International Standard 4365

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION•МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ•ORGANISATION INTERNATIONALE DE NORMALISATION

Liquid flow in open channels — Sediment in streams and canals — Determination of concentration, particle size distribution and relative density

Mesure de débit des fluides dans les canaux découverts — Sédiments dans les cours d'eau et les canaux — Détermination de la concentration, la distribution des particules et la densité relative

First edition — 1985-03-15

UDC 627.157 : 531.75 **Ref. No. ISO 4365-1985 (E)**

Descriptors : open channel flow, sedimentation, sediments, concentration, determination, density (mass/volume), evaporation, filtration, definitions.

Price based on 30 pages

ISO 4365-1985 (E)

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. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 4365 was prepared by Technical Committee ISO/TC 113, *Measurement of liquid flow in open channels*.

Printed in Switzerland

Contents

		Page
0	Introduction	1
1	Scope and field of application	1
2	References	1
3	Definitions	1
4	Units of measurement	2
5	Properties of sediment	2
6	Sampling	2
7	Concentration	2
8	Particle size analysis	3
9	Determination of relative density	6
10	Determination of particle size distribution characteristics	6
11	Data processing	6

Annexes

A	Determination of the concentration of suspended sediment by the evaporation method	7
B	Determination of the concentration of suspended sediment by the filtration method using filter paper	8
C	Determination of the concentration of suspended sediment by the filtration method using Gooch fritted glass crucibles	9
D	Determination of the particle size distribution of suspended sediment	10
E	Determination of the particle size distribution of bed load and bed material	13
F	Determination of relative density	28
G	Determination of particle size distribution characteristics	29

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Liquid flow in open channels — Sediment in streams and canals — Determination of concentration, particle size distribution and relative density

0 Introduction

In problems of sedimentation and sediment transport, a knowledge of the concentration and the characteristics of the sediment, such as particle size distribution and relative density, is of great importance. For this purpose, sediment samples are collected by suitable samplers and analysed in a laboratory. The results of the analysis are used in the calculation of sediment load, mean diameter and other characteristics.

1 Scope and field of application

This International Standard specifies methods for the determination of the concentration, particle size distribution and relative density of sediment in streams and canals.

The detailed methods of analysis are set out in annexes. Annexes A, B and C deal with the determination of suspended sediment concentration by evaporation and filtration. Annexes D and E deal with particle size analysis of suspended sediment and bed load and bed material sediment respectively. Annex F deals with the determination of the relative density of sediment, and annex G with the determination of particle size distribution characteristics.

2 References

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

ISO 4363, *Liquid flow measurement in open channels — Methods for measurement of suspended sediment.*

ISO 4364, *Liquid flow measurement in open channels — Bed material sampling.*

3 Definitions

For the purpose of this International Standard, the definitions given in ISO 772, together with the following, apply.

3.1 bed load : The sediment in almost continuous contact with the bed, carried forward by rolling, sliding or hopping. (See figure 1.)

3.2 bed material : The material, the particle sizes of which are found in appreciable quantities in that part of the bed affected by transport.

