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Liquid flow measurement in open channels — Dilution methods for measurement of steady flow — Part II : Integration (sudden injection) method

Mesure de débit des liquides dans les canaux découverts — Méthodes de dilution pour le mesurage du débit en régime permanent — Partie II : Méthode par intégration (injection instantanée)

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FOREWORD

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Draft International Standards adopted by the Technical Committees are circulated to the Member Bodies for approval before their acceptance as International Standards by the ISO Council.

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It has been approved by the Member Bodies of the following countries :

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Liquid flow measurement in open channels – Dilution methods for measurement of steady flow –

Part II : Integration (sudden injection) method

1 SCOPE AND FIELD OF APPLICATION

This International Standard deals with the measurement of flow in open channels, under steady flow, by the dilution method using the integration (sudden injection) procedure. This method is applicable to the measurement of the flow in open channels where the degree of turbulence is sufficiently high to ensure efficient mixing of the injected solution throughout the whole flow.

The following clauses describe the principle of the method, the choice of a measuring reach, recommendations relating to the duration of injection and sampling, the operational procedure, the principal tracers used and their analyses, and finally, the calculation of errors inherent in the method.

NOTE – Although this method is mostly used for smaller rivers, in 1970, discharges up to 2 000 m³/s were measured with confidence using the methods described here and it is anticipated that the measurement of flow rates greater than this will not present insuperable difficulties.

2 REFERENCES

2.1 ISO 555, *Liquid flow measurement in open channels – Dilution methods for measurement of steady flow – [Part I :] Constant rate injection method.*

2.2 ISO 772, *Liquid flow measurement in open channels – Vocabulary and symbols.*

2.3 "A simple method of fitting an asymptotic regression curve." *Biometric Magazine*, Vol. 12, p. 323, September 1956.

3 TERMINOLOGY

For the purposes of this International Standard, the definitions given in ISO 772 apply.

4 UNITS OF MEASUREMENT

The basic units used in this International Standard are : metre, kilogram and second.

5 PRINCIPLE OF THE METHOD

A solution of a suitably selected tracer is injected for a short duration into a cross-section at the entry to the measuring reach of the channel, in which the rate of flow is constant throughout the test period.

At a second cross-section at the downstream end of this reach, far enough from the former for the injected solution to be uniformly diluted throughout this cross-section, samples are taken over a period of time t sufficiently long to ensure that the whole of the tracer has passed the second cross-section.

Since all the tracer injected passes through the sampling cross-section the following equation is obtained :

$$M = Q \int_0^t (C_2 - C_0) dt$$

where

M is the mass of the tracer injected;

Q is the volume rate of flow of the stream;

C_2 is the concentration of tracer at the point of sampling during a period of time dt , in kilograms per cubic metre;

C_0 is the concentration of tracer in samples of stream water in its natural state, in kilograms per cubic metre.

This equation implies that the value of the integral

$$\int_0^t (C_2 - C_0) dt$$

is the same at each point of the sampling cross-section, and the solution injected can be considered to be well mixed with the stream if this requirement is satisfied.

If V is the volume of solution injected and if C_1 is the concentration of tracer in the solution, then

$$M = C_1 V$$

and

$$C_1 V = Q \int_0^t (C_2 - C_0) dt$$

from which

$$Q = V \left/ \left(\int_0^t \frac{C_2 - C_0}{C_1} dt \right) \right. \quad \dots (1)$$

The integral of equation (1) can be determined in two different ways :

- either by measuring the concentrations C_0 , C_1 and C_2 (see 5.1) independently of each other,
- or by determining the ratio $(C_2 - C_0)/C_1$ by diluting C_1 in known proportions, this being known as the method of comparative dilutions (see 5.2).

5.1 Methods of direct measurement of concentration

5.1.1 Multiple consecutive samples

Consecutive samples are taken from a fixed point in the sampling cross-section, the first before the arrival of the tracer and the last after all the injected tracer has passed this point.

The rate of sampling is kept constant during the whole of the sampling period. If m samples are taken during consecutive periods $t_1, t_2, t_3, \dots, t_r, \dots, t_m$ and their volumes are respectively $V_1, V_2, V_3, \dots, V_r, \dots, V_m$ and their concentrations $C'_1, C'_2, C'_3, \dots, C'_r, \dots, C'_m$, it is then possible to determine the mean volume rate of sampling q by the formula :

$$q = \left(\sum_{r=1}^m V_r \right) / \left(\sum_{r=1}^m t_r \right) \quad \dots (2)$$

and the dilution ratio N by the formula :

$$N = M / \left\{ \sum_{r=1}^m V_r (C'_r - C_0) \right\} \quad \dots (3)$$

The volume rate of flow Q of the stream is $Q = qN$.

In this method, samples of natural stream water are taken before, during and after the passage of the tracer, upstream of the point of injection.

5.1.2 Average sample (single sample)

A single sample is taken at a constant rate q , from a fixed point of the sampling cross-section for a time t , sufficient for the whole of the tracer to have passed this point.

The mass of tracer taken per unit of time is $C_2 q$. The total mass of tracer taken is therefore

$$\int_0^t C_2 q dt = q \int_0^t C_2 dt \quad \dots (4)$$

and if $\bar{C}_2$ is the concentration of the average sample,

$$\bar{C}_2 = \frac{1}{t} \int_0^t C_2 dt \quad \dots (5)$$

from which

$$\int_0^t (C_2 - C_0) dt = (\bar{C}_2 - C_0) t \quad \dots (6)$$

can be deduced, so that

$$Q = \frac{VC_1}{t(\bar{C}_2 - C_0)} \quad \dots (7)$$

NOTE — This method may be less suitable than those described in 5.1.1 or even 5.1.3 when the period of passage of the tracer is prolonged.

5.1.3 Average samples (successive approximations)

When it is feared that sampling cannot be carried out for a period of time sufficiently long for the solution to pass completely throughout the sampling cross-section, it is advisable to proceed in the following manner :

If t is the estimated period of passage of the tracer throughout the sampling cross-section, n average samples will be taken at a constant rate from one fixed point of the sampling cross-section, all n samples to have the same time-origin prior to the arrival of the tracer. Sampling is terminated at time $t_1, t_2, t_3, \dots, t_n$.

One alternative, which is the safest but which results in either greater tracer masses or lower concentrations for sampling terminated at time $t_2, t_3, \dots, t_n$, consists in assuming $t_1 = t$.

In this case, if t has not been under-estimated all samples indicate the true rate of flow.

If t has been under-estimated, the apparent flow rate calculated from the first samples will be too high but some samples such as $t_4, \dots, t_n$ will give the true value (figure 1). In the most unfavourable case, an asymptotic fit of the curve of Q against t will lead to the correct flow value¹⁾ (figure 2).

Another alternative which is more economical consists in assuming for example that :

$$t_3 = t \text{ with } t_1 < t \text{ and } t_2 < t \\ t_4 > t, \quad t_5 > t, \quad t_n > t$$

- if t has been rightly estimated, the analysis of samples $t_3, t_4, t_5, \dots, t_n$ will lead to the true value of the flow rate; t_1 and t_2 will lead to values which are too high (figure 1) (t_3 will be at the concentration assumed as optimal for analysis, t_4, t_5 and t_n at smaller concentrations);

1) See 2.3.