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Petroleum liquids — Automatic pipeline sampling

Produits pétroliers liquides — Échantillonnage automatique en oléoduc

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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 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 3171 was prepared by Technical Committee ISO/TC 28, *Petroleum products and lubricants*.

This second edition cancels and replaces the first edition (ISO 3171 : 1975) of which it constitutes a technical revision.

Users should note that all International Standards undergo revision from time to time and that any reference made herein to any other International Standard implies its latest edition, unless otherwise stated.

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0 Introduction

The purpose of collecting a sample of the material flowing through a pipeline is to determine the mean composition and quality of the bulk quantity. Samples of the bulk quantity in the line may be analysed to determine composition, water and sediment content, or any other important attributes such as density, viscosity or, with special precautions, vapour pressure.

Manual methods of pipeline sampling are adequate for homogeneous liquids whose composition and quality do not significantly vary with time. If this is not the case, automatic sampling is the recommended procedure since the continuous or repetitive extraction of small samples from a pipeline ensures that any changes in the bulk contents are reflected in the collected sample. In order that the sample shall be as representative as possible it is essential to ensure that the recommendations of this International Standard with respect to the required homogeneity of the liquid at the sampling location and to the required frequency of extraction of the small samples are met.

Consideration should be given to having standby samples provided by manual methods that may be referred to if the automatic sampler fails to perform satisfactorily; however, manual sampling will be subject to uncertainty if pipeline conditions are varying. (See ISO 3170.)

The equipment and techniques described have generally been used for sampling stabilized crude oil, but may also be applied to unstabilized crude oil and refined products provided consideration is given to the relevant safety precautions and the difficulties of sample handling.

Representative sampling of crude oil for density and water and sediment content is a critical process. Extensive studies have shown that, in crude oil transfers, four distinct steps are required for determining representative values:

a) adequate stream conditioning of the pipeline contents;

b) reliable and effective sampling, ensuring proportionality between sampling ratio and flow rate in the line;

c) adequate conservation and transporting of the sample;

d) adequate conditioning and dividing into parts for accurate laboratory analysis.

This International Standard refers to existing methods of sampling and the type of equipment presently in use. It is, however, not intended that it should exclude new equipment not yet developed for commercial use, provided that such equipment enables samples to be obtained that are representative, and is in accordance with the general requirements and procedures of this International Standard.

The annexes to this International Standard contain calculation procedures about pipeline mixing theory and profile testing and also give basic guidelines for sampler location.

It is realized that in many countries some or all of the items covered by this International Standard are subject to mandatory regulations imposed by the laws of those countries; such regulations must be rigorously observed. In cases of conflict between such mandatory regulations and this International Standard, the former should prevail.

1 Scope and field of application

1.1 This International Standard recommends procedures to be used for obtaining, by automatic means, representative samples of crude oil and liquid petroleum products being conveyed by pipeline.

NOTE — Although throughout this International Standard the term crude oil is used, this should be taken to include other petroleum liquids where the technique and equipment are also applicable.

1.2 This International Standard does not apply to the sampling of liquefied petroleum gases and liquefied natural gases.

1.3 The principal purpose of this International Standard is to give guidelines for specifying, testing, operating, maintaining and monitoring crude oil samplers.

1.4 The sampling procedures for crude oil are intended to provide representative samples for the determination of

a) the oil composition and quality;

b) the total water content;

c) other contaminants that are not considered to be part of the crude oil transferred.

If the sampling procedures for a), b) and c) are in conflict, separate samples may be required.

NOTE — The results of the laboratory analysis may be used for calculating adjustments to the declared quantity of crude oil transferred. The procedure for carrying out the adjustments does not form part of this International Standard.

1.5 Sample handling is included, covering all aspects following collection to the transfer of the sample to laboratory apparatus.

1.6 This International Standard describes the practices and procedures believed at the present time to be the most likely to lead to representative sampling and hence to accurate water determination. However, the accuracy of the water determination on pipeline samples obtained using automatic samplers will depend upon the arrangement and characteristics of all the various elements making up the sampling system, and on the accuracy of the subsequent analytical procedures.

A theoretical technique for evaluating the combined accuracy of the automatic sampling system and the analytical test is given in clause 16. A practical test procedure for field use is described in clause 15.

Normally, the acceptable accuracy limits for a particular automatic sampling system will be specified in agreement between the interested parties.

Table 4 of clause 15 classifies the performance of automatic sampling systems by ratings based on the accuracy of practical test results. These ratings may be used as a guide to possible performance and as a basis for individual agreement.

2 References

ISO 3165, *Sampling of chemical products for industrial use — Safety in sampling.*

ISO 3170, *Petroleum products — Liquid hydrocarbons — Manual sampling.*

NOTE — See also clause 17, Bibliography.

3 Definitions

For the purpose of this International Standard, the following definitions apply.

3.1 acceptable (accuracy) limits: The limits within which the determined concentration of water in a sample is acceptable relative to the true value or other specified value, at the 95 % probability level.

3.2 automatic sampler: A system capable of extracting a representative sample from the liquid flowing in a pipe. The system consists of a sampling probe and/or a separating device, an associated controller and a sample receiver.

3.2.1 intermittent sampler: A system for extracting liquid from a flowing stream, a sample receiver to contain the sample grabs taken from the stream, and a means for controlling the amount of sample taken by varying the sampling frequency or grab volume in relation to flow rate.

3.2.2 continuous sampler: A system for extracting liquid from a flowing stream which has a separating device which continuously withdraws liquid from the main pipeline in relation to flow rate, an intermediate sample receiver, and a means for controlling secondary withdrawal to a final sample receiver.

3.3 calculated sample volume: The theoretical sample volume obtained by multiplying the sample grab volume by the number of actually collected grabs.

3.4 competent person: A person who by reason of his or her training, experience, and theoretical and practical knowledge is able to detect any defects or weaknesses in the plant or equipment and to make an authoritative judgement as to its suitability for further use.

NOTE — This person should have sufficient authority to ensure that the necessary action is taken following his or her recommendation.

3.5 controller: A device which governs the operation of the automatic sampler in order to provide a representative sample.

3.6 fixed-rate sample; time-proportional sample: A sample taken from a pipeline during the whole period of transfer of a batch, composed of equal increments at uniform time intervals.

3.7 flow-proportional sample: A sample taken from a pipeline during the whole period of transfer of a batch, at a rate which is proportional to the rate of flow of the liquid through the pipeline at any instant.

3.8 grab: The portion of liquid extracted from the pipe by a single actuation of the separating device. The sum of all the portions results in a sample.

3.9 homogeneous mixture: A liquid is homogeneous if the composition is the same at all points. For the purposes of this International Standard a liquid is homogeneous if the variation in composition does not exceed the limits provided in 4.4.

3.10 integrity of the sample: The condition of being complete and unaltered, i.e. the sample being preserved with the same composition as when it was taken from the bulk of the liquid.

