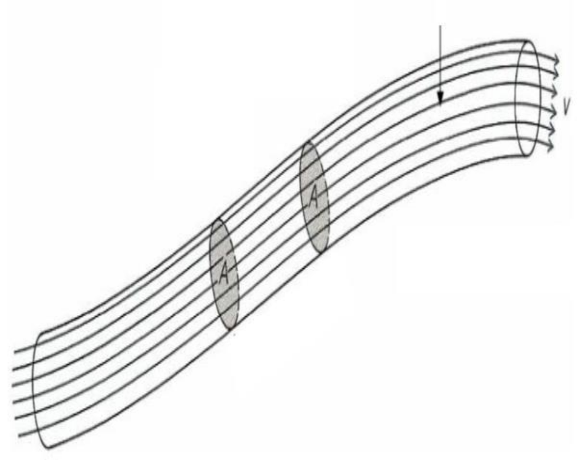
picture 3

We shall agree to draw the streamlines so that their density (characterized by the ratio of the number of lines ΔN to the magnitude of the area ΔA at right angles to them through which they pass) is proportional to the magnitude of the velocity at the given place. The pattern of the streamlines will thus permit us to assess not only the direction, but also the magnitude of the vector $\vec{v}$ at different points of space: the streamlines will be closer together where the velocity is higher and, conversely, farther apart where the velocity is lower (picture 3).

Since the magnitude and the direction of the vector $\vec{v}$ may change with time at every point, then the pattern of the streamlines may also change continuously. If the velocity vector is constant at each point of space, then the flow is called steady. In steady flow, any particle of a liquid passes a given point of space with the same value of v. The pattern of the streamlines in steady flow remains unchanged, and the streamlines in this case coincide with the trajectories of the particles.



Picture 3 - red lines represent the streamlines. The black arrows and broken black lines show the direction and magnitude of the flow velocity, these black arrows are tangential to the streamline.



Picture 4

A portion of a liquid confined by streamlines is called a flow tube. Homogenous flow tube (picture 4) is tube with constant cross-section area, and velocity vector is constant in each point (in magnitude and direction).

FLOW RATE

The flow rate of a liquid is how much liquid passes through an area in a given time
We used two different rates to describe how quickly fluids flow: mass flow rate and volumetric flow rate.

Mass flow through a cross-sectional area per unit time is called the mass flow rate.

$$q_m = \frac{m}{t}$$

The SI unit is kg/s (kilogram per second). Since mass is a scalar quantity, the mass flow rate is also a scalar quantity.

Volume flow through a cross-sectional area per unit time is called the volumetric flow rate

$$q_V = \frac{V}{t}$$

The SI unit is m^3/s (cubic metres per second). Since volume is a scalar quantity, the volumetric flow rate is also a scalar quantity.

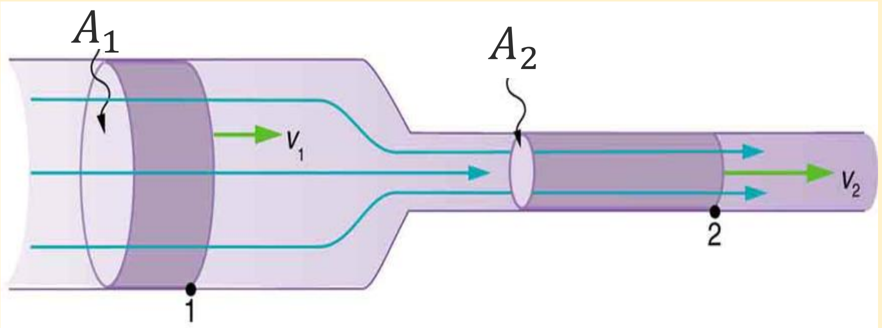
Formulas that connect the flow rate and velocity of liquid through a cross-section of the flow tube are:

$$q_m = \rho \cdot A \cdot v$$
$$q_V = A \cdot v$$

Where: A is the cross-sectional area, v is velocity of liquid and ρ is the density of the liquid
The flow rate of liquid is higher if there are a higher velocity of liquid and a larger diameter of the tube.

CONTINUITY EQUATION

In the case of stationary flow: at the same time intervals, the mass of the fluid that is passing through varying cross sections of the flow tube.is the same. If not, then the mass of the fluid between the two cross sections A_2 and A_1 would increase or decrease.



picture 5

The mass flow rate has the same value at every position along a tube that has a single entry and single exit for fluid flow. We saw from the picture 5 that: mass flow rate at position 1 is equal mass flow rate at position 2

$$q_{m1} = q_{m2} = const \Rightarrow \rho_1 A_1 v_1 = \rho_2 A_2 v_2 \Rightarrow \rho A v = const$$

ρ_1, v_1 and A_1 are mass density, velocity and cross-sectional area at position 1.
Similary, ρ_2, v_2 and A_2 are mass density, velocity and cross-sectional area at position 2.

For the case of an incompressible fluid $\boldsymbol{\rho_1 = \rho_2 = \rho}$ =const

$$A_1 v_1 = A_2 v_2 = const \Rightarrow \mathrm{A}v = const$$

This expression is called the **continuity equation**. From this result, we see that **the product of the cross-sectional area of the pipe and the fluid speed at that cross section is a constant**. Therefore the speed is high where the tube is constricted and low where the tube has a larger diameter. The product *Av*, which has dimensions of volume per unit time, is called the **flow rate**. **The condition *Av* constant is equivalent to the fact that the volume of fluid that enters one end of the tube in a given time interval equals the volume of fluid leaving the tube in the same interval, assuming that the fluid is incompressible and there are no leaks.**

PROBLEMS

1. Throught cross-section of pipe pass 300l of the water in half minute. Find:
   a) volume flow rate
   b) mass flow rate
   of water in the pipe

2. Water flows throught a horizontal pipe of varying cross-section: the radius of the wider part of the pipe is 1,5 time greater than radius of narrow part of the pipe. Find the velocity of the water in the narrow part of the pipe, if the velocity of the water in wider part of the pipe is $20\, m/s$.

3. Carbon dioxide flows throught a horizontal pipe with the radius 1cm. In half hour throught cross-section of the pipe pass 0,5kg of carbon dioxide.
   a) Find the velocity of carbon dioxide in the pipe
   b) At one point this pipe is branching in two narrow pipes with radius 0,6cm. Find the velocity of carbon dioxide in two narrow pipes ? Density of carbon dioxide is $7{,}5\, kg/m^3$.

4. In the human body, the cross-section area of aorta is $3cm^2$ and the blood passing throught has a speed of $30\, cm/s$. A capillary has a cross-section area of $3 \cdot 10^{-7} cm^2$ and the speed passing throught it is $5 \cdot 10^{-2}\, cm/s$. Approximately how many capillarres are found in our body? Every capillary has the same cross-section area.

5. A fire hose nozzle held horizontally at a height of h$= 2m$ discharges a water jet of a cross-section area of $A_2 = 4cm^2$ and strikes the ground at a distance of $l = 8m$ away from the nozzle.

a) What time does the water jet take to reach the ground?

b) With what velocity does the water jet leave the nozzle?

c) With what velocity does the water flow throught a wider part of the hose of a cross-section area of $A_1 = 50cm^2$?