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Liquid flow measurement in open channels — Flow measurements under ice conditions

Mesure de débit des liquides dans les canaux découverts — Mesurage de débit dans des conditions de glace

Reference number
ISO 9196:1992(E)

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 9196 was prepared by Technical Committee ISO/TC 113, *Measurement of liquid flow in open channels*, Sub-Committee SC 7, *Special problems and methods of measurements*.

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Liquid flow measurement in open channels — Flow measurements under ice conditions

1 Scope

This International Standard deals with water discharge measurements in rivers and channels under ice conditions and provides information additional to that published in previous International Standards.

This International Standard does not specify measuring instruments and equipment, which are dealt with in other International Standards.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 555-1:1973, *Liquid flow measurement in open channels — Dilution methods for measurement of steady flow — Part 1: Constant-rate injection method.*

ISO 555-2:1987, *Liquid flow measurement in open channels — Dilution methods for the measurement of steady flow — Part 2: Integration method.*

ISO 748:1979, *Liquid flow measurement in open channels — Velocity-area methods.*

ISO 772:1988, *Liquid flow measurement in open channels — Vocabulary and symbols.*

ISO 1100-2:1982, *Liquid flow measurement in open channels — Part 2: Determination of the stage-discharge relation.*

ISO 1438-1:1980, *Water flow measurement in open channels using weirs and Venturi flumes — Part 1: Thin-plate weirs.*

ISO 3846:1989, *Liquid flow measurement in open channels by weirs and flumes — Rectangular broad-crested weirs.*

ISO 3847:1977, *Liquid flow measurement in open channels by weirs and flumes — End-depth method for estimation of flow in rectangular channels with a free overfall.*

ISO 4359:1983, *Liquid flow measurement in open channels — Rectangular, trapezoidal and U-shaped flumes.*

ISO 4360:1984, *Liquid flow measurement in open channels by weirs and flumes — Triangular profile weirs.*

ISO 4377:1990, *Liquid flow measurement in open channels — Flat-V weirs.*

ISO 5168:1978, *Measurement of fluid flow — Estimation of uncertainty of a flow-rate measurement.*

WMO (World Meteorological Organisation) Technical Note No. 117 (WMO No. 280), *Use of weirs and flumes in stream gauging.*

3 Definitions

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

4 Methods of water discharge measurement under ice conditions

Discharges of water can be measured under ice conditions using velocity-area methods, representative vertical methods, dilution gauging methods and by means of notches, weirs and flumes.

4.1 Velocity-area method

The principle of this method is described in ISO 748. For channels in which a surface layer of ice exists, the cross-sectional area of water flowing is taken as the area bounded by the bed line (or wetted perimeter) and the lower edge of the ice cover or slush. When flow is between layers of ice, the cross-sectional area also includes the area bounded by the lower ice layer and the lower surface of the ice cover or slush.

4.1.1 Selection of site

Discharge measurements under ice conditions are usually conducted at the same sites used for open channel measurements. The site may be unsuitable for observations if

a) more than 25 % of the cross-section is filled with slush, which is distributed unevenly over the cross-section;

b) dead zones occupy more than 10 % of the cross-section;

c) there are large areas with very low stream velocities (less than 0,3 m/s) which cannot be measured using current meters;

d) it is located in the backwater zone downstream of an ice gorge or ice jam;

e) there is a large open water area that remains unfrozen throughout the winter (but see 4.1.7);

f) it is liable to ice up owing to the freezing of water flowing through cracks on the surface of the ice cover indicating a possible breakup of the ice.

During the open water period, i.e. the period when there is no ice cover, sites additional to those normally used for water discharge measurements should be selected and marked on the banks. After the ice cover at the river reach selected for measurements has stabilized, a preliminary survey shall be made to select a longitudinal profile with a length equal to several widths and an appropriate number of holes shall be drilled along the profile to determine the occurence of slush and its distribution. In channels in which slush is found to be present, and when it is impossible to select another measurement reach, the measurement site shall be located at the centre of a uniform river reach.

Following the preliminary choice of the site, four or five holes shall be drilled across the river at equal distances to determine whether a regular velocity distribution exists and to establish the slush and ice thickness over the cross-section. Sites in which slush divides the river into separate streams shall be avoided. Braided channels which, in the open water period, are unsuitable for the measurement of discharge owing to the multiplicity of channels, may be suitable under winter conditions since the shallower channels may become blocked by slush or ice, leaving the main channel unblocked and flowing.