3.11 isokinetic sampling: Sampling in such a manner that the linear velocity of the liquid through the opening of the sampling probe is equal to the linear velocity of the liquid in the pipeline at the sampling location and is in the same direction as that of the bulk of the liquid in the pipeline approaching the sampling probe.

3.12 mixer: A device which provides a homogeneous mixture of the liquid within a pipeline or container in order to obtain a representative sample.

3.12.1 powered mixer: A mixing device which depends on an external source of power for the energy required to mix the liquid.

3.12.2 static mixer: A mixing device having no moving parts and located within a pipe or tube. It depends on the kinetic energy of the moving liquid for the energy required to mix the liquid.

3.12.3 variable-geometry static mixer: A mixing device with parts inside the pipe or tube which can be adjusted to modify its characteristics at different flow rates.

3.13 pipeline: Any section of pipe used for the transfer of liquid. An unobstructed pipe does not have any internal fittings such as a static mixer or orifice plate.

3.14 profile testing: A technique for simultaneous sampling at several points across the diameter of a pipe. Terms used in connection with profile testing are as follows:

3.14.1 overall mean: The average of either the point averages or the profile averages. (Note that the result is the same.)

3.14.2 point: A single sampling orifice in the profile.

3.14.3 point average: The average of the water concentration at the same point in all profiles (neglect points with less than 1 % water).

3.14.4 profile: A set of samples taken simultaneously at several points across a diameter of the pipe.

NOTE — The term is also used to denote the series of sampling points themselves and the set of results obtained by analysis of the samples taken at these points.

3.14.5 profile average: The average of the water concentration at each point in the same profile (neglect the profile if it has less than 1 % water).

3.15 representative sample: A sample having its physical or chemical characteristics identical to the average characteristics of the total volume being sampled.

NOTE — Since errors cannot be quantified exactly, compliance with this ideal can only be expressed as an uncertainty that can be obtained either from practical tests or by theoretical calculation.

3.16 sample: The portion of liquid extracted from the pipeline that is subsequently transferred to the laboratory for analysis.

3.17 sample conditioning: Homogenization necessary to stablize the sample during sample handling in preparation for analysis.

3.18 sample container: A vessel used for the storage, transportation and preconditioning of the total quantity, or a proportion of the total quantity, of the sample for analytical work or for division into identical small sub-samples to be analysed.

3.19 sample handling: The conditioning, transferring, dividing and transporting of the sample. It includes transferring the sample from the receiver to the container and from the container to the laboratory apparatus in which it is analysed.

3.20 sample loop: A by-pass to the main pipeline being sampled through which a representative portion of the total flow is circulated.

3.21 sample receiver; receptacle: A vessel connected to the automatic sampler in which the sample is collected during the sampling operation. A receiver may be permanently attached to the sampler or it may be portable. In either case, it should be designed to maintain the integrity of the sample.

NOTE — In certain circumstances, it is possible to collect the total sample in more than one sample receiver. In such circumstances, the sample integrity has to be maintained for each individual sample volume.

3.22 sampler performance factor (PF): The ratio between the accumulated sample volume and the calculated sample volume (see 14.6).

3.23 sampling frequency: The number of grabs taken in unit time.

3.24 sampling interval: The time between successive grabs.

3.25 sampling location: The cross-section of the pipe where the sampling probe is, or is proposed to be, located.

3.26 sampling probe: The sampler element that extends into the pipeline.

3.27 sampling ratio: The quantity of pipeline contents represented by one grab.

NOTE — It can be expressed as either the volume, in cubic metres per grab, or the equivalent length of pipeline, in metres per grab.

3.28 separating device: A device that separates a small volume of liquid from the batch of liquid that the small volume represents.

3.29 stream conditioning: The distribution and dispersion of the pipeline contents, upstream of the sampling location.

3.30 time-proportional sample: See 3.6.

3.31 water.

3.31.1 dissolved water: The water contained within the oil forming a solution at the prevailing temperature.

3.31.2 suspended water: The water within the oil that is finely dispersed as small droplets.

NOTE — It may, over a period of time, either collect as free water or become dissolved water, depending on the conditions of temperature and pressure prevailing.

3.31.3 free water: The water that exists as a separate layer from the oil, and typically lies beneath the oil.

3.31.4 total water: The sum of all the dissolved, suspended and free water in a cargo or parcel of oil.

3.32 worst-case conditions: The operating conditions for the sampler that present the most uneven and unstable concentration profile at the sampling location.

NOTE — This will usually be at minimum flow rate, minimum oil density and minimum oil viscosity but may also be influenced by other factors such as emulsifiers and surfactants.

4 Principles

4.1 Purpose

This clause defines the principles which it is essential to observe during sampling operations in order that the representativity of the sample taken corresponds to the specifications of this International Standard, and meets the acceptability criteria given in 4.4.

4.2 Principles to be observed

In order to determine the oil composition, quality and total water content of a batch of crude oil, samples that are representative of the batch are taken and analysed. The batch may be either a discrete pipeline transfer over a given period of time, or the whole or part of the cargo of a tanker, either loading or unloading.

Representativity depends on four conditions, all of which should be observed, since failure to comply with any one of them could affect the quality of the final result.

4.2.1 The first condition is that the samples that are taken from the pipeline should have the same composition as the average composition of the crude oil over the whole cross-section of the pipeline at the location and time of sampling. It is not easy to comply with this condition, because of the possibility of a variable concentration gradient existing across the section.

This condition requires that at the sampling location:

a) the distribution or concentration of the water in the crude oil should be uniform across the section of the pipeline within the acceptance limits given in 4.4;

b) the diameter of the entry port of the sampling probe should be large in relation to the maximum water droplet size. The port opening should not be smaller than 6 mm (see 7.3).

4.2.2 The second condition is that representativity should persist throughout the period of transfer of the batch, the composition of which may change between the start and finish of sampling. The rate of sampling, whether it is continuous or intermittent, should be in proportion to the flow rate in the pipe. When an intermittent sampler is used the sampling frequency and grab size should both be sufficient to guarantee acceptable representativity.

Furthermore, the representativity of the sample should be maintained in the automatic sampler from the sampling probe up to the final receiver. Samples should be taken with an appliance that complies with the recommendations in clauses 7, 8, 9 and 10.

4.2.3 The third condition is that the sample should be maintained in the same condition as at the point of extraction, without loss from it of liquid, solids or gases and without contamination.

Storage and transfer of samples should comply with the recommendations in clause 11.

4.2.4 The fourth condition concerns division of a sample into a number of sub-samples in such a way as to ensure that each of them has exactly the same composition as the original sample.

The procedure for dividing each sample into sub-samples, and for transferring them to laboratory appliances, is given in clause 12.

NOTE — It should be emphasized that this fourth condition concerns a critical activity and any error introduced is capable of destroying the representativity achieved by the first three.

4.3 Sampling tolerances and validation

In order to ensure that each sample sent to the laboratory for analysis is representative of the whole batch, the composition of the sample should not differ from the composition of the batch by more than the tolerances given in table 4 and as applied in 15.5.

