INTERNATIONAL UNION OF
PURE AND APPLIED CHEMISTRY

DIVISION OF APPLIED CHEMISTRY
SECTION FOR WATER, SEWAGE AND
INDUSTRIAL WASTES

A GUIDE TO FLOW MEASUREMENT AND SAMPLING WITH SPECIAL REFERENCE TO PULP AND PAPER MILL WASTE WATER SYSTEMS

A Report prepared by

H. O. BOUVENG

The Swedish Water and Air Pollution Research Laboratory,
Stockholm

LONDON
BUTTERWORTHS

CONTENTS

DIVISION OF APPLIED CHEMISTRY

SECTION FOR WATER, SEWAGE AND INDUSTRIAL WASTES

A GUIDE TO FLOW MEASUREMENT AND SAMPLING WITH SPECIAL REFERENCE TO PULP AND PAPER MILL WASTE WATER SYSTEMS

1. INTRODUCTION

A correct control of a waste water with reference to its polluting capacity should include both flow measurement and sampling for analysis. Attention should be paid not only to the total discharge of material that may pollute the receiving water course but also to such constituents of the waste water, for instance recoverable chemicals and fibres, that have the character of losses. The method chosen for the flow measurement will depend on the type of sewer (channel, pipe, etc.), the accessibility for installation of measuring equipment and the properties of the effluent, especially corrosiveness and the presence of suspended solids.

In this guide an outline is given of methods for flow measurement in waste-water systems together with recommendations for sampling and sampling equipment. Special attention is paid to the particular problems presented by pulp and paper mill effluents. The formulae and recommendations given in section 2 are intended as a guide: (i) in assessing whether measuring equipment already installed is in fact suitable and is functioning satisfactorily; (ii) in the choice of type and dimensions of equipment for installation in an existing plant; (iii) in providing a satisfactory control system on the outlet side of a new plant; (iv) to flow measurement in temporary installations.

Equipment for flow measurement and sampling should be installed in the first place at all outlets to the water course, and secondly at internal sewers from production units issuing water with a high pollutant potential. In the case of permanent installation, continuously recorded flow measurement and automatic sampling is essential.

When the waste-water system in a mill is to be mapped down, measurements often have to be carried out where, under normal conditions, they are not required. Then a sampling station of a temporary and sometimes primitive nature will often be installed. Here, too, continuous recording of flow measurements and automatic sampling are desirable. A temporary station may also be set up for obtaining data required for the dimensioning of a permanent station.

2. FLOW MEASUREMENT

General symbols:

Q = flow, m³/s
v = velocity, m/s
g = acceleration due to gravity, m/s²
ρ = density, kg/m³

2.1. Weir measurement

2.1.1. *Principle*

A weir is a dam placed in a channel, flume or pipe outlet and over which the water flows with a free fall (*Figure 1*). The flow is calculated from the geometry of the weir and the water level upstream of it.

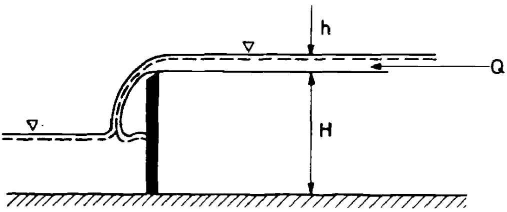

Figure 1. Flow over a weir.

2.1.2. *Construction and installation*

Weirs are made of steel plate or planed wood. The edges of the weir plates in contact with the flowing medium should be sharp and cut so as to form an angle of 45° to the direction of flow.

Weirs are mounted accurately at right angles to the direction of flow and with the upper edge horizontal (spirit-level). The mounting can be carried out by one of the following methods, care being taken to ensure tight seals against the walls and the bed of the channel.

(i) The weir is mounted between rails or bolts. For temporary installations it will often suffice to bolt strong strips to each channel wall (the water pressure will normally be great enough to keep the weir in position), and to seal with machine felt, foam rubber or foam plastic. The sealing material is chosen with regard to the properties of the flowing medium. This alternative is to be preferred.

(ii) The weir, which shall be made slightly wider than the channel, is forced into position, care being taken to avoid damaging the edges.

(iii) The weir can be secured with wooden wedges, but this method entails problems in sealing.

2.1.3. *Types of weir; formulae*

The following symbols are used:

B = width of channel, m.
b = width of weir opening, m.
H = distance from the channel bed to the edge of the weir, m.
h = upstream water level relative to the edge of the weir, m.
μ = coefficient of discharge.

(i) *Choice of weir type*. The choice of a suitable weir is made on the basis of the channel width, the accessible dam height and the range within which the flow is expected to vary. Insertion of these values into the formulae below will indicate what type is suitable or, alternatively, what changes should be made in the existing system for measurement to be possible.

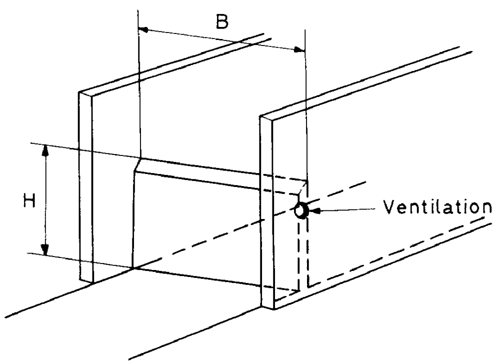

Figure 2. Weir without end-contraction with external ventilation hole.