4.1.2 Frequency of water discharge measurements

The frequency of water discharge measurements during the winter period shall be such as to ensure a reliable estimation of the discharge. If conditions of stable ice cover exist, methods of hydraulic interpolation of winter flow may be used. However, under difficult conditions (such as those of unstable ice cover and incomplete freezing) measurements shall be taken as frequently as possible, since in this case the discharge is computed by the interpolation of the observed discharges. The time at which the daily discharge measurement shall be made shall be determined from experimental data to ensure that a discharge measurement as close as possible to the daily mean value, in rivers with considerable daily variations in discharge, is obtained.

4.1.3 Measurements of ice cover thickness

The ice cover thickness shall be measured using ice-measuring sticks which are lowered into holes drilled by hand or using mechanical drills. A zero reading may also be obtained.

4.1.4 Measurements of slush depth

For small depths of slush, measurements may be made using an ice-measuring stick. The slush depth is indicated by a change in the resistance to clockwise and anticlockwise rotation of the stick during its rise, i.e. the resistance to rotation increases when the slush layer is reached. For thicker depths of slush, measurements may be made in a similar manner using a special rod with a stop plate or a perforated disc attached to its end. In addition, current meters are frequently used for slush depth measurements. The current meter is lowered below the slush layers and is then gradually lifted until a zero reading is obtained. It should be borne in mind, however, that the actual slush depth may be somewhat smaller than that obtained by measurement, because a zero reading will also be obtained when the flow velocity decreases to 0,03 m/s to 0,04 m/s.

4.1.5 Determination of the effective depth

In an ice-covered channel, the effective depth is computed by subtracting the distance between the water surface and the bottom of the ice layer or slush from the total depth. The total water depth in the channel is measured using a rod or a cable-suspended sounding weight which is lowered using a winch; the latter method is similar to the depth measurements made from a boat under open channel conditions.

4.1.6 Flow velocity measurements

4.1.6.1 Use of current meters under winter conditions

Flow velocity measurements are carried out using current meters which are lowered into holes drilled in the ice cover. Special equipment has been developed (e.g. the arm-rotating installation, see figure 1) to enable a current meter to be lowered vertically into a hole and then for it to be rotated into a horizontal position. When a sufficiently deep and wide hole is available, a standard current meter with a suspended weight or a current meter on a rod may be lowered directly in a horizontal position. The current meter can be lowered using a suspension rod, a hand-operated cable (for small depths) or cable suspension equipment (for depths exceeding 3 m to 4 m). During velocity measurements, the device by which the current meter is held shall be located near the upstream side of the hole and shall be held rigidly at the upper edge of the hole to avoid the influence of vertical stage pulsation.

To prevent the current meter from freezing up when it is carried between one measurement site and another, it may be placed in a bucket containing heated water, or in a hot-air chamber. In measurement sites with shallow water depth, when the current meter is lowered on a rod without a tailpiece, care shall be taken to ensure the correct position of the current meter with regard to direction of flow at the site. In measurement sites where slush is present, vane current meters may be used in preference to cup-type meters which are liable to become blocked by slush ice.

Before the current meter is lowered, it is advisable to clean a passage in the slush by means of a steel or wooden pole with discs or by using an elliptical (round-shaped) weight suspended on a cable.

4.1.6.2 Selection of verticals for velocity measurements

The principles governing the location of velocity verticals under ice conditions are similar to those governing the location of velocity verticals under open channel conditions. These principles are as follows.

a) The minimum number of velocity verticals shall be 20, to ensure sufficient accuracy in velocity interpolation with respect to the channel width. Sections between successive verticals shall contain substantially equal proportions of the total water discharge.

b) The location of the vertical shall be such as to reflect the flow structure and the cross-section of the river bottom in the best possible way.

c) The distance between each vertical shall exceed the propeller diameter of the current meter; therefore, in very small rivers (brooks) there may be a small number of verticals.

The profile of the bottom at the gauging station shall be determined and the location of the verticals shall be selected prior to the formation of ice cover. When this is not feasible, approximately 20 holes shall be drilled along the cross-section at equal distances. (From hydrometric practice it has been found that 20 is the minimum number of holes required to reproduce the channel profile with sufficient accuracy.) Additional holes shall then be drilled to ensure sufficient accuracy of discharge measurements. The location of the edges of the channel cross-section shall be determined after all other necessary holes have been drilled, since it is easy to blunt the tip of the drill during this procedure.