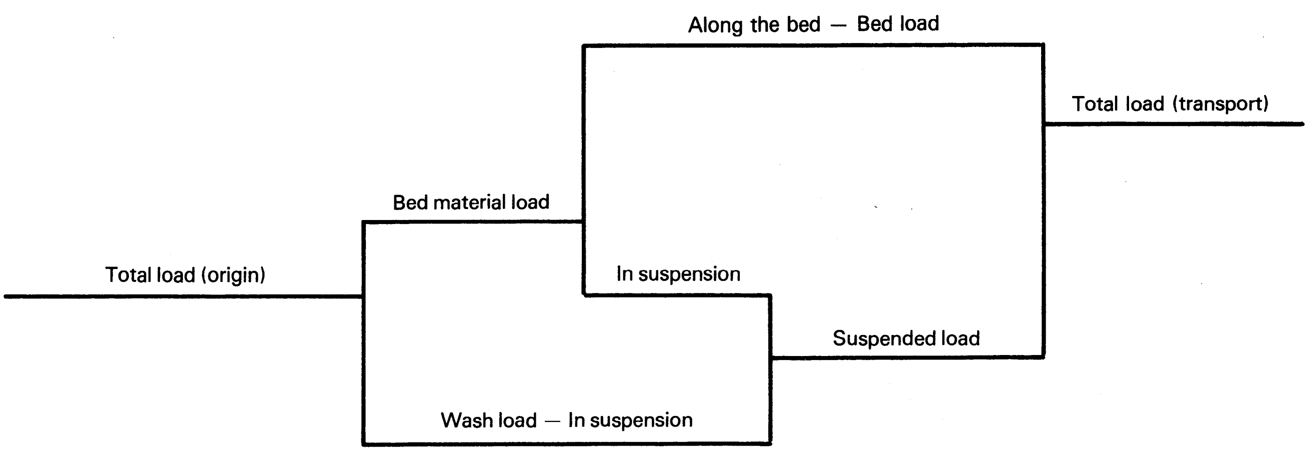

Figure 1 — Definition sketch

3.3 bed material load : That part of the total sediment transported which consists of the bed material and the rate of movement of which is governed by the transporting capacity of the channel. (See figure 1.)

3.4 nominal diameter : The diameter of a sphere of the same volume as the given particle.

3.5 projected diameter : The diameter of a circle which just encloses the projected image of a particle when viewed in the plane of maximum stability.

3.6 sediment concentration : The ratio of the mass or volume of dry sediment in a water-sediment mixture to the total mass or volume of the suspension.

3.7 sedimentation diameter : The diameter of a sphere having the same relative density and terminal settling velocity as a given particle in the same sedimentation fluid.

3.8 sieve diameter : The width of a square opening through which the given particles will just pass.

3.9 relative density : The ratio of the mass of a given volume of sediment to the mass of an equal volume of water.

3.10 suspended load : That part of the total sediment transported which is maintained in suspension by turbulence in the flowing water for considerable periods of time without contact with the stream bed. It moves practically with the same velocity as that of the flowing water; it is generally expressed as a mass or volume per unit of time. (See figure 1.)

4 Units of measurement

The units of measurement used in this International Standard are those of the International System of Units (SI) and litres.

5 Properties of sediment

5.1 General

The transport of sediment depends as much upon the properties of the sediment as upon the hydraulic characteristics of the flow. The properties of sediment are defined by individual particle characteristics and bulk characteristics.

5.2 Properties of individual particles

Sediment size is the most commonly used parameter to designate the properties of individual particles. While the size of sediment and its packing directly affect the roughness of the bed, the settling velocity of the particles characterizes their reaction to flow and governs the movement of the sediment. This in turn depends upon the relative density, shape and the size of the particle.

Since particles of natural sediment are of irregular shape, a single length or diameter has to be chosen to characterize the size. Four such diameters, i.e. nominal diameter, projected diameter, sedimentation diameter and sieve diameter, are used for different particle sizes or purposes (for example, sieve diameter for coarse and medium particles, sedimentation diameter for fine particles which are not usually separated by sieves). The nominal diameter has little significance in sediment transport, but is useful in the study of sedimentary deposits.

5.3 Bulk characteristics

As sediments consist of large numbers of particles differing in size, shape, relative density, settling velocity, etc., it is essential to find some parameters that can represent the characteristics of the group of particles as a whole. Therefore, a sample of sediment is usually divided into classes according to characteristics (size, settling velocity, etc.) and the percentage by mass of the total in each class is determined for the particular characteristic. Frequency distribution curves may be drawn from this data and their parameters (mean, standard deviation, etc.) determined.

6 Sampling

Samples of suspended sediment shall be collected as specified in ISO 4363.

7 Concentration

7.1 Suspended sediment concentration

7.1.1 Methods for determination of suspended sediment concentration

7.1.1.1 General

Suspended sediment concentrations may be determined by the following methods :

a) evaporation method;

b) filtration method;

c) hydrometer method (also used for determination of particle size).

Although the evaporation method [a)] requires less time, the filtration method [b)] has the advantage that the fractions collected can be photographed on the filters and are available for further examination. However, the filtration method is prone to greater loss of material, whereas in the evaporation method, the ratio of sample mass to tare mass is small. Therefore, no hard and fast guidelines can be provided for their choice, and each case should be judged on its merits.

7.1.1.2 Evaporation method

The evaporation method is specified in annex A.

7.1.1.3 Filtration method

7.1.1.3.1 The filtration may be carried out using either filter papers in conical glass funnels, or in Gooch, fritted glass or Alundum crucibles, with the application of a vacuum aspirator system to accelerate the passage of the filtrate.

The filtration method using filter papers and funnels is specified in annex B.