In order to ensure that any departure from the conditions given above (see 4.2) does not result in a sample representativity which exceeds the tolerances given in table 4, each step of the sampling operation should be validated as shown in figure 1.

4.4 General principles for sampling

Hydraulic laws governing the behaviour of heterogeneous liquids which will mix or will not mix in the pipe show that for stream conditioning a sufficiently high energy dissipation rate should be provided to keep drops of water and heavier solid particles suspended in the crude oil. Such an energy dissipation rate may be provided either from the velocity in an unobstructed pipe, or from a mixing device immediately upstream of the sampling location.

In considering the distribution of water over the cross-section, the acceptable limits of the values found in the profile test (clause 6) should be relative to the mean concentration of water in that plane and should be within ± 0,05 g/100 g for samples having a water content up to 1 g/100 g and should be ± 5 % of the mean concentration (relative) for samples having a water content greater than 1 g/100 g [but see also case 2 (4.4.2)].

NOTE — Although the concentrations above are quoted in mass units, they also apply to volume units.

In a horizontal pipe, three cases may be used to describe the ways in which the concentration of the different phases may vary over the cross-section of the pipe depending on hydraulic conditions (flow rate, product density and viscosity, dispersed phase composition, interfacial tension modifiers, etc.).

4.4.1 Case 1 (see figure 2, profile type 1)

In this case, the concentration is the same, within the acceptable limits as defined above, across the entire cross-section of the pipeline for all concentrations of water. The existing conditions are acceptable for sampling, since water is evenly distributed over the pipe cross-section. A representative sample consequently exists at the inlet of the sampling probe, which can be placed at any point on the diameter although it is essential that care should be taken not to place the sampling probe too near the wall in order to minimize wall effects.

4.4.2 Case 2 (see figure 2, profile type 2)

In this case, the concentration varies from one point to another in the cross-section, but with a uniform gradient such that there is at least one point where the concentration is equal to the mean concentration across the entire section. Based on a theoretical analysis, this point is generally found between 0,4 and 0,5 of the vertical diameter from the bottom of a horizontal pipeline.

Sampling at this location will only be acceptable if the water concentration found at the sampling point under worst-case conditions is equal to the mean concentration within the acceptable limits as defined above.

4.4.3 Case 3 (see figure 2, profile types 3a and 3b)

In this case, the concentration across the cross-section of the pipe is non-linear, indicating the presence of segregation (type 3a). Some erratic profiles may also be encountered (type 3b).

As there is a range of concentrations at different points in the cross-section, sampling at a predetermined point is unacceptable, and it will be necessary to install a mixing device (see 5.3).

NOTE — If there is any free water, or an emulsion having a high concentration of water, at the bottom of the pipe, representative sampling is not possible.

4.5 Dispersed phase — variations with time

It is unlikely that the concentration of a dispersed phase component in the bulk liquid will be constant with time. For example in the discharge of crude oil from a marine tanker, in addition to more gradual changes in the base water content, there may also be periods when peaks of relatively high concentrations of water travel down the pipeline. Experimental observations indicate that these "transients" may contain over 50 % water and may be shorter than a minute in duration. Depending on the unloading procedures, the significance of the water discharged in the form of transients may vary relative to the base level carried with the bulk of the discharged cargo.

It is apparent that the representativity of samples taken in such applications will be dependent upon the ability of the automatic sampler system to reflect, both accurately and proportionally, the integrated water content of these peaks in the total collected sample volume.

With intermittent-type samplers, accuracy will depend on the type of equipment and its frequency of operation in relation to the frequency and duration of the transients. With continuous-type samplers, accuracy will depend on the external collection and mixing arrangements and on the rate of secondary sampling if applied. For both types of sampler, the overall duration of the oil transfer, the duration of any water transients and the sampling frequency have statistical significance in the determination of sampling accuracy.

Theoretical analysis of the effect of dispersed phase transients on the performance of the different types of samplers leads to the following general conclusions:

a) in short-term transfers in which there is a possibility of frequent, short-duration transients, the accuracy of the continuous type of automatic sampler is least affected by the transients;

b) in short-term transfers in which there may be relatively few long-duration transients, the accuracy of the intermittent-type sampler approaches that of the continuous type of automatic sampler;

c) for long-term transfers, the mean error introduced by transients of any duration, using either type of sampler, is within the limits of acceptability defined in this International Standard.

4.6 Low water content

Attention is drawn to the fact that, if the concentration of water is about 0,1 % (m/m), i.e. near the level at which water is soluble in crude oil, the concentration profiles will show a good uniformity of water distribution under all hydraulic conditions.

5 Selection of sampling point (including stream conditioning)

5.1 General

As has been emphasized in clause 4, it is essential that the sampling probe is presented with a portion of the liquid flowing in the pipeline which is representative of the whole. This depends on the extent of mixing within the pipeline, which in turn depends on a number of factors including flow rate and pipe configuration upstream of the sampling location.

The guidance given in this clause for the selection of the sampling point assumes that the pipeline remains full at all times.

5.2 Initial selection of sampling probe location

5.2.1 The force of gravity tends to promote stratification in horizontal pipelines whereas distribution tends to be more uniform in vertical lines. For this reason, given the choice between vertical and horizontal, and assuming identical operating conditions, the preferred location is in a length of vertical pipe, provided that the pumping rate is significantly higher than the water and sediment settling rate (see annex A, A.2.2).

Reference should be made to annex C for a useful guide to the initial screening of potential sampling locations but annex A is preferred as it provides a more detailed treatment.

5.2.2 The turbulence which exists naturally in a long horizontal pipeline can be, but frequently is not, sufficient to provide adequate mixing. The minimum natural turbulence for adequate mixing depends on flow rate, pipe diameter, viscosity, density and interfacial tension. If the natural turbulence is not sufficient for representative sampling, then the additional mixing offered by specific pipeline components should be introduced (see 5.3 and annex A).

5.2.3 The minimum acceptable flow rate and/or the minimum energy to be provided by a mixing device should be determined. Suitable procedures using formulae or nomographs described in annex A may be used.

5.3 Mixing devices

5.3.1 General

Mixing devices produce homogeneity by the addition of kinetic energy from outside or the conversion of pressure energy from within the pipeline.

In situations where there is an insufficient rate of energy dissipation for pipeline fittings or static mixers to be effective, consideration should be given to the use of powered mixers.

Reference should be made to annex C for a useful guide to the initial screening of potential sampling locations.

5.3.2 Pipeline fittings

Pipeline fittings may be used as in-line mixing devices. The fittings which may be suitable in this respect are valves, orifices, pipe reducers and expanders, manifolds, T-junctions and metering stations. These, however, vary in their effectiveness as mixers and may create concentration zones, leading to zigzag concentration profiles over a downstream distance equivalent to about 20 pipe diameters.

5.3.3 Reduced pipe diameter

If the velocity is too low for sufficient mixing, a length of pipe of reduced diameter can often be installed to advantage but not to the extent that the obstruction caused by the sampling probe will distort the water distribution (see 7.2).

