SUBJECT NAME & CODE: PHARMACEUTICAL ENGINEERING(BP304T)

UNIT: 1 **(FLOW OF FLUIDS)**

CLASS:3

TOPIC: MEASUREMENT OF RATE OF FLOW OF FLUIDS

MEASUREMENT OF RATE OF FLOW OF FLUIDS

Whenever fluids are used in a process, it is necessary to measure the rate at which the fluid is flowing through the pipe. This is required for optimization of process parameters in a chemical industry. Measurements are required for the calculation of auditing (for example, town planning of water supply) and cost of usage (for example, cost of water used in the houses). Methods of measurement may be classified as:

1. Direct weighing or measuring

2. Hydrodynamic, methods

(a) Orifice meter

(b) Venturi mete

(c) Pitot tube

(d) Rotameter

3. Direct displacement meter

Some of the above mentioned meters are discussed in the following sections.

Direct Weighing or Measuring Meters

The liquid flowing through a pipe is collected for a particular period at any point and weighed or measured. Thus, rate of flow can be determined. Gases cannot be weighed. On commercial scale, it is not convenient to weigh the liquids. Therefore, these methods are impracticable.

Orifice Meter

Principle: The orifice meter is a thin plate containing a narrow and sharp aperture. When a fluid stream is suddenly allowed to pass through the narrow constriction, the velocity of the fluid at the orifice meter increases compared to the velocity of the fluid in the upstream. This results in corresponding decrease in the pressure head. Bernoulli's theorem provides the basis for correlating the increase in the velocity head with the decrease in the pressure head between two points. The difference in the pressure head (ΔH) may be read from a manometer. If the diameter of the orifice is small compared to the diameter of the pipe, velocity of the fluid at the point before entering the orifice may be considered negligible. In such cases the manometer reading directly gives the velocity of the fluid.

The velocity of the fluid at the thin constriction may be written as:

$$U_0 = C_0 \sqrt{2g.\Delta H} \qquad (29)$$

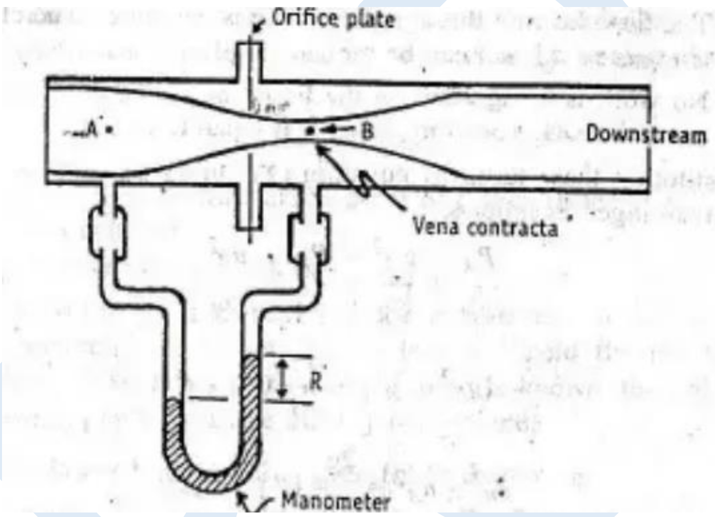
Where, u_0 = velocity of fluid at the point of orifice meter, m/s

Co = a constant

ΔH = difference in head from manometer, m

The ΔH can be measured using a manometer, which is connected to the pipe section between the initial stage and the orifice section. It can be substituted in equation (29) in order to get the velocity of the liquid flowing through the orifice. When cross section of the pipe is known, the volume of the liquid flowing per hour can be determined.

Construction: The orifice meter is considered to be a thin plate containing a sharp aperture through which a fluid flows. Normally, orifice plate is placed between long straight pipes, so that other fittings do not alter the flow rate that is being measured. Although it is possible to place orifice meter in the side or bottom, for the present discussion, the plate is introduced into the pipe (Figure). A manometer is connected at points A and B as shown in Figure.