4.1.6.3 Velocity measurements on a vertical

Owing to roughness of the lower surface of the ice sheet, the vertical velocity curve for the winter period differs from that under open-channel conditions. At the lower surface of the ice cover, the velocity distribution is very similar to that found in a pipe. The degree of reduction in velocity varies with the roughness of the lower surface of the ice.

If depth permits, the distance from the current meter axis to the river bed and that from the current meter axis to the lower ice surface should be no less than twice the diameter of the vane propeller.

Proceeding from the above criterion, the one-point method can be applied where the effective depth is about 0,30 m to 1,0 m; in this case, the current meter is located at 0,5 times the effective depth. To compute the mean velocity, a coefficient of 0,88 to 0,90 shall be applied (see ISO 748).

When the effective depth is equal to or exceeds 1,0 m, the two-point method is preferable (at 0,2, 0,6 and 0,8 times the effective depth). For greater effective depths, velocities may be measured at three points (at 0,15, 0,5 and 0,85 times the effective depth). However, to ensure a high accuracy of water discharge measurements, current velocities should be measured at six points, i.e. at 0,2, 0,4, 0,6 and 0,8 times the effective depth, and at the lower surface of the ice and the bottom of the river.

4.1.6.4 Computation of mean velocity on a vertical

When the two-point or three-point method is used, the mean velocity on a vertical shall be computed as the arithmetic mean of the measured values. For six-point measurements, the following equation (see ISO 748) shall be used to compute the mean velocity on a vertical:

$$\bar{v} = 0{,}1(v_{\text{surface}} + 2v_{0,2} + 2v_{0,4} + 2v_{0,6} + 2v_{0,8} + v_{\text{bed}})$$

4.1.7 Discharge measurements under partial ice cover conditions

If the water at the gauging station is not completely frozen over, discharge measurements in ice-covered sections can be carried out by using the methods specified in 4.1.6. In an ice-free part of the stream, open channel methods are applied using a gauging footbridge, cableway or a boat. If current meters cannot be used in the open water section of the stream, velocity measurements shall be made using floats; special floats or floating ice can be used to this end. During the period of ice drift on large rivers, the airborne method of velocity measurement is practically the only safe method to use. When drifting ice is distributed evenly over the river, the ice floes may be photographed to determine the flow discharge in the same way that flow discharge measurements are made using floats. Where there is an uneven distribution of ice over the river width, special floats shall be dropped from an aircraft into the open water part of the stream and additional photographs shall be taken to supplement the data.

4.1.8 Discharge measurements under multilayered ice conditions

When there are two or more ice layers at the measurement site, this site shall not be used and another site shall be selected for the discharge measurements. The discharges determined at this alternative site shall be correlated with the water levels at the permanent gauging station.

4.1.9 Discharge measurements under conditions of water flow above ice

If water flows over the ice surface as well as below, the discharges above and below the ice cover shall be obtained separately. The discharge below the ice cover shall be determined before water appears above the ice using the method described in 4.1.6. The cross-sectional area of the water flowing below the ice is determined using the data obtained in the preliminary measurements. However, the distance between the water surface and the upper surface of the submerged ice shall be measured.

The flow velocities above the ice shall be measured using procedures similar to those for ice-free channel discharge measurements.

If the channel freezes to the bottom in winter and is filled with ice and snow, it is advisable to make, before the start of the spring flood, a ditch in the snow 0,5 m to 1,0 m wide and no less than 20 m long to contain the first stream of water.

4.1.10 Safety practice for measurements from ice cover

As a general rule, to ensure the safety of personnel taking discharge measurements from ice cover, the ice thickness shall not be less than 0,1 m and the air temperature shall be below 0 °C.

The strength of the ice cover shall be tested using an ice chisel before a river is crossed. The speed of a vehicle crossing the ice cover shall be low (especially near the river banks) to prevent wave formation which could increase the pressure on the ice. Stricter precautions shall be taken where water flows above the ice, or when new ice layers are formed, since the ice cover is likely to be thin.

Operators taking measurements of discharge from the ice cover may use crampons to prevent slipping on the ice. In addition, a means of rescue shall be available.

4.1.11 Discharge computation

The computation of the discharge under ice cover shall be made in accordance with the rules for open channel discharge computations (see ISO 748), the only difference being that the effective rather than the total depth is used.