5.3.4 Vertical loops

The improved distribution afforded by a vertical length of pipeline (see 5.2.1) can be obtained by inserting a vertical loop into a horizontal line. If sufficient line pressure is available the flow rate may be increased by reducing the diameter in the vertical loop to below that of the main line. In a vertical loop, the sampling probe should be preferably installed in the downstream leg, at a minimum distance of three, but preferably greater than five, pipe diameters from the upstream bend and a minimum distance of 0,5 pipe diameters from the downstream bend.

It should be noted that water can accumulate at the bottom of vertical piping until these accumulations reach such a size that they are carried forward in the form of slugs. As a result of this phenomenon, water transients occur and this should be taken into account.

5.3.5 Static mixers

Static mixers are commercially available devices specially designed in one or more stages to provide adequate distribution and dispersion of the pipeline constituents prior to sampling. Reference should be made to the manufacturer for advice on the minimum flow rate at which the mixer is still effective.

The maximum flow rate will be limited by the acceptable pressure drop across the mixer, but a wide flow range can be accommodated using a variable geometry mixer.

5.3.6 Powered mixers

Powered mixers can be dynamic versions of the static mixer in which the mixer elements are driven from an external power source to introduce a high shearing action which effects the maximum dispersion of the contacting media. Alternatively, mixing may be achieved when a portion of the flow is reintroduced into the pipeline via a pump and high-velocity injector(s), upstream of the sampling probe.

5.4 Position of the sampling probe

5.4.1 If the contents of the pipeline have been adequately mixed the position of the sampling probe relative to the pipe wall is relatively unimportant. However, to avoid wall effects, which could influence the flow rate as well as the water concentration, the sample should be drawn from the centre of the pipe. In horizontal or vertical pipes the sampling probe should be positioned to withdraw from the shaded areas shown in figure 3.

5.4.2 Under some conditions, centrifugal forces occurring at bends may act to separate the dispersed phase from the bulk liquid. Therefore the exclusive use of single bends to provide mixing upstream of the sampling location is not recommended.

5.4.3 The distance between the mixing device and the sampling probe should be sufficient to avoid the effects of swirl and asymmetry generated by the device but not so great as to lose the mixing effect provided by the device. Recommended distances are between one-half of a pipe diameter and 8 pipe diameters, depending on the type of mixing device being used.

5.5 Checking the location of the sampling probe

Whatever location is chosen for the sampling probe, or whatever additional form of mixing is employed, it is recommended that the concentration profile at the sampling location be checked. The test procedure for this check is described in clause 6. Other methods of checking may be used if they provide equal assurance that the sample taken will be representative.

6 Profile testing

6.1 Introduction

This clause describes methods which may be used to test the uniformity of water distribution across the pipeline at the chosen sampling location.

6.2 Principle

Profile testing can verify that a representative sample is available at the proposed or existing sampling location. The extent of stratification or non-uniformity of water concentration can be determined by taking samples simultaneously at several points across the diameter of the pipe and analysing these for water content. A multipoint probe, as opposed to a traversing probe, is required to eliminate uncertainties due to non-simultaneous sampling.

In order to make a valid judgement regarding uniform dispersion, a minimum of five profile tests should be made, although only three profile tests are required to demonstrate stratification. For acceptable results when using manual methods of test, the mean water concentration should be between 1 and 5 %.

NOTE — If centrifuge tubes are being used for the water determination and the water concentration is above 20 % extreme care should be taken when taking the readings because of the larger volumes between graduations.

If an automatic continuous method of determining water content is employed, then the water content should be within the working range of the instrument. To cope with conditions of complete water separation, the instrument should tolerate 100 % water without failure.

6.3 Methods

The choice is between three methods of test, depending upon the level of water concentration that can be assured throughout the period of testing and the ability to achieve reliable and stable conditions. Generally, a level of at least 1 % water is necessary for a valid test.

- Method 1 employs the injection of additional water into the pipeline. It is the preferred procedure and should be used whenever there is doubt that the natural level of water concentration in the crude oil will be consistently more than 1 % during the test period.

- Method 2 relies upon the natural level of water concentration. To be valid, this method should only be used when there is certainty that the natural water concentration in the crude oil during the period of test will be at least 1 %.

- Method 3 is an alternative method for use with ships. Under some circumstances additional water may be introduced into the ship's compartments or storage tanks to increase the level of water concentration to at least 1 %.

NOTE — A water concentration of 1 % is enough to determine whether the dynamics of the system can provide adequate mixing while minimizing the effects of the inherent measurement error.

6.4 Determining the water concentration profile in a pipeline and validation of the sampling location

6.4.1 Equipment

6.4.1.1 Multipoint sampling probe

The test is performed using the multipoint probe illustrated in figure 4. The probe openings should face upstream into the direction of flow and are internally reamed to minimize entry flow disturbances. The probe should be fitted horizontally into a vertical pipe, or vertically into a horizontal pipe. When the probe is fitted vertically, the recommended direction of flow in the probes is vertically downward where possible. In horizontal pipes, an extra straight-tube without bend is positioned vertically with the entry opening as near as practicable to the bottom wall of the pipeline (see figure 5). This point is used to check that no free water is running along the bottom of the pipe.

The centre of the tube opening of the first and last points of sampling should be located 20 mm from the wall of the pipeline. All tubes leading to the external valves should be approximately the same length to ensure that simultaneous samples are taken.

A probe with a minimum of 5 sample points is recommended for 300 mm (12 in) pipe size or larger. Below 300 mm (12 in) pipe size, three sample points should be used.

NOTE — The internal bore of the tubes should be large enough to avoid blockages. For crude oil, 6 mm is the recommended minimum internal diameter.

As a safety precaution, the probe should be installed and removed during low pressure conditions. However, the probe should be equipped with safety chains and stops to prevent blow out should it be necessary to remove it during operating conditions. (See also clause 13.)

6.4.1.2 Measurement

The measurement of water content at each point across the pipeline may be made by either manual or automatic means.

When measurement is made by a manual laboratory technique, other than the centrifuge method, the sample should be collected into a receiver of adequate capacity for the test, following the procedure described in 6.4.2. When the centrifuge method is used, the sample may be collected directly into the centrifuge tube, but it may be difficult to dispense the exact volume.

Alternatively, when continuous monitors are employed (for example capacitance cells), the samples are passed directly through individual measurement cells, one for each profile point. This procedure has obvious advantages in that profile changes can be seen as they occur by observation of suitable indicating or recording apparatus. This automatic method also avoids the necessity for a very large number of repetitive laboratory tests.

With both methods, provision should be made for the collection and disposal of waste oil passed through the probes during the test period.

6.4.2 Operating procedure

If the application requires a range of crude oils to be sampled, the worst case conditions shall be selected. If this is not possible the formulae in annex A can be used to extrapolate the results to other conditions. The results of extrapolation should be treated with great care.