(ii) *Weir without end contractions*. The edge of the weir extends across the entire width of the channel ($b = B$; *Figure 2*). This type is used for heavy flows. The flow is given by

$$Q = \frac{2\mu}{3} bh\sqrt{2gh}$$

$$\frac{2\mu}{3} = 0{\cdot}4224 + 0{\cdot}00053/h$$

(iii) *Weir with end contractions*. The weir is combined with a constriction of the channel (*Figure 3*). This type is used for moderate flows.

$$Q = \frac{2\mu}{3} bh\sqrt{2gh}$$

$$\frac{2\mu}{3} = 0{\cdot}3838 + 0{\cdot}0386b/B + 0{\cdot}00053/h$$

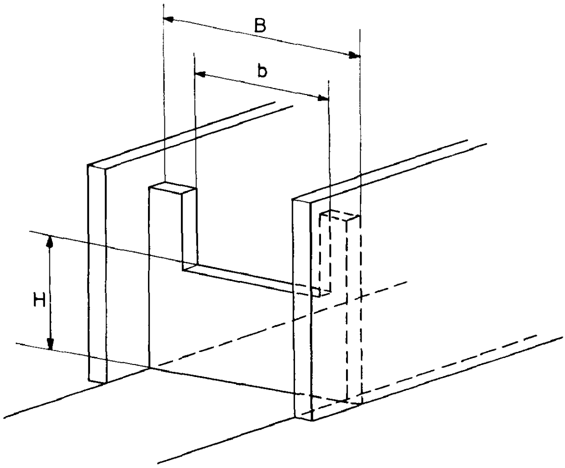

Figure 3. Weir with end-contraction.

(iv) *V-notched weir* (*Thompson weir*). The weir consists of a V-shaped notch (*Figure 4*) in the dam. This type is used for light flows.

$$Q = \frac{8\mu h^2}{15}\sqrt{2gh}\cdot\tan\frac{\theta}{2}$$

$$\mu = 0{\cdot}5650 + 0{\cdot}00868h^{-1/2}$$

where θ is the angle of the notch. (When, as is usually the case, $\theta = 90°$, $\tan\theta/2 = 1$.)

(v) *Special types*. Weirs can have other shapes of opening, e.g. hyperbolic or ones in which h is proportional to the flow. For the relevant calculations, reference is made to the literature.

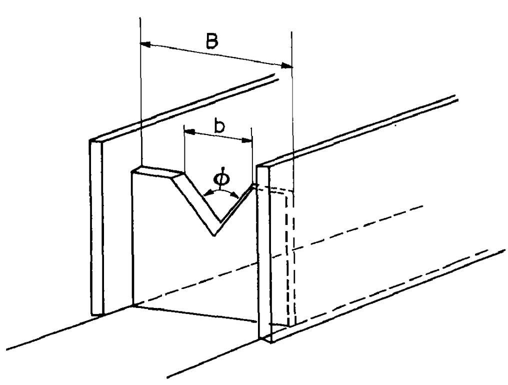

Figure 4. Thompson weir.

2.1.4. *Gauges*

According to the above the calculation of flow over weirs requires measurement of only the water level relative to the weir edge. For this a gauge is placed upstream of the weir and distant from it (if possible) at least 2·5 times the maximum level (*h*) above the weir (*Figure 5*).

For permanent installations it is preferable to place the gauge in a separate, cylindrical measuring chamber (stilling well) close to the channel and communicating with it. The tendency for microbial growth in the measuring chamber can be counteracted by admitting a tangential stream of fresh water, small in relation to the diameter of the communicating pipe.

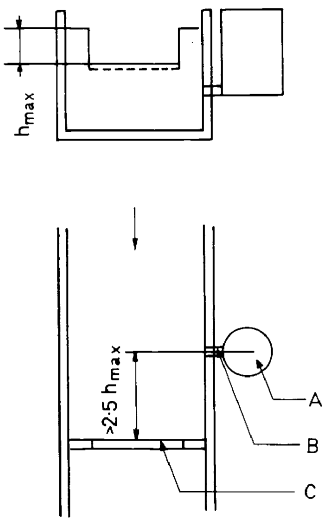

Figure 5. Arrangement of measuring chamber on a weir. *A*, Measuring chamber (internal diam. 300–400 mm with float; 100–150 mm with bubble tube). *B*, Connecting tube. *C*, Weir.

(i) *Scale.* When the channel is accessible for direct inspection the water level can be measured directly on a scale on the channel wall. This method is suitable for temporary installations where for some reason automatic recording cannot be arranged. The accuracy of measurement is limited only by that with which the scale can be read; troublesome in this connection is the presence of foam in the channel.

(ii) *Bubble tube.* This device for measuring the water level consists of a narrow vertical tube (internal diameter *c.* 10 mm) submerged in the channel with its orifice on a level with the weir edge. (For temporary installations the orifice should be as near this level as possible; the position should be determined with a spirit level.) The tube is fed with compressed air via a reduction valve, so that there is a steady flow from the orifice of 1 or 2 bubbles per second. The pressure in the tube is measured and, after conversion, transmitted to a recording instrument.

The bubble tube is recommended for temporary installations because it can easily be mounted directly in the channel. It should be noted, however, that a high velocity of the flowing medium might cause the pressure in the bubble tube to be reduced. Low values for the flow will then result. The effect may be diminished or eliminated by shielding the bubble tube with an outer tube (diameter 1–1·5″) open in both ends. It is mounted with its ends about 5 cm above and below the orifice of the bubble tube, respectively. For permanent installation a separate measuring chamber (with an internal diameter of 100 to 150 mm) is recommended.