Construction and assembly of Orifice meter

Working: Orifice meter is referred to as variable head meter, i.e., it measures the variation in the pressures across a fixed constriction placed in the path of flow consisting of a constant area.

When fluid stream is allowed to pass through the cross-section of the orifice, the velocity of fluid at point B increases at the expense of pressure head. As a result, the pressure at point A is higher than at point B. Bernoulli's equation provides the basis for correlating the increase in velocity head with the decrease in pressure head. The difference in pressure (ΔH metres) may be read from a manometer, connected to the points A and B as shown in Figure

Bernoulli's equation may be applied for two points (A and B) for the given experimental conditions, as given below:

$$\sqrt{u_o^2 + u_A^2} = C_o\sqrt{2g.\Delta H} \qquad (30)$$

Where, u_o = velocity of fluid at the point of orifice meter, m/s

U_A = velocity of fluid at the point A, i.e., before orifice meter, m/s

Co = a constant

ΔH = difference in head, m

If the diameter of the orifice is 1/5th of the pipe diameter or less, u_A is small compared to u_o. Then u_A term may be neglected. Then equation (30) becomes:

$$U_o = C_o\sqrt{2g.\Delta H} \qquad (29)$$

ΔH can be measured using a manometer. It can be substituted in equation (29) in order to get the velocity of liquid flowing through orifice pipe. When cross-section of the pipe is known, the volume of liquid flowing per hour can be directly determined.

Mathematical treatment: Consider a fluid flowing through a pipe at a certain velocity (u_A). If the edge of orifice is sharp, fluid does not lose the velocity at once, while passing through the orifice. Two points A and B on either side of the orifice meter are chosen and Bernoulli's equation is applied. The Bernoulli's equation is

$$\frac{P_A}{g\rho_A} + X_A + \frac{u_A^2}{2g} - F + W = \frac{P_B}{g\rho_B} + X_B + \frac{u_B^2}{2g} \qquad (23)$$

In equation (23), the following assumptions may be made based on the working of orifice meter.

(1) Let the sections of pipe be horizontal, so that the heights (metres) of the points A and B are same (Figure). Then, two X terms are identical and get cancelled.

(2) Let the friction losses will not be appreciable and considered negligible. Then, F term becomes zero.

(3) The fluid flowing through the orifice is the same. Therefore, ρ_A is equal to ρ_B, and can be termed simply ρ

(4) No work is being done on the quid or by the liquid, since no pump is used. Therefore, w term is equal to zero.

Substituting these terms in equation (23) gives an equation, which can be rearranged as follows.

$$\frac{P_A}{g\rho} + \frac{u_A^2}{2g} = \frac{P_B}{g\rho} + \frac{u_B^2}{2g}$$

$$\frac{1}{2g}(u_B^2 - u_A^2) = \frac{1}{g\rho}(P_A - P_B)$$

$$(u_B^2 - u_A^2) = \frac{2g}{g\rho}(P_A - P_B) \qquad (31)$$

$$(u_B^2 - u_A^2) = \frac{2g}{g\rho}\,\Delta P \qquad (32)$$

From the principles of statics, (ΔP/gρ) = AH in metres. Introducing this term in equation (32) gives:

$$u_B^2 - u_A^2 = 2g.\Delta H \qquad (33)$$

Normally, the diameter of the fluid stream would be less than the diameter of the orifice (Figure). This point of minimum cross section is known as the *vena contracta*. Though the pipe is full, of liquid on both sides of the orifice, still the *vena contracta* exists and is surrounded by swirling liquid. Point B is chosen at the *vena contracta*.