6.4.2.1 Manual measurement

a) The sampling frequency should provide at least one profile every 2 min and at least five profiles at the minimum flow rate with a water concentration of at least 1 % (*m*/*m*).

b) If method 1 (see 6.3) is used, water shall be injected upstream from the multipoint probe, at a sufficient distance from the probe and upstream of any mixing elements, so that a representative profile is obtained, but in a manner which will not create an energy dissipation rate significantly higher than the existing one [see annex A, A.4.2.2, equation (26)].

c) The injection operation should be made in accordance with figure 6, using a pump that will produce the proper flow rate and pressure. If necessary, water should be injected in successive percentages of 1, 2, 3, 4 and 5 % or more of the volume of crude oil flowing in the pipeline. The operation should be repeated at five representative but different flow rates and particularly at the minimum flow rate. These should be constant to within 10 % during the period of each test.

d) If method 3 (see 6.3) is used, the ship's compartment to be spiked with water should be selected such that it can be pumped without creating trim problems.

e) Each element of the probe should be rinsed out thoroughly before sampling by running through it an adequate amount of crude oil.

f) Flow rates in the multipoint probe should be regulated before sampling so that the entry velocity at each point of the probe is the same and is preferably equal to the velocity of the liquid flowing in the pipeline. If not, any differences should be recorded.

g) Sampling should begin before the calculated water arrival time and continue, without alteration of the flow rates in the probe, until sufficient profiles have been taken to obtain a minimum of five which meet the requirements of 6.2.

h) Sampling should continue during the time-period that injected water is passing. The time-lag between water injection and arrival at the sampling location should be taken into account (see figure 6).

6.4.2.2 Automatic measurement

a) The provisions of 6.4.2.1 b), c), d), e), f), g) and h) apply.

b) A recent development is the use of capacitance cell profile test systems to demonstrate continuously the degree of homogeneity across the profile and with time. The capacitance of water in crude oil mixtures will vary with crude oil composition; it will also vary with temperature and may vary with water droplet size and shape. The individual cells comprising such an automatic profiling system should be zeroed on the particular crude oil being sampled, and steps taken to ensure that temperature and flow rate differences between cells are minimized.

In profile testing, the measurement of interest is the relative concentration of water at each point across the pipe.

Therefore, provided that capacitance cells with similar characteristics are used, there may be no need to adjust the span for different crude oil types.

c) Timing is much less critical than for manual testing, as is the need for steady conditions. A visual display will indicate the profile conditions as they occur, enabling the worst (or best) conditions to be identified.

d) Figure 7 shows a typical bar graph presentation, based on experimental work, from a profile test at three different sampling locations along the pipe.

6.4.3 Typical test data

6.4.3.1 Manual measurement

Annex B shows some typical test data from a profile test at a crude oil terminal. Tests were made at two flow rates and six profiles were obtained for eight points across the pipe for each flow rate.

After excluding all profiles where the water content is less than 1 % (m/m), the point averages, profile averages and overall mean are calculated. The next step is to obtain the percentage deviation of each point average from the overall mean. Profiles should be drawn as shown in annex B.

6.4.3.2 Automatic continuous measurement

With automatic profile test equipment, using continuous water monitors connected to a microprocessor, it is possible to continuously display and record the water profile in any suitable form such that changes caused by flow rate variations or injected water percentage can be observed as they occur. The effect of variable energy mixing devices can also be observed.

Similarly, calculation of mean and average water contents and percentage deviations at points across the pipe can be carried out instantaneously. These results can be displayed or recorded with the profile and other test data.

6.4.4 Presentation and interpretation of results

Each profile may have the general appearance of one of the types P_0 to P_5 shown in figure 8.

a) P_0 represents the most suitable distribution, since the concentration ratio is within the acceptable accuracy limits at any point of the cross-section.

b) P_1 and P_2 represent acceptable distributions, provided that the sampling probe is positioned according to the recommendations in 4.4.2 and 5.4.1.

c) P_3 to P_5 represent unacceptable distributions with concentration ratios outside the acceptable accuracy limits.

Any profile beyond the acceptable accuracy limits indicates that sampling results cannot be expected to be representative. To achieve an acceptable distribution either a higher flow rate or a mixing device should be used.

Annex A gives a simplified theoretical relationship between flow rate and oil characteristics on the one hand, and the profile on the other hand.

7 Sampling probe design

7.1 The sampling probe and/or the separating device should be of sufficient strength to withstand the bending moments imposed by the maximum flow in the main pipeline and to withstand the vibrations caused by vortex shedding. Although the actual determination of strength is difficult, conservative approaches can be made by treating the member as a cantilevered beam.

7.2 The sampling probe should be designed to create the minimum of disturbance to the main pipeline flow. One approach is a pitot-tube type probe entry with a chamfered edge. The entry should face upstream into the direction of the flow.

7.3 It is recommended that the diameter of the sampling probe opening be not less than 6 mm.

8 Sampler design and installation

8.1 Design

8.1.1 Automatic samplers should be designed to procure representative samples of the liquids flowing through pipelines and to store these in one or more receivers. Samplers may be of the continuous or intermittent type.

NOTE — There are two types of intermittent automatic sampling system. One system locates the separating device directly in the main line [see figure 9a)], whereas the other system locates the separating device in a sample loop [see figure 9b)].

8.1.2 The petroleum liquids to be sampled may contain wax, abrasive particles and corrosive components such as sulfur compounds and water. They may, in certain cases, possess poor lubricating properties. These facts should be taken into account in designing an accurate, reliable and durable sampling system.

8.1.3 The installation of piping and valves between the separating device and the receiver should be so designed that there is no separation of components, such as water and crude oil, at any point. It is desirable to keep the volume to a minimum.

8.1.4 A sample loop usually consists of a circulating loop, a suitable pump and a separating device [see figure 9b)]. Any connection between the loop and the separating device should be of minimum volume.

8.1.5 The sample loop entry velocity should be as near as possible to the maximum expected velocity in the main pipeline. If the separating device is not in the immediate vicinity of the sampling probe, care should be taken ensure that the flow rate within the sample loop is high enough to produce fully turbulent flow and thus avoid water settlement.

8.1.6 The inclusion of a device to indicate that there is a flow in the sample loop is recommended. If there is no circulation in the sample loop and sampling continues, erroneous sampling will result.

8.2 Installation

8.2.1 The separating device and the sample receiver should be installed as close as possible to each other in order to minimize dead volume. Connections should be made with short lengths of pipe consistent with the application, and the number of bends should be kept to a minimum. Where possible, the sample receiver should be at the lowest point in the system.

8.2.2 Where for practical reasons it is not possible to install the separating device and the sample receiver close to each other, then a sample loop is recommended. Precautions should be taken to ensure that both the sample in the sample loop and the sample taken from the sample loop are representative.

8.2.3 Automatic samplers should be installed with suitable valves and connections to enable equipment to be flushed automatically or manually either with the liquid being sampled or with some suitable solvent. Proper arrangements should be made for the disposal of the flushings and solvents used. All solvents should be removed from the receiver and the circulating lines to avoid contamination of the next sample.