(iii) *Measurement of electrical capacitance.* A sensing element in the form of an electrically insulated rod- or plate-shaped conductor is placed vertically in the channel or in a separate measuring chamber. The lower edge of the sensing element should be on level with the weir edge. The sensing element is coupled to a measuring circuit in such a way that the conductor and the surrounding medium form a capacitor. The capacitance of the circuit is determined by the depth to which the sensing element is submerged, and this in turn is determined by the flow. Plate-shaped conductors can be of such a shape that the capacitance is directly proportional to the flow.

This type of gauge is sensitive to microbial growth and deposited debris. The system cannot be calibrated before equilibrium is obtained between deposition and erosion. Since the properties of the deposit near the surface (drying out, moistening) vary with the water level, the method permits of only moderate accuracy. For this reason a separate measuring chamber, ventilated with fresh water, is recommended for permanent installations.

(iv) *Float.* Measurement of level by means of a float should always be carried out in a separate measuring chamber with a diameter of the order of 300 to 400 mm. The level is transmitted by a cable to a meter or, preferably, to a recorder. With a mechanical transmission system a float will be sensitive to corrosion and therefore unsuitable for systems in which the waste water contains sulphide, sulphite or chlorine.

Provided that there is no interference from growth in the measuring chamber or from corrosion, the float yields reliable and accurate measurements.

2.1.5. *Comments on weir measurement*

(i) *Installation.* Because of the simple mounting, weirs are recommended for temporary installations in channels, flumes and pipe outlets. The following points regarding installation and operation should be noted.

The edge of the weir should be situated at least 10 cm above the maximum water level on the downstream side. In the case of weirs without end contractions air must be led in under discharging water (ventilation of the weir). In the case of open flumes an upward bent tube (*Figure 2*) can be fitted externally just after and below the edge of the weir. Alternatively, a vertical tube having an orifice between the outflowing water and the water surface in the channel can be mounted just downstream of the weir. Since completely satisfactory ventilation is often difficult to accomplish, a weir having end contractions should be chosen when possible.

For a satisfactory accuracy of measurement the water level (h) above the weir edge on the dam side should not fall below 5 cm. The upstream dam height (the distance between the channel bed and the weir edge) should preferably be at least 2·5 times the maximum water level above the weir edge ($H > 2{\cdot}5h$, see below).

To ensure an acceptably steady flow at the weir the upstream part of the channel should have a straight portion whose length is at least 10 times its width. To reduce the turbulence a grating or guide baffles can be inserted before the weir. The weir should be easily accessible for cleaning.

(ii) *Accuracy*. Under practical conditions flow measurement by means of weirs can be carried out to an accuracy of approximately ± 10 per cent. On the other hand, it is assumed that the turbulence in the channel is reduced and, furthermore, that the weir and gauge are kept free from sediment.

The formulae are valid for free fall. This requires the speed of the water in the channel immediately upstream of the weir to be close to zero, that is, the ratio h/H should be small. For careful measurements, H should exceed $2{\cdot}5h$; an acceptable practical limit is $2h$.

The error due to the speed is given by the formula $h_1 = h_2 + \bar{v}^2/2\,g$, where h_1 is the corrected water level, h_2 the observed level and $\bar{v}$ the average velocity before the weir.

Provided that sedimentation and microbial growth both on the weir and in the measuring chamber are controlled, and that the sensing device is protected against corrosion, weirs are extremely reliable in their operation.

2.2. Measurement with orifice plates, flow nozzles, Venturi tubes and rotameters

2.2.1. *Principle*

Constriction of a pipe results in an increase in the speed of the flowing medium and in a corresponding drop in its pressure, in accordance with Bernoulli's law:

$$v_2^2 - v_1^2 = 2g(p_1 - p_2)/\rho$$

The flow ($Q = v_1F = v_2f$) is calculated from the geometry of the constriction and the observed pressure drop. Normally the following equation is applicable for incompressible liquids

$$Q = \frac{f\sqrt{2g\Delta h}}{\sqrt{1 - m^2}}$$

where F = cross-sectional area of the pipe, m²
f = aperture of the constriction, m^2
m = area ratio f/F
Δh = pressure head, metres of water column.

The main types of measuring devices are orifice plates, flow nozzles and Venturi tubes. The pressure difference is measured manometrically and square root is taken, this being proportional to the flow. In practice an experimentally determined factor α, known as the coefficient of discharge is used in which the term $1/\sqrt{1 - m^2}$ is usually included. Standards are given in the literature[1,4–7,11].

2.2.2. *Orifice plates*

A standardized orifice plate consists of a thin plate with a central sharp-edged hole and is mounted perpendicularly to the direction of flow (*Figure 6a*).

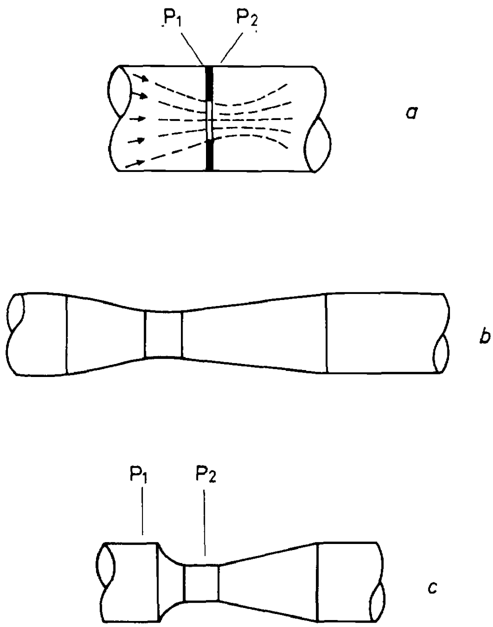

Figure 6. (*a*) Orifice plate. (*b*) Conical Venturi tube. (*c*) Venturi nozzle.