7.1.1.3.2 Gooch crucibles consist of a small porcelain cup, with a capacity of approximately 25 ml, which can be adapted to a vacuum aspirator system. The flat circular base of the crucible is perforated with openings, each about 0,7 mm in diameter. Prior to filtration of a sample, a small portion of uniform asbestos fibre slurry should be firmly spread over the bottom of the crucible. This layer of asbestos which serves as the filtering medium should be uniform and provide a complete cover of the crucible base. This asbestos layering may be assisted by applying a vacuum.

The filtration method using Gooch crucibles is specified in annex C.

7.1.1.3.3 A fritted glass crucible is similar in size and shape to a Gooch crucible, but is made of Pyrex glass. The base of the crucible is fusion fitted with a fritted disc insert available in three porosity grades (coarse, medium and fine). The particular grade should be selected according to the apparent classification of sample material. The method using fritted glass crucibles is similar to that of Gooch crucibles. However, in this method, the asbestos medium is replaced by circular microfibre glass filter and prefilter discs which should be firmly inserted over the fritted base of the crucible prior to filtration.

Fritted glass crucibles provide several advantages:

a) the filter discs facilitate the rapid preparation of crucibles for taring;

b) the loss of fine asbestos in the initial filtration is neglected;

c) the porosity of the filter discs is fine, so any loss in sample material is negligible.

7.1.1.3.4 Alundum crucibles are similar in size and shape to Gooch or fritted glass crucibles, but are made of fused aluminium oxide. There are plain and ignition types, available in three porosities (porous, medium porosity and dense). The particular type and porosity should be selected according to the nature of the sample.

method of using Alundum crucibles is similar to that using Gooch or fritted glass crucibles (see annex C). However, Alundum crucibles should be used without the addition of a filtering medium.

Alundum crucibles present four advantages :

a) the pores are fine, so the loss of material through them is negligible;

b) the crucibles are light in mass, which facilitates greater sensitivity in weighing operations;

c) the tare masses are less subject to change;

d) fine particles of asbestos from an asbestos layer are not lost in the initial filtration.

7.1.1.4 Hydrometer method

The hydrometer method is specified in annex D, clause D.1. If the sediment concentration is low, however, the hydrometer method is not suitable, and an alternative method is suggested in annex D, clause D.2.

7.1.2 Expression of concentration

The concentration of suspended sediment shall be expressed as the mass or volume of dry sediment per unit mass or volume of suspension.

7.2 Bed load transport

Bed load transport is usually expressed either as dry mass per unit of time, or apparent volume (including voids).

8 Particle size analysis

8.1 Particle size analysis of suspended sediment

For the analysis of particle size, suspended sediment may be classified in terms of sedimentation diameter as follows :

a) **coarse sediment,** comprising particles of diameter greater than 0,25 mm;

b) **medium sediment,** comprising particles of diameter 0,062 to 0,25 mm;

c) **fine sediment,** comprising particles of diameter less than 0,062 mm.

The methods of analysing suspended sediment of these classes are specified in annex D.

NOTE — In the case of suspended sediment, grading by particle size into divisions finer than 0,062 mm is usually not carried out because of the unimportance of accurately separating the small amount of solid particles that generally exist in suspension. If, however, closer separation between the coarse and medium sediments is required, it may be carried out by the procedure specified in 8.2 for bed load and bed material.

8.2 Particle size analysis of bed load and bed material

For analysis of samples of the bed load or bed material for particle size distribution and mean diameter, samples are classified broadly into those of diameter greater than, and those of diameter less than, 0,5 mm. Classification of material in these two ranges is suitable in the computation of bed load.

The methods of analysing bed load and bed material are specified in annex E.

The particle size distribution of sediment may be determined by sieving (when particles are all coarse), by a combination of sieving and settling velocity, or indirectly by measuring particle settling velocities in a column of liquid. It would be advantageous to use only one measure of diameter over the entire range of sizes for all sediments, preferably the sedimentation diameter, but this is not practicable since large particles will settle very rapidly in the sedimentation liquid, causing difficulties in dispersion, and would thus require larger equipment. On the other hand, sieve dimensions and the quantity of material available will set a limitation on the size of fine particles. Therefore, in practice, the coarser particles of suspended sediment (diameter greater than 0,25 mm) and the coarser particles of bed load and bed material (diameter greater than 0,5 mm) are analysed by sieving and all the finer material by sedimentation techniques. This may result in a small abrupt break in the particle size distribution curve, which may be adjusted by the use of the following approximate relationship between the diameters :

$$D_{sd} = 0{,}94\, D_{sa} = 0{,}67\, D_{pd}$$

where

D_{sd} is the sedimentation diameter;

D_{sa} is the sieve diameter;

D_{pd} is the projected diameter.