8.2.4 If necessary, a non-return valve or equivalent device should be installed in the sampling line to prevent any possibility of the sample being returned to the pipeline from which it was drawn. This should not restrict the free passage of sediment into the receiver.

8.2.5 The method of installation of an automatic sampler should provide easy access for maintenance and cleaning; it may be essential that this can be carried out without shutting down the pipeline.

8.2.6 The sampling probe should be installed through a stub-mounted full-bore valve and a suitable insertion and withdrawal mechanism should be provided. If the probe has to be withdrawn without depressurizing the pipeline, means, such as safety chains, should be provided to prevent the probe being ejected by the pipeline pressure. If this system is installed, sufficient space should be allowed for fitting the mechanism and withdrawing the probe.

8.3 Precautions

8.3.1 There may be a tendency for water or heavy particles to drop out in the sampler tubing and components, and appear in the sample receiver during subsequent sampling, To minimize this, the system should be free from pockets or enlarged sections and should be pitched downwards towards the receiver. Care should also be taken to ensure that there are no pockets in which vapours or water can be trapped.

8.3.2 To prevent solidification of high-pour-point crude oils or products, the separating device, associated tubing and components should be heat-traced and insulated. Care should be taken not to over-heat the sample liquid, although the temperature should be high enough to keep the material in the liquid phase to ensure proper operation of the automatic sampler system. Thermostatic temperature control may be necessary if self-limiting heat tracing is not used.

8.3.3 If sampling lines and systems which are not in use are likely to block through cooling and wax deposition, flushing oil should be used to fill such lines and systems.

8.4 Special characteristics

The general recommendations on automatic samplers for crude oil are applicable to automatic samplers for refined products. However, certain products have specific characteristics which may require special sampling conditions. Some examples are given in table 1. In these cases, the automatic sampler should be adapted so that it fulfils the required sampling conditions.

9 Control equipment

9.1 Function

The functions of the control equipment for an automatic sampler are to control the separating device to take either a flow-proportional sample or a fixed-rate sample, and it may also include a system to

a) continuously monitor the number of grabs and the volume of sample collected;

b) verify, at any time during sampling, the proportionality between the sample collection rate and the pipeline flow rate if operating in the flow-proportional mode.

NOTE — Continuous monitoring of density and/or water content may be used as an added monitoring facility.

9.2 Control equipment

9.2.1 The control equipment may be remote from the sampler in a control centre. Alternatively, it may be local to the sampler, in which case consideration should be given to the electrical safety classification of the hazardous area in which it is installed.

9.2.2 The control equipment should enable the operator to

a) set the equipment for the prospective cargo or batch size or for the necessary sampling ratio to meet the required operating criteria (see 14.2);

b) put the sampler into operation, and switch it off.

9.2.3 Facilities should be provided for monitoring the following during operation:

a) the flow rate in the main pipeline;

b) the sample receiver to indicate that the sample volume collected is proportional to the totalized flow in the main pipeline;

c) the number of grabs.

9.2.4 The equipment should provide an alarm if the flowmeter is indicating flow but no sampling is taking place and vice versa.

9.2.5 Alarms are recommended for

a) high level in the sample receiver;

b) low flow in the main pipeline;

c) low flow in the sample loop;

d) loss of power;

e) sampling probe failure (for motor-driven probes).

10 Flow measurement

10.1 Accuracy and rangeability

A flow-proportional sampler requires a flow signal to pace the sampler. The flow transmitter should have enough rangeability (turndown) to produce a reasonably accurate signal over the expected flow range of the pipeline. The accuracy of the flow signal should not degrade the representativity of the sample beyond the tolerance of the analytical technique (see clause 16). An accuracy of better than ± 10 % of actual flow over the operating flow range should be achieved. When the water concentration figure is higher at low flows it is particularly important that the flowmeter produces a reasonably accurate signal at the minimum flow.

10.2 Use of custody transfer meters for samplers

If the location uses meters for custody transfer, the signals from the custody transfer meters should be used to pace the sampler. If the pipeline flow is measured by several meters, the sampler may be paced by an electronically combined total flow signal or a separate sampler may be provided for each meter.

10.3 Special flowmeters for samplers

If the measurement for custody transfer is by shore tank gauging, a separate flowmeter should be provided for flow-proportional sampling.

Table 1 — Recommended sampler characteristics for crude oil and refined products

Pipeline liquid contents[1]	Special characteristics of the automatic sampler		
	Heating of the cabinet containing the sampling system	Provision of a means of separating the sample from the atmosphere	Receiver kept at + 4 °C
Crude oil	Yes[2]	Yes[2]	No
Naphtha	No	Yes	No
Gasoline	No	Yes	No
Jet fuel	No	Yes	Yes[4]
Gas oil/domestic fuel oil	No[3]	No	No
Heavy fuel 1/heavy fuel 2	Yes	No	No

1) Pipeline conditioning is not required for homogeneous pipeline contents.

2) Only if required, dependent on type of crude oil and operational requirements.

3) Except in severe climatic conditions.

4) Only if necessary (silver corrosion characteristic).

10.3.1 Insertion turbine meters are often used in large-diameter pipelines. The meter signal is a pulse train which simplifies the electronic design of the controller. Rangeability may be limited and accuracy can be seriously affected by changes in the viscosity of the metered liquid. Insertion turbine meters may be fouled by fibrous matter or other debris in the oil, and therefore consideration should be given to the possibility of installing a second flowmeter.

10.3.2 Ultrasonic flowmeters are often used. The flowmeter signal is a pulse train and current which simplifies the electronic design of the controller. Ultrasonic flowmeters are not affected by viscosity. Minimum flow rate is typically 0,09 m/s.

10.3.3 Orifice plate flowmeters may be used; alternatively, either venturi meters or flow pitot tubes may be used to minimize the permanent pressure loss. The pressure drop across the flow element is measured by a differential pressure transmitter which provides an output that is proportional to the square root of the measurement. A single transmitter installation has a range in the ratio of about 4 to 1. Two transmitters, one with a high and the other with a low differential pressure range, may be used to extend the range. However, the controller design for a two-transmitter installation is complicated and problems can arise.

10.3.4 For small flow rates, a line-size positive displacement meter or turbine meter may be used. The meter installation can be simple since it does not have to provide custody transfer accuracy. Proving and calibration facilities are not required.

10.3.5 Other flowmeters, such as vortex shedding meters, may be used.

10.3.6 It may be possible to use a signal derived from a tank level gauge provided that the precision is within the limits recommended for flowmeters in 10.1.

10.4 Precautions

Any meter should be capable of operating both in the presence of a high concentration of water and in the presence of particulate matter or gas bubbles.

The final step of a cargo off-loading operation is usually the stripping. Consideration should be given to the possibility that during this operation quantities of undefined gas might be fed into the unloading line, simulating a liquid flow at the flowmeter output and also damaging mechanical meters by operating them too quickly.

