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Measurement of water flow in closed conduits — Tracer methods — Part VI : Transit time method using non-radioactive tracers

*Mesure de débit de l'eau dans les conduites fermées — Méthodes par traceurs —
Partie VI : Méthode du temps de transit utilisant des traceurs non radioactifs*

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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 :

Australia	Germany	Romania
Belgium	India	Turkey
Chile	Italy	United Kingdom
Finland	Mexico	Yugoslavia
France	Netherlands	

No member body expressed disapproval of the document.

Measurement of water flow in closed conduits — Tracer methods — Part VI : Transit time method using non-radioactive tracers

0 INTRODUCTION

This International Standard is the sixth of a series of standards covering tracer methods of water flow measurement in closed conduits.

The complete series of standards will be as follows :

- Part I : General.
- Part II : Constant rate injection method using non-radioactive tracers.
- Part III : Constant rate injection method using radioactive tracers.
- Part IV : Integration (sudden injection) method using non-radioactive tracers.
- Part V : Integration (sudden injection) method using radioactive tracers.
- Part VI : Transit time method using non-radioactive tracers.
- Part VII : Transit time method using radioactive tracers.

1 SCOPE AND FIELD OF APPLICATION

This International Standard specifies the transit time method using non-radioactive tracers for the measurement of water flow rate in closed conduits.

2 PRINCIPLE

Flow-rate measurement by the transit time method (formerly called "Allen velocity method") is based on measuring the transit time of "labelled" fluid particles between two cross-sections of the conduit a known distance apart. Labelling of the fluid particles is achieved by injecting a tracer into the flow upstream of the two measurement cross-sections (i.e. detector positions) and the transit time is determined from the difference of the mean arrival times of the tracer at each of the detector positions.

Under certain conditions (see clause 3), the flow rate q_v is given by

$$q_v = \frac{V}{\bar{t}}$$

where

V is the volume of the conduit between the detector positions;

$\bar{t}$ is the transit time of the labelled fluid particles.

In general, the theoretical condition for the validity of the formula is that the measuring section be "closed to diffusion" : i.e. that the ratio of the local velocity to the longitudinal dispersion coefficient be equal at both ends of the measuring section.

In practice this condition is fulfilled when the conduit has a constant cross-section.

The value of $\bar{t}$ is obtained by measuring the difference in abscissae of characteristic points (in theory : centre of gravity, but in practice other characteristic points may be found, see 5.6) of recorded distributions, corresponding to concentration/time distributions or their integrals, obtained at each detection cross-section. The signal from the detectors shall be proportional to the tracer concentration. The value of the proportionality coefficient and hence the absolute concentration value need not, however, be known exactly.

3 REQUIRED CONDITIONS

3.1 Tracer

The tracer shall meet the general requirements defined in clause 5 of part I.

Sodium chloride is commonly used as the tracer, mainly because of the linear relationship between the conductivity of its solutions and concentration over a wide range of concentrations, and the ease with which it can be measured with an appropriate electrode system.

3.2 Mixing of tracer

The tracer must be sufficiently mixed with the flow at the first detector position for the recorded concentration/time distributions at both detectors to be adequately representative of the mean flow in the conduit (see 4.1). The selection of the positions for the injection and the detectors is controlled by the fluid velocity, tracer dispersion, and the conduit layout. The conditions for this selection are dealt with in clause 4.

3.3 Test procedure

The procedure for the preparation and injection of the concentrated solution, which in practice should be injected as rapidly as possible to minimize the duration of the concentration/time function, is covered in 5.2 and 5.3. The internal volume of the measuring section must be determined with sufficient accuracy (see 5.7). Other requirements relating to the tests and the calculation of the transit time from the data are given in clause 5.

4 CHOICE OF MEASURING LENGTH

In the transit time method, the measuring length consists of two parts :

- the length of conduit between the injection point and the position of the first detector;
- the length of conduit between detectors.

4.1 Length of conduit between injection and first detector

When the concentration of tracer C_2 at only a single point in each measurement cross-section is measured, the length of conduit between the injection point and first detector shall be equal to or greater than the mixing distance.

The mixing distance is defined as the shortest distance at which the maximum variation of $\int_0^\infty C_2 dt$ over the cross-section is less than some predetermined value (for example 0,5 %) — see clause 6 of part I. This distance can be calculated theoretically according to 6.2.1 of part I. Figure 3 of the latter shows the measured variation of mixing distance with respect to variations in $\int_0^\infty C_2 dt$ across the cross-section, for various injection arrangements. Methods of reducing the mixing distance are described in 6.3 of part I.

There are, however, insufficient experimental results available to relate variations in $\int_0^\infty C_2 dt$ at the first detector position to the overall accuracy of transit time as determined from concentration measurements at single points in the measurement cross-sections.

If the measurement of concentration at each detector position represents the mean concentration in the cross-section (for example by simultaneous measurements at many points or by a detector sensitive to tracer across the cross-section), the degree of mixing required at the first detector position is not as great as that corresponding to the mixing distance. In these circumstances the necessary distance between the injection position and the first detector position may be considerably less than the mixing distance.

For example, in the application of the transit time method for the on-site testing of hydraulic machines, the use of a multipoint injection of sodium chloride and a suitable arrangement of electrode detectors can enable flow-rate to be measured accurately with a distance between injection and first detector equivalent to only seven conduit diameters (see annex A).

This application of the method has the advantage that only short lengths of conduit are required but has the disadvantage of necessitating the installation of injection points and electrode systems within the conduit.