The flow rate is highest and the contraction greatest slightly after the orifice. In the formula for standardized orifices

$$Q = \alpha f \sqrt{2g\Delta h}$$

the coefficient of discharge α takes account of the contraction and of the area ratio m. The magnitudes of α for various values of m, provided that Reynolds number, Re, exceeds the values indicated below are as follows:

m	0·20	0·30	0·40	0·50	0·60	0·70
$Re \cdot 10^5 >$	0·6	0·9	1·3	1·7	2·3	3·0
α	0·615	0·634	0·660	0·695	0·740	0·802

In practice, Re is normally large enough for the error in the above values to lie within 2 per cent[11]. It is further assumed that the sensing device is not connected directly to the pipe but to an annular chamber connected to the pipe via slits placed immediately in front of and behind the plate.

Orifice plates give a high level of accuracy at the expense of a large pressure loss, which increases the pumping costs. They do not function satisfactorily in the presence of suspended particles (sediment on the upstream side cause low results) and are therefore unsuitable for permanent installation in systems conducting fibres.

The fact that orifice plates can sometimes be easily inserted at pipe connections in existing systems renders them suitable for temporary installations.

2.2.3. *Venturi tubes*

A Venturi tube consists of an inlet section (confuser), which can be conical (conical Venturi tube; *Figure 6b*) or of the nozzle type (Venturi nozzle; *Figure 6c*), and a conical outlet section (diffuser). For a conical Venturi tube the following formulae are applicable

$$Q = \alpha' f \sqrt{2g\Delta h}/\sqrt{1 - m^2}$$

$$0{\cdot}96 < \alpha' < 0{\cdot}99$$

No standards are available for conical Venturi tubes. For VDI standard Venturi nozzles[5,6] the following formula applies:

$$Q = \alpha f \sqrt{2gh}$$

The magnitude of α for various values of m provided that Reynolds number exceeds the values indicated are as follows:

m	0·2	0·3	0·4	0·5	0·6
$Re \cdot 10^5 >$	1·1	1·3	1·5	1·8	2·0
α	1·00	1·02	1·05	1·09	1·16

What was mentioned above concerning Re for orifice plates is also applicable to Venturi nozzles[11].

Venturi tubes are expensive to install. This disadvantage is balanced by the fact that the pressure loss and the associated increase in the pumping cost is considerably lower than for orifice plates. Since the tubes are self-cleaning they are well suited for permanent installation in waste-water systems.

Because of its smaller dimensions and the availability of relevant standards, the Venturi nozzle is preferable to the conical Venturi tube.

2.2.4. *Flow nozzles*

A flow nozzle closely resembles a Venturi nozzle without a diffuser. Flow nozzles are as sensitive as orifice plates to deposition of solids and are thus unsuitable for permanent installation in waste-water systems. For temporary installation they offer no advantages over orifice plates. For formulae see standards[7].

2.2.5. *Installation*

The standards assume a smooth flow through the measuring device. The required straight length of pipe upstream of the device, can be calculated from the ratio of length to diameter (L/D), given for different values of m:

m	0·2	0·4	0·6
L/D	5–12	10–20	20–40

These values of the ratio assume favourable conditions of flow. If a valve with a non-linear flow path, a T-tube or a pump is installed upstream of the measuring device the required straight length is doubled. On the downstream side the required length of the straight section is such that $L/D > 5$.

2.2.6. *Rotameters*

A rotameter consists of a vertical conical tube, increasing in diameter upwards, in which direction the flow occurs. The tube is constricted by a floating body, which is forced upwards in the tube as the flow increases, thus increasing the discharge area. The floating body is sometimes furnished with stabilizing spiral groves or slits to stabilise its rotation. The vertical position of the body is a function of the flow, the densities of the medium and the body, and the geometry of the tube.

Rotameters are available that are calibrated for media of a given density. Variations of 5 per cent in the density of the medium normally affect the measurements by less than 1 per cent. The operation, however, is influenced by growth formation. Rotameters can be designed for continuous recording. They are manufactured from glass for flows up to 20 m^3/h and from metal for flows up to about 100 m^3/h. Because of their limited capacity and their sensitivity to growth formation, rotameters in water systems of pulp and paper mills can be used only for measuring small flows of clean water, for instance spray water.

2.3. Magnetic measurement of flow

When an electrical conductor is moved in a magnetic field, a voltage is generated in the conductor. Magnetic measurement of flow is based on this principle; the flowing medium constitutes the conductor. For such a meter the following equation is applicable:

$$E = kHQ/F = k'Q$$

where E = electromotive force generated
H = strength of magnetic field
k, k' = dimensional constants
F = cross-section of the pipe.

E is independent of temperature, viscosity, turbulence and (above a certain minimum) conductivity.

Magnetic flow meters consist of a straight pipe section fitted with standard flanges. Two small electrodes of corrosion-resistant material are mounted inside the pipe, which is surrounded by a shell where the magnetic circuit is placed. The device is manufactured in standard dimensions from 1/2 to 72 in.

Magnetic flow meters are expensive. They are highly accurate, do not cause any pressure drop and are indepentent of turbulence. They are resistant to corrosion and unaffected by the presence of suspended particles (with the possible exception of sand and similar other heavy particles which can damage the electrodes).

2.4. Measurement with Venturi and Parshall flumes

2.4.1. *Principle*

As in the case of pipes a constriction in a channel causes an increase in velocity of the flowing medium. Whereas in a tube a drop in pressure results, and in an open channel there is a drop in level. For a suitably shaped constriction, the flow can be obtained with sufficient accuracy by measuring the level upstream of the constriction.

