Methods of determining flow rate of fluid.

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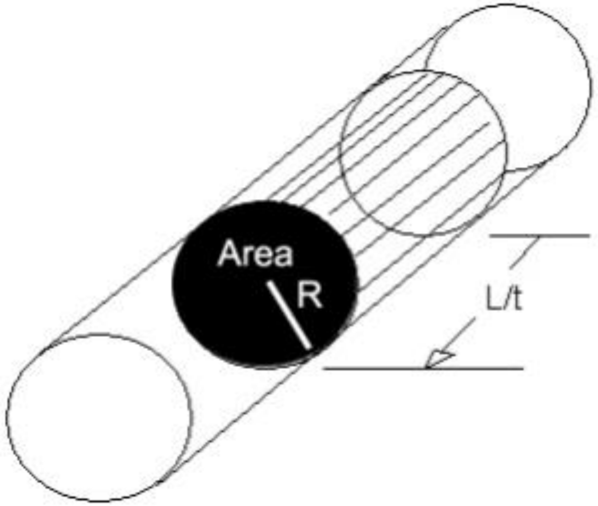
Definition of flowrate

In hydraulics, flowrate (Q) is defined as a volume (V) of liquid that flows through a given section of a channel per time unit (t).

$Q = \Delta V / \Delta t$ (1)

To express a flowrate, one of the variables has to be time dependent. Assuming that the area (A) is constant, the other variable (L) is expressed in terms of distance of movement as a function of time. The expression of the length of movement (ΔL) as a function of time (Δt) gives the speed (U).



- $U = \Delta L/\Delta t$ (2)
- $V = AU\Delta t$ (3)

Also, by replacing (V), in equation (1), with the value determined in equation (3), the discharge equation can be expressed as follows:

- $Q = AU$ (4)

To express mass, the discharge (Q_m), equation (4) must be changed to include the density factor of the liquid being measured. The equation therefore becomes:

- $Q_m = \rho AU$ (5)

where **ρ** is the density of the liquid kg/m^3; **A** is the area in m^2; **U** is the velocity of the liquid through the area in m/s.

2. Purpose of flow measurement

Precise and uniform methods of flow measurement are necessary to:

- determine the pollution load of urban, industrial and agricultural sources;
- determine the size of equipment for the transport and treatment of effluent and feed water;
- understand variations of flow and load in terms of time;
- measure, locate, analyze and solve problems relating to water collection and distribution networks;
- assess (оценивать; прогнозировать) the performance of treatment equipment;
- determine the quality of water bodies and calculate available water resources. These measurements are also necessary to enforce environmental laws and regulations.

3. Types of flow measurements

- 3.1. Point-specific flow measurement

Point-specific measurements are performed at a specific moment in time and generally cover a very brief period (a few minutes). They are therefore only representative of the moment at which they were taken.

Point-specific measurements are used primarily to:

- verify the calibration of certain hydraulic structures (ex. pumps, flumes);
- determine the flowrate of a stable discharge (ex. prolonged effluent aeration pond);
- immediately determine a flowrate;
- determine the measurements of hydraulic transport and treatment equipment.

The methods generally used to perform this type of measurement are as follows:

- volumetric method (see section 4.2);
- dilution method (see section 4.1.3);
- area/velocity method (see section 4.4);
- a point-specific reading of water depth using a portable combined insertion weir (see section 3.7).

When you are forwarding results, it is important to provide information about the location, date, time and method of measurement, to avoid confusion when results are interpreted.

3. Types of flow measurements

- 3.2. Continuous flow measurement

Continuous flow measurements consist of a series of point-specific measurements at very close time intervals (a few seconds apart), using instruments capable of recording values during the procedure. The advantage of this type of measurement is the fact that it can extend over an extended time period (a few hours to a few days) and reveals variations in flowrate that occurs during this period. Information that is obtained is therefore more complete. This type of measurement usually requires a temporary or permanent primary measuring device.

Volumetric method

In the case of small flows, the volumetric method often appears to be the simplest method for performing a point-specific measurement.

Principle of the method

This method, which is a "gauged-capacity" type, consists of filling a container, the exact volume of which is known, and tracking the time required to fill it. The following equation interprets the relation between the flow, volume and time:

$V/t = Q$

where: Q is the flowrate as a function of time unit; V is the volume; t is the time unit.

Applications

The volumetric method is generally used for:

− point-specific flow measurements;

− flow measurements where the flowrate is steady;

− calibration of primary measuring devices.