In practice. the diameter of the stream at the *vena contracta* is not known, but that of the orifice diameter is known. A constant, Co. is. therefore, included in equation (33) in order to correct the differences between velocities at orifice and at *vena contracta*. Therefore, equation (33) may be modified in terms of the velocity through the orifice (u_0).

$$\sqrt{u_o^2 - u_A^2} = C_o \sqrt{2g \,.\Delta H} \qquad (30)$$

The constant C_o also includes some losses due to friction. It depends on the construction (ratio of the orifice diameter to the pipe diameter and position of the orifice taps) and the nature of flow of liquid (Reynolds' number)

If the diameter of the orifice is 1/5th of the pipe diameter or less, u_A is small compared to u_O. Then,

u_A term may be neglected. Then equation (30) becomes:

$$u_o = C_o \sqrt{2g.\Delta H} \qquad (29)$$

where, u_o = velocity of fluid at the point of orifice meter, m/s

Co = a constant

ΔH = difference in head, m

ΔH can be measured in metre using a Manoneter. It can be substituted in equation (29) to get the velocity of liquid flowing through orifice pipe. When cross section of the pipe is known, the volume of liquid flowing per hour can be directly determined.

Applications: Equation (30) is useful to determine:

(1) velocity at either of the points A or. B. Ratio of u_o and u_A can be related to ratio of the area of the orifice to the area of the pipe, which is normally known.

(2) volume of the liquid flowing per hour when u_A and cross-section of the pipe are known.

Venturi Meter

Principle: Venturi meter consists of two tapered sections in the pipeline with a gradual constriction (throat) at its centre. When fluid stream is allowed to pass through the narrow throat, the velocity of the fluid increases at the venturi compared to the velocity of the upstream. This results in corresponding decrease in the pressure head. Bernoulli's theorem provides the basis for correlating the increase in the velocity head with the decrease in the pressure head between two points. The difference in the pressure head (ΔH) may be read from a manometer. If the diameter of the venturi is small compared to the diameter of the pipe, velocity of the fluid at the point before entering the venturi may be considered negligible. In such cases, the manometer reading directly gives the velocity of the fluid.

The velocity of the fluid at the. narrow constriction (throat) may be written as:

$$U_V = C_V \sqrt{2g \,.\Delta H} \qquad (34)$$

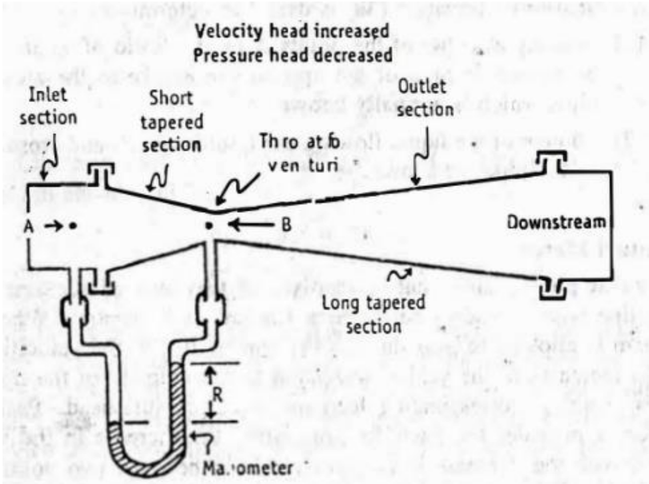
where , u_V = velocity at the throat of the venturi, m/s

C_V = coefficient of the venturi meter

ΔH = difference in head from manometer, m

ΔH can be measured using a manometer. It can be substituted in equation (34) in order to get the velocity of the liquid flowing through the venturi. When the cross-section of the pipe is known, the volume of liquid flowing per hour can be determined.

Construction: A venturi meter consists of two tapered sections inserted in a pipeline (Figure). Normally, venturi meter is placed between long straight pipes, so that other fittings will not alter the flow rate that is being measured. The upstream cone is normally shorter than the down stream. The tapers are smooth and gradual. Therefore, eddies in the down stream are absent and no power loss is observed. In addition, the cross-section of the high velocity part of the stream is well defined. A manometer is connected at points A and B as shown in Figure.