2.4.2. *Venturi flumes*

A Venturi flume is the open channel equivalent of a Venturi tube (*Figure 7*). For a Venturi flume the following equation is applicable:

$$Q = \alpha hb\sqrt{2g(H-h)}/\sqrt{1-(hb/HB)^2}$$

where B = channel width, m
b = minimum width of the Venturi flume, m
H = depth of channel before the constriction, m
h = depth of channel at b, m
α = coefficient of discharge

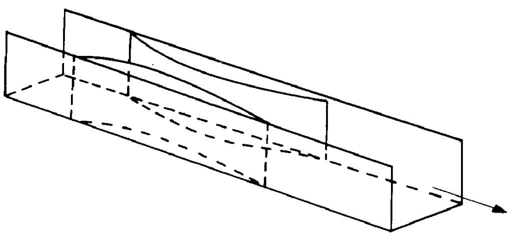

Figure 7. Venturi flume.

Under conditions of free flow, i.e. when the water level downstream of the constriction is not affected by the water level upstream of it (see section 2.4.4.), $h = 2H/3$, the above formula will be

$$Q = \frac{2\alpha_f Hb/3}{\sqrt{1-(2b/3B)^2}}\sqrt{2gH/3}$$

or for a given flume ($0{\cdot}95 < \alpha_f < 0{\cdot}99$).

$$Q = \text{const } H^{3/2}$$

No standards are available for Venturi flumes.

2.4.3. *Parshall flumes*

The Parshall flume (*Figure 8*) is a modified Venturi flume of standardized dimensions[4,10]. The following empirical equation is applicable to the Parshall flume:

$$Q = 0{\cdot}1132b(3{\cdot}28H)^n$$

where b = width of the contraction, ft
H = water level, m, measured according to the standard[4,10]
$n = 1{\cdot}522b^{0{\cdot}026}$.

The equation is applicable to free flow—that is to say the water head in the constriction, h, should not exceed $0{\cdot}7H$ (both being measured from the plane section of the flume). In the cases of submerged flows measurement of both h and H is necessary. A correction term based on the observations is then required.

The standards contain curves and tables for the calculation of Q and the necessary correction for submerged flow.

2.4.4. *Installation and use*

Measuring flumes are usually cast in concrete on the site. When designing the flume, attention should be given to any future increases in flow, for instance, as a result of a rise in production.

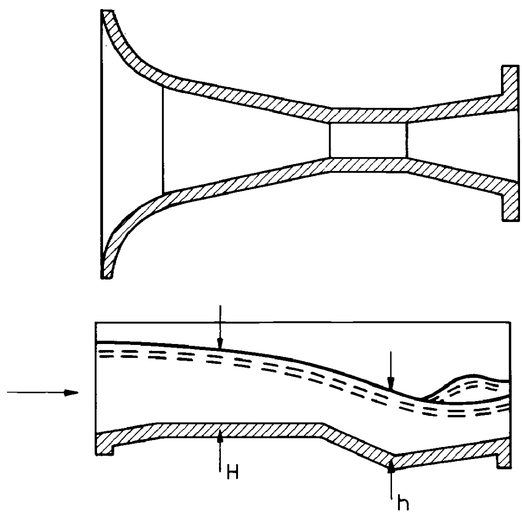

Figure 8. Parshall flume.

In order to prevent submerged flow in the flume, and thus more complicated calculations, a slope of reasonable gradient should be constructed downstream of the flume.

The measuring device should be mounted in a separate measuring chamber. When a bubble tube is used (to be preferred) the measuring chamber should be constructed sufficiently deep to allow the bubble tube to be mounted with its orifice on a level with the bottom of the flume. Otherwise as for gauges for weirs (see Section 2.1.4.).

To ensure steady enough flow, measuring flumes should have a straight flow path about 10 times as long as the channel width. If this cannot be arranged, gratings or guide baffles should be installed.

As they are self-cleaning, flumes are reliable in their operation and little maintenance is called for. For waste-water systems conducting fibres they are therefore preferable to weirs. For satisfactory operation they require a slightly smaller level drop than weirs, but are more expensive to install, especially in already existing plants.

2.5. Measurement by dilution methods

A concentrated solution of a substance (tracer) that can easily be determined at high dilutions is injected into the medium at a constant, known rate, usually for about 10 min. The concentration of the tracer is then measured far enough downstream for complete mixing to have taken place. Provided that no water has been drawn from or run into the system between the point of injection and the point of measurement the following equation will be applicable:

$$QC_0 + qC_1 = (Q + q)C_2$$

where q = injected flow, m^3/s
C_0 = background concentration of tracer in the stream
C_1 = concentration of tracer in injected flow
C_2 = concentration of tracer after mixing.

C_0, C_1 and C_2 must be expressed in the same units. If, as normally is the case, $C_0 = 0$, the equation reduces to

$$Q = q(C_1 - C_2)/C_2$$

If q is negligible compared to Q the general equation reduces to

$$Q = qC_1/(C_2 - C_0)$$

and if furthermore the background concentration is zero

$$Q = qC_1/C_2$$

If part of the stream is branched off between the injection and measuring points, Q applies upstream the branching point, and if effluents are added at a branching point Q applies downstream. If the added stream is Q_1

$$Q = qC_1/C_2 - Q_1$$

(i) *Salt dilution.* For occasional measurements an inorganic salt is a suitable tracer. Normally the concentration of the cation is measured. Modern methods of analysis (flame photometry or atomic spectrometry) permit measurement of extremely low concentrations. Sodium salts cannot be used in pulp and paper mill systems on account of the high and variable background. Potassium and lithium salts are usually superior in this respect.