8.3 Expression of particle size distribution

8.3.1 Frequency distribution tables

Frequency distribution tables should be prepared to present the data from size analyses in an orderly form.

In order to draw up the frequency distribution, the total range of sizes (diameters in millimetres) is divided into intervals, called "class intervals", the number of which will depend on the classes into which the sample has been divided. The percentage of the total mass of the sample falling within one of these intervals is tabulated against that interval. Thus, if an interval has limits of 0,10 mm and 0,08 mm, the percentage of the total mass of the sample falling within this size range is tabulated against the interval and called the frequency of that particular class interval.

For size distribution of coarser material, particularly for the analysis of bed load or bed material, the distribution is obtained with unequal class intervals, but for the size distribution of suspended material, a class interval of 0,02 mm is adopted over the range 0,062 to 0,50 mm. Particles larger than 0,50 mm and smaller than 0,062 mm are broadly classified as "class > 0,50 mm" and "class < 0,062 mm" respectively.

8.3.2 Graphical presentations

8.3.2.1 The data from a particle size analysis may be presented in three different graphical forms :

a) histograms;

b) frequency polygons and frequency curves;

c) cumulative curves or particle size summation curves.

The simplest manner of depicting the results of mechanical analysis is to prepare a histogram of the data. The diameter, in millimetres, is usually chosen as the independent variable, with the frequency as the dependent variable. In general, the class intervals are the abscissae, and, above each class, a vertical rectangle of width equal to the class interval and height proportional to the frequency in the class, is drawn (see figure 2).

8.3.2.2 In addition to the use of histograms as frequency diagrams, a common statistical device is to indicate variations in frequency by means of a line diagram instead of rectangular blocks. Such frequency diagrams are called frequency polygons (see figure 3).

8.3.2.3 Cumulative frequency curves are based on the original frequency distribution data, and are drawn by plotting ordinates which represent the total amount of material larger or smaller than a given diameter. Two types of cumulative curves are possible, the "more than" curve and the "less than" curve. Either may be used, as they provide the same type of information (see figure 4).

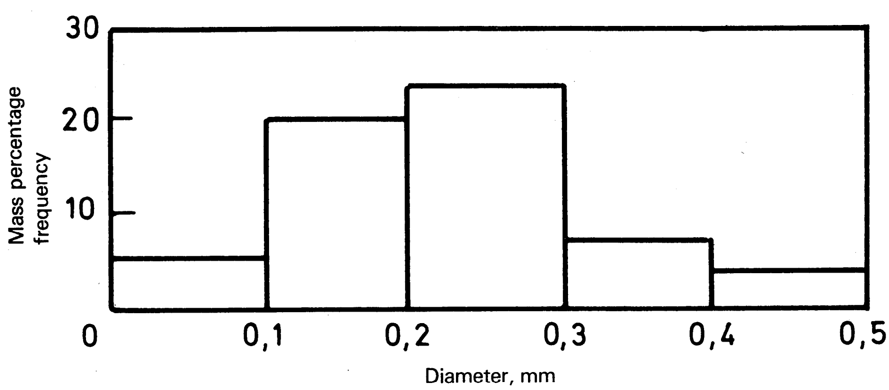

Figure 2 — Example of a histogram for presentation of particle size distribution

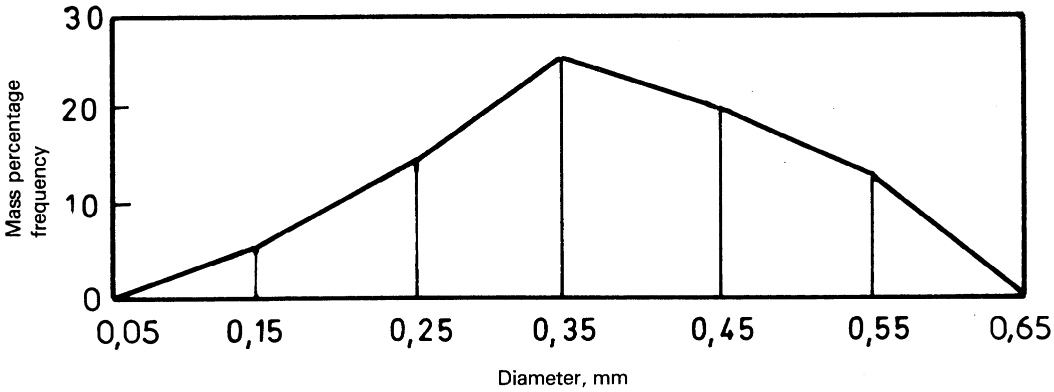

Figure 3 — Example of a frequency polygon for presentation of particle size distribution