Construction of a venturi meter

Working: Venturi meter is referred to as variable head meter, i.e., it measures the variable differential pressure across a fixed constriction placed in the path of flow consisting of a constant area. In a venturi meter, the velocity of the fluid is increased at the throat, due to the constriction. This results in decreased pressure in the up-stream cone. The pressure drop in the upstream cone is utilised to measure the rate of flow using a manometer. Venturi meter nearly confirms the theoretical equations obtained for an orifice meter. On similar lines of equation (30), an equation for venturi meter may be written as:

$$\sqrt{u_V^2 - u_A^2} = C_V \sqrt{2g.\Delta H} \qquad (35)$$

Where, u_V = velocity at the throat of the venturi, m/s

U_A = velocity at point A (venturi throat), m/s

C_V = coefficient (= 0.98)

If the diameter of the smaller, section is one-fifth of the pipe diameter or less, u_A^2 is considered to be small compared to u_V^2. Therefore, u_A^2 term may be disregarded. A simplified form of equation (35) is:

$$U_V = C_V \sqrt{2g.\Delta H} \qquad (34)$$

The difference in pressure (ΔH) can be read in metres directly from the manometer. Thus velocity of the flow may be measured. The value given by the venturi meter is average velocity of the flow. The velocity then decreases and the original pressure is recovered in the down stream conc.

Applications: Venturi meter is commonly used for liquids, especially water. It can also be used for the measurement gases.

Disadvantages: (1) Venturi meter is expensive.

(2) Venturi meter occupies more space.

(3) The ratio of throat diameter to pipe diameter cannot be changed.

Differences Between Orifice Meter and Venturi Meter

Orifice meter	Venturi meter
1. Cheap	1. Expensive
2. Easy to install	2. fabrication is highly technical
3. construction can be made	3. It should be purchased from the instrument dealer
4. Head losses are more	4. Head losses are insignificant
5. Power losses are more particularly on fluid that is carried for long periods of time	5. Power losses are less
6. Normally used for testing purposes, for example, steam lines etc.,	6.Used in on-line installation
7. Greater flexibility	7.Not flexible, permanent
8. Reading of the orifice meter is larger under identical conditions	8. The reading of venturi meter is comparatively smaller under identical conditions

MCQ Each question carries 1 mark

1. The device which is used for making the temporary measurement of flow is………………

a. Venturimeter

b. Dull flow tube

c. Orifice plate

d. Discharge tube

2. After the suddenly allow of fluid stream towards the narrow constriction the following will increase.

a. Increase velocity of fluid at orifice meter

b. Increase pressure of the fluid at orifice meter

c. Increase temperature of the fluid at orifice meter

d. Moderate temperature of the fluid at orifice meter

3. What is the constant of orifice meter?

a) C0

b) ΔH

c) Both a and b

d) U0

4. Orifice meter is also referred as

a) Venturimeter

b) Pitot meter

c) Variable head meter

d) Rota meter

5. The orifice meter helps us to calculate________ at point A and B.

a) Temperature

b) Velocity

c) Pressure

d) Humidity

6. Orifice meter is____________ plate.

a) Thick

b) Wide

c) Thin

d) Broad

7. Choose the formula of orifice meter

a) PV= nRT

b) √uv2-u02

c) u0 = C0√2gΔH

d) u0 = C0√2gΔT

Each question carries 2 marks

1. What is a 'differential head meter? Name some devices under this category.
2. What is a pressure head? How is it calculated
3. What are vertical head meters? Describe one such meter.

Each question carries 5 marks

1. Difference between orifice meter and venturi meter
2. What are the merits and demerits of venturi meter over orifice meter?
3. What is the condition of hydrostatic equilibrium? Obtain the barometric equation

Each question carries 10 marks

1. Deduce relevant equations for calculation of flow rates using orifice meter
2. Explain the working. principle and construction of venturi meter. Write the expression for the volumetric flow rate of fluid. Through a pipe with relevant equation.