The injection can be carried out by means of a dosage pump. Before the injection, samples are taken for background determination. During the injection at least three samples are taken for analysis. Significant differences between the analyses of the samples may depend on inconstancy of the flow, on incomplete mixing of the injected tracer or on unsatisfactory operation of the pump.

(ii) *Isotope dilution.* Radio-isotopes offer high sensitivity and an almost constant background (natural radioactivity). The method is expensive, however, and requires specially trained personnel. The isotopes ^{82}Br and ^{24}Na are suitable for waste-water systems.

(iii) *Use of dyestuffs.* Dyestuffs are usually unsuitable for use in pulp and paper mills effluents because they are unstable and easily adsorbed on particles. Their colour is often dependent on the pH.

The tracer must be injected in such a way as to ensure thorough mixing. In pipe systems advantage should be taken of the possibility of injecting the tracer before a pump or valve. Special care should be taken when concentrated salt solutions are used because, owing to their high density, they do not mix readily with the effluent unless there is considerable turbulence.

The flow should be fairly constant during the measurement procedure. The method can also be used to measure variations in flow; this requires a large number of samples taken at frequent intervals.

2.6. Measurement of flow velocity

2.6.1. *Measurement with a velocity-indicating instrument*

If the flow area is known the flow can be calculated from the velocity of flow, as measured with a velocity-indicating instrument. Since the velocity varies over a cross-section of the flow, it is necessary to know the approximate velocity distribution across the section. For this, measurements of at least 3 to 5 points are required. From the velocity distribution the mean velocity $\bar{v}$ is calculated. From this and the area of flow, F, the flow Q is obtained:

$$Q = \bar{v}F$$

The precise determination of the position of each point of measurement will be required. The calculations are time-consuming and the method is impracticable.

For estimating the order of magnitude of a flow it will suffice to measure the velocity at one point, preferably in the centre of the flow where at smooth flow the velocity is a maximum. The approximate mean velocity is then given by

$$v_{\max} > \bar{v} < 0{\cdot}5\ v_{\max}$$

If the measurement of flow velocity, in spite of its limited accuracy, is to be used in a permanent installation, the measuring device should be mounted where the deviation from the mean velocity is least. This can be determined experimentally.

When measuring flow velocity in channels and flumes, account must be taken of the fact that the depth, and thus the area of flow, usually varies with the velocity.

(i) *Pitot tubes.* The difference between dynamic and static pressure in the system may be measured by means of a pitot tube connected to a differential manometer. The velocity at the point of measurement is given by:

$$v = \sqrt{2g\Delta h}$$

where Δh is the differential pressure in metres of water column. Pitot tubes are inexpensive and can often be mounted at connection points or pipe joints, but they are especially sensitive to the deposition of solid particles.

(ii) *Current meters.* A current meter consists of high-pitch impeller with a low-friction bearing. The speed of rotation, which is dependent on the flow velocity, is transmitted to a recording instrument. The flow velocity is read from a calibration curve which should be checked periodically.

Current meters are expensive and their sensitivity is low at both low and high velocities of flow. The accuracy is affected by corrosion and growth.

2.6.2. *Measurement of time of passage*

A salt solution or a radio-isotope is injected instantaneously and the time is measured for it to reach a given point or to pass between two given points. For a salt solution the interval is measured conductometrically, and for a radio-isotope a suitable detector is used. For measurements in tubes, a radio-isotope has the advantage that the sensing element can be placed outside the tube, whereas the device for conductometric measurement must be mounted within the tube.

Because of the variation in velocity over the cross-sectional area the volume injected will spread in the direction of the flow. For radio-isotopes, concentration time curves can be recorded with a two-channel highspeed recorder. The mean velocity is obtained from the distance between the centres of gravity of the areas under the curves. When only an indicating instrument is available, the time to produce the maximum deflection is noted.

When a recorder is used, the time should not be less than 5 s, and with an indicating instrument, not below 10 s.

For rough estimates in a straight flume or channel, it suffices to measure the time for a floating object (such as a cork or wood chip) to pass between two points. The value so obtained is the velocity in the surface. The mean velocity can be taken as about 85 per cent of this value. Chips and surface indicators are not good indicators where stock consistency rises to 0·75 per cent or more. In these cases a neutral density plug whose dimensions approach the cross-sectional area is more satisfactory.

2.7. Miscellaneous measuring methods

When, as is often the case, the flow cannot be measured directly, usually because the system is inaccessible for the installation of measuring equipment, other methods must be resorted to.

If the system includes vats or containers that are accessible for measurements of level, the flow in the inlet can be obtained from the rate at which the level rises on closing the outlet valve.

Where feasible the effluent may be diverted to a suitable container and the time required to fill it determined. Since the time for reasonably satisfactory measurement should not be less than 10 s, 1 and 2 m^3 containers will suffice for flows less than 6 and 12 m^3/min, respectively.

If the concentration of the liquor before and after an evaporator and either the inlet or the outlet flow are measured by any suitable method, the other flow can be calculated. Foaming (liquor-containing condensate) introduces an error.

When no other possibility exists the flow can be calculated from the pulp concentration before and after a thickener or a filter unit and the rate of pulp output. The largest source of error lies in the determination of the inlet pulp concentration. If water is added to the system between the sampling points, the respective flows must be measured and corresponding corrections made.