The length of conduit between the injection position and the first detector should preferably contain no pipe fittings or sections likely to increase significantly the longitudinal dispersion of tracer at the detector positions.

Examples of such fittings and sections are valves, flow regulators and flow distribution headers.

4.2 Length of conduit between detector positions

The length of conduit necessary between the detector positions depends on the linear velocity of the fluid, the spatial dispersion of the tracer at the detector positions and the required accuracy of the measurement of transit time.

The length of straight conduit (L) between detector positions, the various ratios (p) of the transit time to the mean time for the tracer "pulse" to pass each detector position (i.e. corresponding to the passage of 99,7 % of the tracer) and the various lengths of conduit (N) between the injection and first detector positions, are related to each other by the following formula :

$$L = 4,25 p (p + \sqrt{N})$$

where L and N are expressed in numbers of conduit diameters.

This relationship is shown graphically in figure 1.

If the concentration/time distributions are recorded on a single-channel recorder, it is necessary for the length of conduit between detectors to be greater than the mean spatial dispersion of the tracer at the detector positions so that the recorded distributions do not overlap ($p > 1$).

If a multi-channel recorder is used, this distance can be reduced, but it is necessary that for accurate measurement of transit time the length of conduit between detectors is not less than a half of the mean spatial dispersion of the tracer. For guidance, it is recommended to use in practice $p \geq 0,5$.

Care must be taken that there is no interaction between the detector points in the conduit during the passage of the tracer. For example, if sodium chloride is used as a tracer and the change in conductivity of the water is the detected parameter, then the "pulse" must not be so long that its presence is sensed simultaneously at both detector electrodes. This is achieved by having $p > 1$ in the case of a common measuring circuit.

4.3 Measuring section

For the highest accuracy of flow measurement, the length of conduit between detector positions shall consist of a straight pipe of uniform cross-section and shall contain no pipe fittings or sections where dead water zones are likely to affect the concentration/time distribution measured at the second detector.

Examples of such fittings and sections are valves, flow regulators, abrupt changes of cross-sectional area, closed-ended branch pipes or sharp bends.

The overall accuracy of the flow rate measurement is dependent on the accuracy with which the internal volume of the measuring section is determined.

4.4 Losses and additions

Additions of fluid upstream of the first detector position, of the same nature as the fluid in the conduit, do not affect the result provided that this fluid is mixed with the main flow at the first detector position.

Losses of fluid from the conduit upstream of the first detector position do not affect the result but, if the tracer is not completely mixed at the point of loss, the amplitude of the concentration/time distribution at the detector positions may be affected and its value changed by a constant factor.

Losses or additions of fluid in the length of conduit between the detector positions would cause serious errors in the measurement of flow-rate. Consequently, it is essential that the conduit between the two detector positions contain no branch connections and be free from leaks.

5 PROCEDURE

5.1 Location of injection points

The number and position of injection points located at the injection cross-section depend mainly on the length of conduit between the injection position and the first detector position and the method of measuring the tracer concentration at the detector positions (i.e. "averaging" method or single-point sample — see 4.1, 4th paragraph).

When the available length of conduit between the injection point and the first detector is less than the mixing distance, it is recommended to proceed as mentioned in 6.3 of part I.

In particular, a suitable procedure is to use a central injection against the flow or any other symmetrical arrangement within the conduit. Alternatively, the injection may be made upstream of a pump or a turbulence-generating device. If several injection points are used, the system shall be so designed as to allow simultaneous injection at all points.

5.2 Preparation of the injection solution

The concentration of tracer in the injected solution shall be uniform. Homogeneity can be achieved by means of a mechanical stirrer or closed-circuit pump.

The required concentration will depend on the volume of fluid to be injected for each measurement, the volume flow rate to be measured, the degree of longitudinal dispersion of the tracer at the detector positions and the sensitivity of the detectors. In the case of a symmetrical mode of injection, an estimate of the maximum concentration C_m of tracer observed in a straight pipe of diameter D and without obstructions at N conduit diameters downstream of the fast injection point can be obtained from the expression :

$$C_m \approx \frac{3A}{4D^3N^{1/2}}$$

where A is the amount, by mass, of injected tracer.

It is of interest to note that the maximum concentration does not depend on the flow rate in the conduit.

When a turbulence-generating device is positioned in the measuring length between the injection position and the first detector, the maximum concentration may be greater than that derived from the above equation.

This expression may also be used to estimate the amount of tracer to be injected for each flow measurement from a knowledge of the sensitivity of the measurement detectors. The amount of injected tracer shall be such that the tracer concentration at the detector positions is within the linear range of the detector.

5.3 Injection of concentrated solution

In order to minimize dispersion of the measured concentration/time distributions, the tracer shall be injected as rapidly as possible with no "tailing" of the injected solution from the injection tubes within the conduit. This can be achieved by any of the following means :

- by means of injection valves at the extremity of each injection point (for example spring-loaded pop-valves); these valves shall open simultaneously, close rapidly and be leak-free;
- by ensuring that the injected solution is flushed into the conduit by a flow of tracer-free water;
- by breaking, with the aid of a suitable device, an ampoule containing tracer introduced into the conduit.

The tracer may be injected into the conduit by means of air or liquid pressure according to methods consistent with one of the above requirements.

It should be noted that at very high concentrations of tracer, the density of the injected solution may be significantly different from the density of fluid in the conduit. This will then affect the symmetry of the injected solution and the distribution of tracer at the detector positions.

It has been found that problems of stratification of the injected tracer solution have been avoided by adopting a lower limit of the mean velocity in the conduit. The value of this limit for satisfactory measurements to be made can