11 Sample receivers and containers

11.1 Sample receiver

The sample receiver should be equipped with a level indicator or equivalent device, for example a weighing system, for monitoring purposes, and a high-level shut-off or alarm device. Means should be provided to mix the contents of the receiver to ensure that representative samples are transferred into laboratory apparatus or other containers.

Two types of sample receiver are in current use.

11.1.1 Sample receivers — fixed volume

These are receivers with a fixed volume into which the sample is admitted so that it contacts the enclosed atmosphere.

11.1.2 Sample receivers — variable volume

These are designed to avoid contact between the crude oil and air, thus preventing possible loss of light ends and water vapour. They may be made of a suitable flexible material so that they are fully collapsible or they may consist of a container with a piston or diaphragm precharged with nitrogen or helium. The latter are particularly applicable to liquid petroleum products with high vapour pressure, and to crude oils.

11.2 Sample container

The sample container may be equipped with an internal homogenizer or with the necessary connections for an external mixing system (see 12.2.3).

11.3 Common characteristics of sample receivers and containers

11.3.1 Fixed-volume receivers should be constructed to provide sufficient space for ullage to remain at the end of the sampling period, and a means of relieving any increase in pressure due to expansion under all conditions. The design of the vessel should be such that any expansion due to heating of the contents to the highest temperature to which the vessel might be subjected will not cause the working pressure to be exceeded.

The vessel should be made of petroleum-resistant material. It should be noted that receivers or containers made of a plastics material may not be suitable for long-term storage of samples because permeability of the plastics may result in differential loss of some of the components of the sample.

The vessel should be capable of being vented through a pressure control valve with an appropriate setting to minimize the loss of low-boiling-point components.

11.3.2 Pressure tests and other inspection work should be performed according to the local regulations. Cleaning and leak testing should be performed at regular intervals.

11.3.3 The design and material of construction should be such that the internal surfaces in contact with the liquid are smooth and of a finish which will inhibit the retention of water when the contents are transferred or removed for analysis. The design should be such that they can be easily cleaned.

11.3.4 The necessary connections should be fitted to permit sample transfer from the receiver to the container, and from the container to the laboratory apparatus, without contamination or loss.

All connections should be fitted with blanking plugs or end caps, except for the relief valves. Gauge glass and drain valve internal lips should be avoided. Dead legs are not permitted.

If necessary, the sample receiver and its connections should be thermally lagged and/or heat traced to prevent solidification of the sample and facilitate drainage (see 8.4).

11.3.5 The volume of the sample required for analysis and for retention as a reference should meet the requirements of the particular application. Furthermore the local or national fiscal authority may require a minimum quantity of sample to be taken.

This will determine the minimum size of the sample receiver(s) and container(s). The duration of the sampling period, the grab size, the sampling frequency and the requirements for adequate mixing (homogenization) are also relevant considerations in determining the receiver size.

If the total sample is contained in more than one receiver or container, great care should be taken to account for differing volumes in each receiver or container filled successively when either recombining the results of analysis, for example for the average water content of the whole sample volume, or in the preparation of composite samples for other analysis if required.

11.4 Sample labelling

11.4.1 Sample containers should be labelled. Oil-resistant tie-on or wire-on labels are preferred and these should be permanently marked.

11.4.2 It is recommended that the following information be provided on the label:

a) place at which sample was drawn;

b) date and time sampling commenced;

c) date and time sampling was completed;

d) sample tag number or identification number of the container;

e) type of liquid being sampled;

f) quantity of liquid represented by the sample;

g) tank number and type, name of ship, flowline reference, etc.;

h) destination of sample;

i) signature of person responsible for collecting sample.

12 Sample handling

12.1 General

12.1.1 The method of handling samples between the point at which they are extracted or drawn and the laboratory test bench or sample storage are devised to ensure that the nature and integrity of the sample are maintained.

12.1.2 The method of handling a sample will depend on the purpose for which it has been taken. The laboratory analytical procedure to be used will often require a special handling procedure to be associated with it. For this reason consult the appropriate method of test so that any necessary instructions as to sample handling can be given to the person drawing the sample. If the analytical procedures to be applied have conflicting requirements, then draw separate samples and apply the appropriate procedure to each sample.

12.1.3 Take particular care in respect of the following:

a) liquids containing volatile material, since loss by evaporation can occur;

b) liquids containing water and/or sediment, since separation tends to occur in the sample container;

c) liquids with potential wax deposition, since deposition can occur if a sufficient temperature is not maintained.

12.1.4 When making up composite samples take great care not to lose light ends from volatile liquids and not to alter water and sediment content. This is a very difficult operation and should be avoided if at all possible.

12.1.5 Do not transfer samples of volatile liquids to other containers at the sampling location but transport them to the laboratory in the original sample container, cooled and inverted, if necessary. Great care is necessary if a sample contains both volatile components and free water.

12.2 Homogenization of samples

12.2.1 Introduction

Procedures are specified for the homogenization of samples that may contain water and sediment, or are in any other way non-uniform, before transfer from the sample container to smaller containers or into laboratory test apparatus. Procedures for verifying that the sample is satisfactorily mixed before transfer are given in 12.3.

It is not possible to agitate manually samples of liquids containing water and sediment sufficiently to disperse the water and sediment within the sample. Vigorous mechanical or hydraulic mixing is necessary in order to homogenize the sample prior to transfer or sub-sampling.

Homogenization may be by various methods. Whichever method is used it is recommended that the homogenizing system produces water droplets below 50 µm, but not less than 1 µm. Water droplets of below 1 µm will give a stable emulsion and the water content cannot then be determined by centrifuge methods.

12.2.2 Homogenization by high-shear mechanical mixer

Insert a high-shear mechanical mixer into the sample container so that the rotating element reaches to within 30 mm of the bottom. A mixer with counter-rotating blades operating at about 3 000 min^{-1} is usually suitable. Other designs may be used if the performance is satisfactory.

In order to minimize loss of light ends from crude oils or other samples containing volatile compounds, operate the mixer through a gland in the closure of the sample container. Mix until the sample is completely homogenized. A mixing time of 5 min is sometimes sufficient, but the size of the container and the nature of the sample affect the homogenization time. Verify that the sample has become homogeneous (see 12.3).

NOTE — High-shear mixers frequently produce stable emulsions and water contents after mixing cannot be determined by the centrifuge method (ISO 3734).

Avoid any significant rise in temperature during the mixing.

12.2.3 Circulation with external mixer

This method can be applied to both permanently sited sample containers and portable containers; for the latter, use a quick-disconnect coupling. Circulate the contents externally using a small pump through a static mixer installed in small-bore piping. Various designs are suitable; follow the manufacturer's operating instructions.