3. SAMPLING

3.1. Planning of sampling stations

At outlets where continuous control of outlet water is to be carried out, apparatus for automatic sampling at frequent intervals should be installed. Automatic techniques give considerably more reliable results than manual sampling and, in the long run, are cheaper.

If a station for sampling and flow measurement cannot be situated indoors a heated shed will be required for housing the equipment. When compressed air is to be used, a compressor (to be preferred) or compressed air conduits at a frost-free depth will also be required.

3.2. Sampling methods

3.2.1. *General considerations*

The choice of sampling device must take into account the characteristics of the system. Waste-water systems of pulp and paper mills call for a corrosion-resistant sampler, where operation is not influenced by microbial growth or by the presence of suspended materials (fibre, filler additives, bark sludge). Furthermore, it should be easy to assemble and to dismantle for inspection and maintenance, the need for which should be limited.

Representative samples are sometimes difficult to obtain by automatic sampling of waste waters containing oil, dense suspended particles or other not easily dispersed constituents.

3.2.2. *Sampling in flumes and channels*

(i) *Scoop-type sampler.* A scoop-type sampler consists of an endless chain or a wheel to which one or more sampling scoops are attached. The sampler is mounted at the flume or channel so that when in the lower position the scoops fill while in the upper position they empty into a collecting vessel. By adjusting the speed of the wheel or chain the sampling interval may be changed. Growth and sedimentation in the scoops may occur. The extent to which the scoop is filled may be dependent on the flow velocity. Scoop-type samplers function unsatisfactorily in most types of waste water.

(ii) *Pneumatic samplers.* In pneumatic samplers (*Figure 9*) the sample is collected in a chamber which is then closed. The sample is forced through a tube to a collection vessel by means of compressed air. The opening and closing of the chamber is operated by a magnetic valve or, more reliably, by compressed air. In pneumatic samplers the sampler either remains open between sampling periods and closes while the sample is being conveyed to the collection vessel, or remains closed except for the moment when the sample is admitted to the sampling chamber.

Samplers of the 'open' type are not to be recommended because of the risk of disturbing microbial growth and accumulation of suspended material in the sampling chamber.

The sampling chamber should have a gasket, made of a material, such as Neoprene, which possesses high resistance to chemicals and is elastic enough to provide reliable sealing in the presence of fine suspended particles, such as fibre and filler. The gasket should be easily replaced.

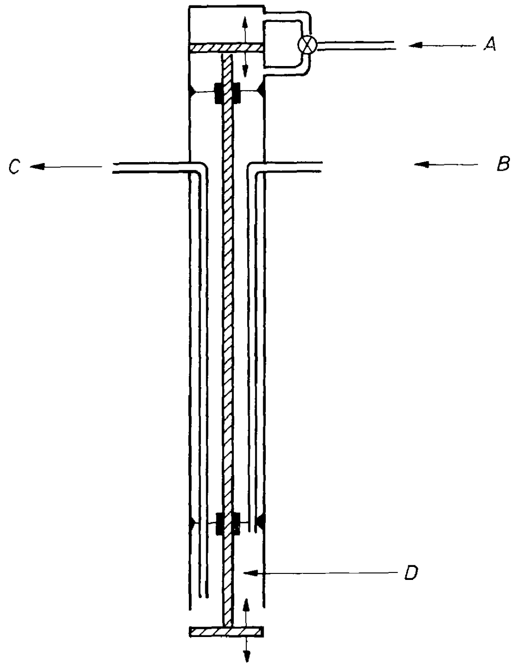

Figure 9. Pneumatic sampler. *A*, High pressure lead. *B*, Low pressure lead. *C*, Sample lead. *D*, Sample chamber.

For sampling in systems containing coarsely suspended material there is invariably a risk of leakage or deposition; the sampler should then be furnished with a device, preferably an automatic one, for back-blowing the sampling leads and chamber.

Pneumatic samplers are less suitable for use in systems containing volatile matter.

(iii) *Sampling by partial flow.* A suitable part of the flowing medium can be diverted by pumping through a submerged tube with the orifice at a suitable height above the bed of the flume (see Section 3.3.1.). The diverted flow may then be led either to a collection vessel or back to the flume. This procedure offers no particular advantages over pneumatic samplers. The use of pumps for sampling in waste-water systems always involves a risk of clogging.

3.2.3. *Sampling from a tube*

There is at present no commercially available pneumatic sampler suitable for sampling from a tube under pressure. It is, however, possible to sample from a diverted flow. When the disposal of the excess part of the diverted flow, say to a flume, is inconvenient, sampling may be effected through a valve mounted on the pipe and opening at intervals. Sealing difficulties can arise through a build-up of suspended material on the pressure side. The volume removed will vary with the pressure in the pipe.

3.2.4. *Size of sample*

The volume removed in the sampling process should not be so large that the total volume collected in a sampling period is difficult to handle. On the other hand, the sample should be large enough for the loss during transport to the collecting vessel to be negligible. This means that in practice the sample size will be between 50 and 100 ml. Samplers taking less than *c*. 40 ml should not be used (this applies to many of the marketed scoop-type samplers).

3.2.5. *Time- and quantity-dependent sampling at intervals depending on the flow*

Sampling at constant intervals can normally be recommended only where the flow and the composition of the effluent varies only moderately as may be the case for main outlets and alike. Sampling at intervals depending on the flow should otherwise be carried out. This can be done following two different principles:

(i) *Constant interval, variable volume.* The sampler is mounted at a weir or a measuring flume in the same way as a gauge. The sample chamber consists of a tubular container whose cross-sectional area increases from base to top. The dimensions of the container are such that at a certain exterior water level the volume taken into the chamber on sampling is directly proportional to the flow. The water in the chamber is transferred pneumatically at intervals to the collection vessel. From the amount of water and the number of samples collected in a sampling period the mean flow and total discharged volume for the period can be calculated. The sampling method is suitable when a fairly accurate and cheap procedure is desired for simultaneous sampling and measurement of a flow. For the design of the sampling device, see Section 3.2.2.