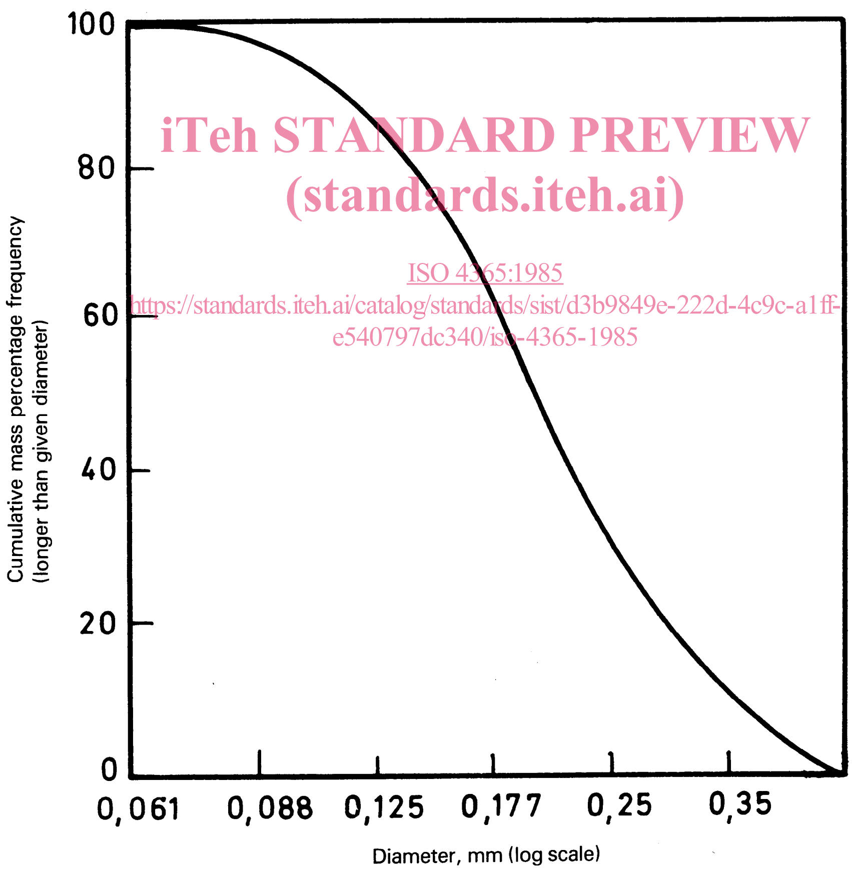

Figure 4 — Example of a cumulative frequency curve for presentation of particle size distribution

8.3.3 Basic distribution of bed material

Size distribution of bed material more or less follows logarithmic normal or log normal distribution, i.e. the logarithm of the variable is distributed normally.

The cumulative distribution function is defined by the equation :

$$P(x) = \phi(u), \text{ with } u = \frac{\log x - \log \varepsilon}{\sigma} \quad (0 < x < \infty)$$

Differentiation of the cumulative distribution function leads to :

$$P(x)\,\mathrm{d}x = \phi(u)\,\mathrm{d}u$$

$$= \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\left\{\frac{(\log x - \log \varepsilon)^2}{2\sigma^2}\right\}\right] \mathrm{d}(\log x)$$

According to the definition :

$$\text{Mean}(\log x) = \log \varepsilon$$

$$\text{Variance}(\log x) = \text{Mean}\{(\log x - \log \varepsilon)^2\} = \sigma^2$$

Thus, the symbol ε does not denote the mean of the variate x, but ε is defined by log ε being the mean of log x.

NOTE — The variate x in this case is "D", the particle size diameter.

9 Determination of relative density

The method for the determination of the relative density is specified in annex F.

NOTE — From a knowledge of the relative density, the density may be computed.

10 Determination of particle size distribution characteristics

See annex G.

11 Data processing

For both manual and automatic data processing, systematic forms and procedures are required, according to specific needs.