The cross-sectional area of flowing water is thus computed from the effective depths at the verticals and the distance between them. The total area of submerged ice and slush at the measuring points and the distance between them. During the freezing-over period in rivers, when the total river width differs considerably from the actual width of the cross-section of flow, two width values are needed: one width value is determined with respect to the water level in the ice holes and the other is determined with respect to the cross-section of flow.

4.2 Representative vertical method

4.2.1 Principle of the method

There is a close relationship between the mean flow velocity in the cross-section and the flow velocity at a given vertical. The discharge Q may thus be obtained from the values of flow velocity measured at a representative vertical in a cross-section using the following equation:

$$Q = C \bar{v} A$$

where

A is the cross-sectional area at the given water level;

$\bar{v}$ is the mean or unit velocity at the representative vertical;

C is a correction coefficient.

4.2.2 Selection of the vertical and determination of the correction coefficient

As a rule, for stable ice cover and in the absence of slush and other ice formations dividing the flow into separate jets, the correlation stated above, between the mean velocity of flow and the velocity at a representative vertical, is valid.

To obtain sufficiently accurate results, the choice of the vertical and the establishment of the relationship which is usually linear is made on the basis of 40 or 50 discharge measurements obtained using a multi-point or two-point method. Measurements shall be carried out under stable conditions and shall cover uniformly the total range of levels.

The measured discharge is plotted versus either the product of the cross-sectional area and the mean velocity of flow $\bar{v}$, on the given vertical, or the product of the cross-sectional area and the velocity flow $v_{0,2}$ at 0,2 of the effective depth where the flow velocity, according to the field data, is closest to the mean flow velocity. For practical purposes, the graph which gives the best curve shall be chosen.

The correction coefficient is obtained as the tangent of the curve as it crosses the origin of coordinates.

4.2.3 Limits of application

The location of a representative vertical in the cross-section of a stream shall be stable throughout the year within the total range of stage. The mean square deviation of the relation between the discharge obtained on the basis of the representative vertical method and the discharges actually measured shall not exceed 5 % to 10 %. The method is not applicable for slush, intermittent backwater and oblique current conditions.

4.2.4 Discharge measurement procedure

The usual procedure, as described in 4.1, shall be followed for measuring the discharge by means of the representative vertical method.

4.3 Dilution gauging method

To obtain the discharge using dilution methods, the degree of trace mixing in the stream shall be determined. The dilution methods are dealt with in ISO 555-1 and ISO 555-2.

Tracer mixing may be unsatisfactory in ice-covered streams, owing to an increase in the area of low velocity currents. Therefore a greater length of measuring reach may be required. Before the fluorometer tests are performed, all the samples of cold river water shall be heated to the same temperature to avoid temperature corrections. Heating can also be helpful to prevent the accumulation on the cuvette side walls of oxygen bubbles which pose difficulties for fluorometric measurements, especially where samples are taken from streams with a high concentration of dissolved oxygen.

4.4 Discharge measurements by notches, weirs and flumes during the winter period

4.4.1 Design and construction

Details on the selection of the best possible type of structure for a given stream, and on the specifications, calibration and operational procedures are given in ISO 1438-1, ISO 3846, ISO 3847, ISO 4359, ISO 4360, ISO 4377 and WMO Technical Note No. 117 (WMO No. 280).

4.4.2 Protection under ice conditions

Discharge measuring structures shall be heated by enclosing the structure and the adjacent channel section in an insulated shelter and by installing various heating sources (e.g. electric radiant heaters, oil stoves and propane radiant heaters) inside the hood of the shelter. Insulating shelters may be made on the basis of a number of designs. The hood of the shelter may be made of thin round timber, single or double pitched, which rests on the elements of the discharge measuring structure or on posts. The hood may be covered with spruce or fir twigs, straw or reeds. When snow falls begin, snow may serve as an additional means of insulation. Inside the shelter there shall be enough space to accomodate heaters and to provide free access to measuring devices. Either the roof or the walls shall be equipped with one or two manholes with heat-insulating doors.

When measuring discharges under ice conditions, ice upstream of the discharge measuring device shall be removed to a distance of about four times the maximum head at the gauging section and ice in the throat section of the measuring device shall be removed during the discharge measurement.