(ii) *Constant volume, variable interval.* The procedure is useful when there are rapid and large variations in volume and concentration of a major component. The flow-measuring device is connected to an additive counter. When a predetermined volume has passed, a signal activates the sampler.

3.3. Installation and operation of sampler

3.3.1. *Installation*

If the medium carries much suspended material it may be difficult to obtain representative samples. When directions for installation are not supplied it will be necessary to find the correct depth and angle to the flow by experiment. This can be done by comparison with samples taken manually at the same time, just downstream of the sampler.

Care should be taken that the sampler is mounted at a point where the sampled water is well mixed. This applies especially to such sewer systems which receive waste waters of widely varying densities.

The sampler should be mounted so as to be easily accessible for inspection and maintenance. It should be readily dismantled for any repair work. For sampling water containing much sand (from barking units, for instance) the distance of the sampler from the bottom of the channel should be such as to prevent the coarser sand particles from entering the sampler.

Sampling in corrosive atmospheres calls for careful selection of the material from which the sampler is made; moreover, all electrical components should be mounted in a separate room, or, failing that, in a ventilated chamber.

If the sampler cannot be located in an existent building it should be housed in a heated shed.

3.3.2. *Sampling period*

For permanent installations in waste-water systems where the variations in flow or concentration are moderate, cumulative samples may be collected for each shift or for each 24 h. From sewers from production units, in which there may be sudden discharges of strongly polluting material, samples should be taken during each shift.

For occasional investigations, for example, of a particular process stage, a sampling period appropriate to the individual circumstances will be chosen.

3.3.3. *Sampling interval*

At the main outlet an interval of 5 to 10 min between sampling may be recommended. For effluents varying greatly in quantity and composition, the interval should be as short as possible (maximum 1 min). Should the variations tend to be periodic, the frequency of sampling should differ from that of the variation. The cumulative sample may otherwise give a false picture of the actual conditions—for instance, fibre losses may be underestimated.

It should be noted that a sampler often functions better if the sampling intervals are short (less likelihood of sedimentation, incrustation, etc.).

3.4. Direct measurement of pH and conductivity

Certain properties of the waste water can and should be measured directly in an outlet to a watercourse. This is especially true of pH and conductivity, as sudden, large changes in the recorded values will indicate operational faults, which might cause serious damage to the watercourse. It is recommended to incorporate in the recording system an alarm that continues to operate until the appropriate counter-measures have been taken and acceptable values are again being recorded.

Conductivity and pH meters should preferably be equipped with a device for automatic cleaning of the sensing component.

4. ADDITIONAL MEASURES

When equipment for flow measurement and sampling are to be installed certain additional measures may be desirable or necessary, especially in older plants. These measures may be summarized as follows:

(i) The waste water system should be checked with regard to the type of waste that is transported in the different sewers. The exact location of the sewers and their possible intercommunications (for instance in the ground) should be established. This is of special importance for sewers into which strongly polluting waste is discharged, either normally or accidentally upon breakdown of operation or through carelessness of the personnel. It should be noted that expensive measures for abating pollution may be vastly reduced in efficiency if the sewer system is incompletely mapped down.

(ii) The existing sewer system should be properly labelled. The labelling should not be neglected upon changes of the system. When the use of a conduit for transporting waste is discontinued, the conduit should be disconnected and removed.

(iii) The effluents from different process unit should if possible be transported in separate sewers, at least initially. Combined sewers should be separated and unnecessary intercommunications removed when opportunities for such work arise.

5. REFERENCES

[1] W. F. Coxon. *Flow Measurement and Control*, Heywood and Co., London, 1959.

[2] J. J. McKeown. *Procedures for Conducting Mill Effluent Surveys*, National Council for Stream Improvement, Bull. 183, New York, 1965.

[3] American Society of Mechanical Engineers, *ASME Power Test Codes*, part 5, chapter 4: Flow Measurement by means of Thin Plate Orifices, Flow Nozzles and Venturi Tubes, 1959.

[4] American Standard for Testing and Materials, *1966 Book of ASTM Standards*, part 23, p. 476; D 1941–62T: Open Channel Flow Measurement of Industrial Water and Industrial Waste Water by the Parshall Flume.

[5] Deutscher Normenausschuss, DIN 1952: VDI-Durchflussmessregeln, 1948.

[6] Deutscher Normenausschuss, DIN Entwurf 1952: Durchflussmessung, 1963.

[7] International Organisation for Standardisation, ISO Recommendation R 541: Measurement of Fluid Flow by means of Orifice Plates and Nozzles, 1967.

[8] International Organisation for Standardisation, ISO Recommendation R 555: Liquid Flow Measurements in Open Channels. Dilution Methods for Measurement of Steady Flow; part 1, Constant Rate Injection Method, 1966.

[9] International Organisation for Standardisation, ISO Draft Recommendation 948: Liquid Flow Measurement in Open Channels by Velocity Area Methods, 1965.

[10] Ohio River Valley Sanitation Committee, *Planning and Making Industrial Waste Surveys*, Cincinnati 1952.

[11] Svenska Teknologföreningen, Handbok 62, *Mängdmätning med munstycke och strypfläns vid genomströmning*, 1938.