Annex A

Determination of the concentration of suspended sediment by the evaporation method

A.1 Procedure

A.1.1 Determine the volume of the sample and the total mass of the sample (sediment + water) plus bottle (capacity not less than 1 l) to the nearest 0,5 g. Record this mass as the gross mass.

A.1.2 Allow the sample to stand undisturbed so that the sediment settles out from the suspension.

Decant the sediment-free liquid after it visibly appears to be clear.

A.1.3 Wash the remaining sediment from the bottle, by means of a stream of water from a wash-bottle, into a previously weighed evaporating dish. Loosen the sediment adhering to the sides of the bottle by means of a rubber-tipped glass rod, ensuring that there is no loss of material during this process.

Determine the mass of the empty bottle after drying, using the same balance, and record this as the tare mass.

A.1.4 Dry the sample in the evaporating dish until all visible water is lost. Then heat the contents in an oven at 110 °C until a reasonably constant mass is obtained.

Cool the evaporating dish in a desiccator.

Weigh the dish and contents to the nearest 0,001 g.

A.2 Expression of results

Calculate the concentration of suspended sediment, determining the concentration in relation to the mass, or the volume, of the suspension, from the formula

$$\frac{m_4 - m_3}{m_2 - m_1}$$

or

$$\frac{m_4 - m_3}{V}$$

where

m_1 is the tare mass, in grams, of the bottle;

m_2 is the gross mass, in grams, of the bottle plus sample;

m_3 is the mass, in grams, of the evaporating dish;

m_4 is the mass, in grams, of the evaporating dish plus dried sediment;

V is the volume of the sample.

Express the result in appropriate units.

A.3 Note on procedure

This method is satisfactory if dealing with coarse sediment particles. With finer grained sediments, the settling time increases until a point is reached at which the method becomes impractical. Also, it becomes undesirable to decant liquid from a point close to the top of the deposited material, because of the danger of withdrawing some of the extremely fine particles. The transfer of sediment to an evaporating dish becomes more difficult owing to the relatively large volume of water used for washing, which may necessitate another settling period. The use of flocculating agents will reduce the settling time, but this introduces additional material and hence requires a correction factor which is difficult to assess with precision in routine estimates.

Annex B

Determination of the concentration of suspended sediment by the filtration method using filter paper

B.1 Procedure

B.1.1 Determine the volume of the sample and the total mass of the sample (sediment + water) plus bottle to the nearest 0,5 g. Record this mass as the gross mass.

B.1.2 Weigh the filter paper to the nearest 0,001 g and record it as the tare mass of the filter paper (see B.3.2).

Fit the filter paper into a funnel.

B.1.3 Allow the sample to stand undisturbed for a period of time and then pour the water-sediment mixture into the funnel, allowing the water to percolate normally (see B.3.3).

Pour all the water from the sample onto the filter paper, and wash the sediment adhering to the inside of the sample bottle onto the filter paper by means of a jet of distilled water. Take special care to ensure removal of dissolved salts.

Weigh the empty bottle, using the same balance, and record it as the tare mass.

B.1.4 After all the water has passed through the filter, fold and place the paper in a previously weighed evaporating dish.

Dry the contents of the evaporating dish until all visible water is lost, then heat to 110 °C in an oven until a reasonably constant mass is obtained.

Remove the evaporating dish and its contents from the oven and place in a desiccator to cool.

Weigh the dish, filter paper and dried sediment to the nearest 0,001 g.

B.2 Expression of results

Calculate the concentration of suspended sediment, determining the concentration in relation to the mass, or the volume, of the suspension, from the formula

$$\frac{m_4 - m_3}{m_2 - m_1}$$

or

$$\frac{m_4 - m_3}{V}$$

where

m_1 is the tare mass, in grams, of the bottle;

m_2 is the gross mass, in grams, of the bottle plus sample;

m_3 is the mass, in grams, of the evaporating dish and filter paper;

m_4 is the mass, in grams, of the evaporating dish, filter paper and dried sediment;

V is the volume of the sample.

Express the results in appropriate units.

B.3 Notes on procedure

B.3.1 If the water-sediment mixture is of such a large volume that all of it cannot be poured in at the start of the filtration, it is necessary either to add it intermittently or to arrange the apparatus so that it filters automatically. This may be accomplished by having the bottle which contains the sample inverted with its opening at the desired water elevation in the filter.

B.3.2 It is desirable to record the tare mass of the filter paper before and after filtration, and it may be dried, if necessary, for the purpose.

B.3.3 For very low concentrations, the entire sample should be filtered without sedimentation or decantation.