To avoid large accumulations of slush (which may block the intakes and stilling wells) upstream of the measuring device, the slush should be pushed through the cross-section of the flowmeter by hand or special slush-directing booms upstream of the flowmeter should be installed. These booms are floating structures consisting of one or two sets of logs attached to a vertical wooden screen 0,5 to 0,6 of the depth in height, which is submerged in the water. They are located at the entrance of the weir or flume to form a funnel converging at the throat section of the measuring device.

5 Stage measurement during the winter period

5.1 Discrete water level measurements

Holes shall be drilled in the ice around staff gauges, measuring piles and reference gauges of water level recorders at a gauging station, to ensure free observations and to prevent damage to the measuring equipment by ice cover rise or by its subsidence. Ice accumulations on staff gauges shall be carefully chipped off or removed by hot air supplied from a portable heater.

5.2 Stilling well

Stilling well and inlet pipes shall be constructed so that system operation during long periods of low temperature is ensured. To this end, the following requirements shall be met.

a) The well shall be constructed of non-conductive materials or it shall be insulated to prevent the penetration of cold air.

b) Where necessary and feasible, the lower inlet pipe shall either be wrapped with electric heat tape or contain electric heat tape so that the pipe may be kept free from ice. A commercial power source or a portable generator may be used as the heat source. A steaming apparatus with a sufficiently long steam hose may also be used to thaw the inlet pipe.

c) The lower inlet pipe shall be located below the bottom of the ice cover and the upper pipe shall be located above it. The recorder shall be operated on the lower inlet during the freezing period; however, if the inlet becomes frozen the upper inlet shall be used during the snowmelt or freshet while the lower inlet is thawing out.

d) Stilling wells mounted far enough in the bank to be below the frost line may be kept free from ice by means of a removable insulated subfloor. It shall be placed below the frost line but above the maximum anticipated water level during the freezing period. Provision shall be made for a free passage of the float and counterweight wires. The subfloor shall be removed before the snowmelt or freshet begins or alternatively a lightweight foam board that will float may be used.

e) As an alternative to d), an open-ended waterproof cylinder, of diameter greater than that of the float may be fixed vertically in the well and filled partially with a non-volatile petroleum distillate (see figure 2). At the beginning of the warm season, petroleum from the cylinder can be pumped out using a syphon. The cylinder shall be of sufficient length to ensure that its lower end is sufficiently below the minimum anticipated water level during the freezing period. Care shall be taken to ensure the free movement of both the float and the counterweight in the cylinder. The cylinder and petroleum distillate shall be removed before the spring freshet. If the distillate escapes from the cylinder, errors in the stage record may occur owing to the difference between the specific gravities of water and distillate; the stage height H_o of water above the gauge zero is less than the stage height H_k of petroleum (this difference is taken into account by adjusting the gauge zero before observations are begun).

f) A stilling well can be heated by using an electric or propane-fuelled heater or an electric light bulb where line power is available. The heater may be installed inside the float to prevent freezing of the stilling well. Overheating which may cause redundant steam formation shall be avoided; steam condensation in the form of hoarfrost may cause damage to the recorder and clock.

Sometimes it is advisable to heat water level recording devices to ensure continuous operation at low temperatures. However, certain instruments can operate at − 45 °C since they use special low temperature lubricants.

5.3 Pneumatic recorder

a) The orifice from which compressed gas exists into the stream shall be mounted below the lower surface of the ice cover usually observed at the gauging station;

b) The orifice shall be located at a sufficient distance from place where bottom ice is likely to occur, e.g. above rapids, to prevent the orifice becoming blocked.

c) If there is a risk of the orifice freezing over, the gas pressure shall be reduced to a value less than the full-scale pressure of the instrument. This will prevent any instrument damage occuring if the orifice becomes blocked.

d) The approach pipe to the orifice shall be buried at a depth sufficient to prevent damage due to scour during the freshet.

e) Since the mercury used in particular instruments solidifies at about − 40 °C, thus impeding the acquisition of water level data at low temperatures, the instrumentation shall be heated to the minimum operating temperatures stated by the manufacturer if uninterrupted operation is required. Battery power supplies may be waterproofed and placed in the stream to provide the necessary power.

6 Assessment of uncertainties in winter discharge measurements and computations

The assessment of errors in winter flow measurements and the computations of daily discharges shall be carried out in accordance with the recommendations given in ISO 748, ISO 5168 and ISO 1100-2.