This method can be adapted using a tipping bucket to obtain continuous flow measurements. Use of this device, however, is limited to flowrates of less than 150 m^3/h.

Volumetric method

Advantages

The principal advantages of the volumetric method are:

– the speed at which it can be performed;

– the extreme precision of results;

– its cost-effectiveness.

Disadvantages

The principal disadvantages of this method are:

– usually limited to measuring small flowrates (< 100 liters/minute);

– usually allows only point-specific measurements to be taken;

– to measure large flows, requires the presence of a regular shape reservoir, the capacity of which at different levels can be measured with 99 % precision.

Equipment required

measure small flowrates (< 100 liters/minute):
graduated container (± 20 liters);
chronometer.

To measure large flowrates (> 100 liters/minute):
– a tank of suitable dimensions;
– a tape measure;
– a level indicator;
– a chronometer.

Volumetric method

- **Number of tests**

The method requires three tests to be performed. The deviation between each test must not exceed 2 %. If deviation is greater than 2 %, determine the causes and repeat the entire operation.

- **Test period**

In all cases, time is calculated in seconds. To measure large flowrates, each test should take at least five minutes. To measure small flowrates, each test should take at least the number of seconds indicated

Flowrate (liters per minute)	Time in seconds
10	120
20	60
30	40
40	30
50	25
60	20
70	17
80	15
90	12
100	12

Volumetric method

- **Precision**

A flow measurement using the volumetric method may yield results with a deviation of ± 1 %, when measurement is carried out with attention to detail.

– The volume of a container must be measured precisely, because most errors can be attributed to this variable.

– If the dimensions cannot be measured exactly, the volume can be deducted by weighing. This method, however, can be burdensome and even impracticable, in the case of large flowrates.

Dilution measurement method

- Flow measurement using the dilution measurement method can be performed using any type of tracer. For the purpose of this document, lithium chloride and rhodamine WT (родамин (краситель)) will be discussed, because these two tracers are commonly used.
- **General**

Use of the dilution method allows you to determine flow without the need to measure dimensions of the flow section. The dilution method is based on a measurement of color, conductivity, fluorescence, chemical concentration or radioactivity.

- **Principle of the method**

The method consists of measuring the degree of dilution of an amount of tracer, injected into a flow, once it has been completely mixed. On the basis of this principle, flow can be determined using the following equation : $Q_1C_1 = Q_2C_2$

where:

Q_1 is the injection flow of the tracer;

C_1 is the concentration of tracer injected;

Q_2 is the desired flowrate;

C_2 is the concentration of tracer mixed in the flow.

The principle appears simple enough; however, practical application requires a thorough understanding of the dispersion process.

Dilution (раствор) measurement method

- General applications

This method can be used to measure flow in an open or closed conduit.

In an open conduit, this method is used when:

– the flow is too fast and turbulent;

– the measurement segment is too irregular;

– the measurement segment contains debris and deposits;

– the segment area and flow velocities are variable;

– access to the measurement segment poses a risk of accident;

– some portions of the measurement segment can only be accessed through small diameter observation wells.

Dilution measurement method

- **Advantages of the method**

– enables flow measurements where other methods cannot be used;

– allows large flows to be measured;

– produces extremely accurate measurements;

the method can therefore be used to counter-check measurement setups and movement of liquids at the site;

– does not require knowledge of dimensions of the flow area and flow velocity(28);

– enables flow measurements in a closed or open conduit.

- **Disadvantages of the method**

– tracers are expensive;

– the method usually yields only momentary flow measurements;

– the procedure requires trained personnel;

– the procedure requires a lot of time(28);

– an number of parameters that can cause interference must be considered when selecting a tracer and must be measured during use;

– flow measurement is not always immediately available.

Dilution measurement method

- Injection equipment

The type of equipment required to carry out the dilution method will vary according to the flow system present at the site and the method of measurement used. The tracer that is used has no bearing or very little bearing on the type of injection equipment used.

- **The following equipment is required:**

– an injection instrument;

– a deflection device to create turbulence in the flow at the injection point; – a mixing tank for the solution;

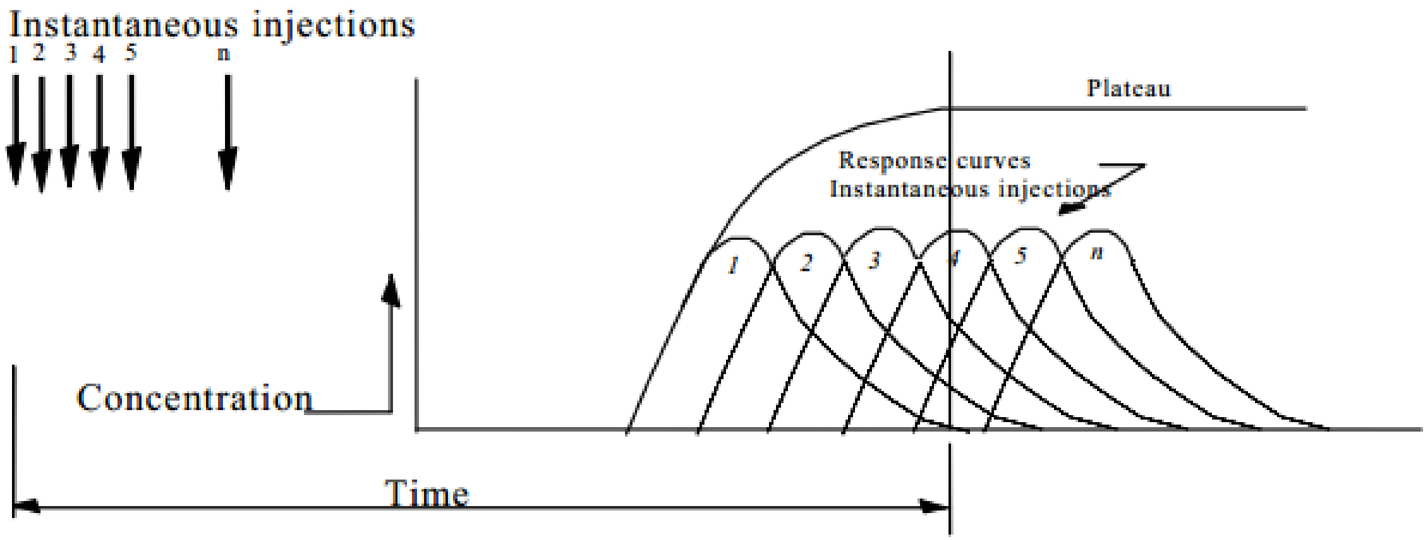
– a tracer;

– a chronometer (an instrument for measuring time);

– graduated containers (cylinders, flasks, pipettes, test tubes) to prepare the stock solution, calibrate the injection instrument, store the stock solution, collect samples and store samples;

– a hose and couplings.

Dilution measurement method



Dilution measurement method

- Procedure
- This method consists of injecting a known concentration of tracer at a constant rate, and measuring the concentration after homogeneous mixing with the discharge. The exact injection rate and exact concentration of the tracer must be known. The injection rate must be much slower than the flow of effluent, and the optimum measurement concentration must be much greater than the natural concentration of tracer in the effluent. To factor in the natural concentration level, the equation is as follows:
- $Q_2 = Q_1 C_1 / (C_2 - C_0)$

Where:

Q2 is the flowrate of the discharge;

Q1 is the rate of injection of the tracer;

C1 is the concentration of the tracer injected;

C0 is the natural concentration of the tracer in the effluent;

C2 is the concentration of the tracer after mixture with the discharge.

Dilution measurement method

The principal causes of error and items to verify to minimize errors are as follows:

CAUSES OF ERROR	CORRECTIONS
Non-uniform tracer solution	Constant mixing during injection
Error regarding the concentration of stock solution	Compare the theoretical value with the analytical value
Inadequate mixture of the tracer solution with the effluent	Change the sampling points, create turbulence at the tracer injection point
Breakdown of the tracer solution during injection	Protect the solution from exposure to direct sunlight during the entire operation
Breakdown of the tracer solution upon contact with the flow	Perform recovery tests before and during measurements
Unstable rate of injection	- Calibrate the injection instrument at the beginning and end of procedure; - check for the presence of air bubbles in the injection system; - place the tracer solution in a graduated container and take note of the volume that is injected at different moments during the injection procedure; - do not allow the injection tube to come into contact with the water surface
Loss of tracer solution at the injection point	Position the injection tube near the water surface to prevent splashing
Analysis problems	In the event that sampling containers have been contaminated, check the analytical method and rate of recovery
Large deviation in concentrations on the plateau of the curve	Verify the permanence of the flow pattern by continuously recording the water depth in the measurement segment

Area/velocity method

The method of determining the area and velocity of flow is perhaps the most common method of measuring the flowrate of a river.

Method principle

The method consists of accurately measuring a cross section area and the flow velocity. According to this principle, the flowrate can be determined using the following equation:
$AU = Q$
where: Q is the flowrate in cubic feet or meters per time unit;
A is the area of the cross section in square feet or meters;
U is the average flow velocity in feet or meters per time unit.

Applications

− measurement of the flowrate of rivers and large artificial channels;

− flow measurement in an open conduit where the flow cross section is uniform;

− flow measurement of large closed conduits.

Area/velocity method

- **Advantages**

The principal advantages of the area and velocity method are:

– low operating costs;

– does not require use of sophisticated instruments;

– results are available immediately.

- **Disadvantages**

The principal disadvantages of this method are:

– does not provide point-specific flow readings;

– requires a uniform discharge during the entire measurement procedure;

– requires a uniform flow cross section, the section of the conduit must be straight and the slope must be uniform;

– requires a number of tests to be performed when the area of the section is large;

– requires deep enough water to ensure that instruments are completely submerged;

– cannot be used in conduits smaller than 203 mm (8 inches);

– the presence of fouling suspended matter and large debris hinders operation of the measuring instrument;

– requires attention to detail during measurements to ensure that errors remain at acceptable levels.

Area/velocity method

- **Flow area**

Measurement of the flow area requires enormous precision to minimize the percentage of error. Flow area is determined in the following manner:

– for a circular conduit,

The inside dimension of the conduit is measured using an inside caliper that takes measurements to within one thousandths of a meter (thousandths of a foot). The diameter is measured on at least three proportional angles, to ensure that the conduit is perfectly round. The number of readings varies according to the difference between the readings obtained and the nominal dimension of the conduit.

Flow depth in the conduit is measured from the centre of the conduit. To determine the centre position of the conduit, measure the width of the flow area. The centre point of the flow area is the centre of the conduit, unless the conduit is not round;

– for another type of conduit or channel,

the width of the flow area is determined using a tape measure or, in the case of very wide channels, using an optical measuring device. Flow depth is measured at several points spaced along the horizontal axis in the following manner:

– for channels measuring 4,572 mm (15 feet) and over, at intervals equal to 5 % the total width of the channel;

– for 2,438 to 4,572 mm (8 to 15 feet) channels, at intervals equal to 10 % of the total width of the channel;

– for 610 to 2,438 mm (2 to 8 feet) channels, at intervals equal to 20 % of the channel's total width;

– for channels measuring 610 mm (2 feet) or less, at intervals equal to 30 % of the total width of the channel.

The profile of the section measured is printed on graph paper and the area of the section is measured using a planimeter.

Area/velocity method

- Velocity measurements should be taken at the same time as a depth measurement, to ensure the representativeness of results. Each velocity measurement should last at least 60 seconds and should be repeated at least five times. The deviation in measurements, between the lowest and highest velocity, measured during all five tests at the same point, must be less than 5 %. A higher rate of deviation will require all tests to be repeated again at the same point.
- Velocity measurements are carried out along verticals and the space between measurements should be as follows:

– for channels measuring 4,572 mm (15 feet) and over, 5 % of the total width of the channel;

– for 2,438 to 4,572 mm (8 to 15 feet) channels, 10 % of the total width of the channel;

– for 610 to 2,438 mm (2 to 8 feet) channels, 20 % of the total width of the channel;

– for channels 610 mm (2 feet) or less, 30 % of the channel's total width. For depth, the measuring points are established as follows:

– for depths less than 610 mm (2 feet), at 0.6 times the total depth measured from the surface;

– for depths 610 mm (2 feet) and over, at 0.2 and 0.8 times the total depth measured from the surface.

- This is the average for velocities measured along a vertical axis that determines the velocity of this section of the flow area;

– if the deviation between the number of revolutions between two verticals exceeds 10 %, measurements should be repeated and the distance between verticals reduced.

The velocity of the flow area is determined by finding the sum of average velocities measured along verticals, divided by the number of verticals.

Area/velocity method

- **Calculation of flow**

Flow is the average velocity multiplied by the flow area measured. The unit of measurement is cubic meter per second or cubic foot per second.

- **Precision**

The characteristic fluctuation, expressed as a percentage of the average velocity for a flow meter, should not exceed 5 %. If all of the precautions listed above have been taken, and if measurements are conducted under optimum conditions, the error of the method should be less than 10 %.

- **Causes of error**

The principal causes of error are as follows:

– instrument handling, more specifically the position of the probe in relation to the direction of flow;

– precision of the instrument;

– lack of precision of the flow area measurement. Particular care must be taken to locate the flow area;

– unstable flow conditions.