Use a circulation flow rate sufficient to circulate the contents at least once per minute. A typical mixing time is 15 min, but this will vary according to the water content, the type of hydrocarbon and the design of the system. When the whole sample is thoroughly mixed, run off the required quantity of sub-sample from a valve in the circulating line whilst the pump is running. Then empty the container and thoroughly clean the entire system by pumping solvent round until all traces of the hydrocarbon and water have been removed.

12.3 Verification of the efficiency of mixing

12.3.1 Whatever means are chosen for obtaining a sub-sample from a non-homogeneous mixture, verify the suitability of the mixing technique and the time required to obtain a suitably mixed sample.

12.3.2 If the sample remains homogeneous and stable after mixing (e.g. where completely miscible components such as lubricant additives have been blended), continue the mixing procedure until successive samples drawn from the main bulk of the sample give consistent results. This establishes the minimum mixing time.

NOTE — As the sample is homogeneous after this time, and will remain so, transfers from the main bulk can be made without further mixing.

12.3.3 If the sample does not remain homogeneous for more than a short period of time after mixing (for example if water and sediment are part of the mixture), use the special method for the verification of mixing described in 12.3.4.

NOTE — It may be necessary, owing to the characteristics of the hydrocarbon, to sub-sample while mixing is still in progress.

12.3.4 Ensure that the sample as drawn fills the containers to about three-quarters full, and homogenize the sample for a known period of time, which should be recorded. During this period draw off small portions at regular intervals and test each immediately for water content by a standard method (see 12.3.5). When the test results are consistent record the value obtained as the blank water content.

Add an accurately measured quantity of water, between 1 and 2 %, and homogenize for the same period of time as for the blank and take samples as before. If there is good agreement between the water content determined, taking account of the blank water content, and the quantity of water added, then repeat by adding a further accurately measured quantity of water, again between 1 and 2 %. If the results continue to give good agreement then assume that the mixing time is adequate.

If the results do not show good agreement (within the repeatability of the method), then discard them. Revert to the beginning of the procedure, and use a longer period of mixing.

12.3.5 Do not determine water content by the centrifuge method (ISO 3734) for this verification of the mixing system, as the method cannot be relied upon to give the total water content.

12.4 Transfer of samples

12.4.1 If the sample container is not portable, or if it is inconvenient to take samples directly from the container into laboratory test apparatus, transfer a representative sample into a portable container for transport to the laboratory.

12.4.2 At every stage of transfer of a sample it is essential to homogenize the contents of the container from which the sample is being taken using one of the methods specified in 12.2.

12.4.3 Verify the mixing time for each combination of container and mixer by one of the methods specified in 12.3.

12.4.4 Complete any transfer of sample within the period during which the mixture is known to be homogenous and stable. This period is short; do not take longer than 20 min to complete any transfer.

13 Safety precautions

13.1 It is essential that the safety precautions set out in this clause should be applied rigorously as the minimum necessary for safe operation. These precautions should be used in conjunction with the appropriate national and/or international safety regulations. Local regulations should always be complied with, but if these are less demanding than the precautions in this clause the latter should also be considered (see also ISO 3165).

13.2 Sampling equipment, and sample receivers and containers should be properly designed for the pressures to which they may be subjected during use or subsequent handling. They should be pressure tested to at least one and a half times the maximum operating pressure before being taken into use, and thereafter at regular intervals dictated by the nature of the apparatus and the pressure range involved. Each vessel should be marked with the date of the last pressure test, the maximum permissible working pressure at ambient temperature and the tare weight. The marking should be etched on the vessel or stamped on a tag firmly attached to it.

13.3 Care should be taken to ensure that the maximum design pressure of the sampling system is not exceeded even if abnormal pressure develops in the pipeline or is generated by the sampler itself. Protection should be provided by fitting suitable relief valves.

13.4 When filling sample receivers or containers sufficient ullage should be left to allow for expansion. It is recommended that a safety device be fitted to give a warning when this safe filling limit is reached. The following precautions should also be observed.

a) A receiver should be fitted with a pressure relieving device to limit the pressure in the vessel to within its certified maximum working pressure.

b) Removable receivers or containers should be constructed and certified to withstand at least one and a half times the maximum pressure and any extreme temperatures that can possibly be encountered during subsequent handling.

13.5 Any materials used in the construction of the receiver which may be in contact with the sampled liquid should be immune from attack by any component of that liquid.

13.6 When handling receivers and containers, it is vital to ensure that there is no spillage or vapour release of flammable or toxic material.

13.7 Care should be taken to avoid breathing petroleum vapour during the sampling operations. Protective gloves of hydrocarbon-insoluble materials should be worn. Eye shields or face shields should be worn where there is a danger of splashing. Additional precautions may be necessary when handling crude containing hydrogen sulfide.

13.8 All electrical components used in connection with automatic sampling apparatus situated in a classified area should be appropriate to the classification of the area and should conform to the appropriate national and/or international safety regulations.

13.9 When handling leaded fuels the national standard safety regulations should be meticulously observed.

13.10 When transporting samples, consideration should be given to the dangers of transporting removable receivers and containers, particularly by air. Reference should be made where necessary to the appropriate national and/or international safety regulations regarding the sea, land or air transport of flammable samples and pressurized sample containers.

13.11 It is essential to bond and earth the complete sampling system during any discharge of volatile hydrocarbons in order to dissipate any static electricity which may be generated. It is also necessary to earth pressurized sample containers whenever liquid or vapour under high pressure is discharged from them, for example during purging.

14 Operating procedures

14.1 General precautions

14.1.1 It is important that the principles of design given in this International Standard should be met by the selected automatic sampler and that it should be correctly installed and operated.

14.1.2 A sample should not include any material other than that to be sampled, and where it is necessary to transfer a sample from a receiver to a container appropriate precautions should be taken to preserve the integrity of the sample. The process of sampling should not cause any change in the sample, for example by evaporation of volatile constituents, by oxidation, or by the chance addition of extraneous matter.

14.1.3 When commissioning or re-commissioning the system or if contamination is suspected, the automatic sampler and connecting lines should be thoroughly flushed before sampling begins. Use the medium to be sampled and flush into a waste container or safe drain system. Care should be taken to ensure that toxic materials are not released into the atmosphere or an open drain system.

14.1.4 The provision of clean sample containers is greatly simplified if containers are reserved and kept separate for different classes of products.

14.1.5 During sampling, the material being sampled should be protected from the effects of atmospheric conditions and, in applications where it is permissible to use an open container, the container should be closed immediately after the sample has been taken.

14.1.6 Care should be taken in subsequent handling to avoid undue temperature rise.

14.2 Operating criteria

14.2.1 Intermittent fixed-grab-volume samplers

14.2.1.1 General

The factors that have to be taken into account when considering the operating criteria of fixed-grab-volume intermittent samplers are as follows.

a) The sample volume should, for practical purposes, be between 5 and 20 l, but the quantity will ultimately depend on the particular application (see 11.3.5).

b) For continuous transfers where the operation may extend over a period of days, it is possible to divide the sampling into accounting periods and to take a 5 to 20 l sample over each period. An alternative practice is to use a larger receiver and to sub-sample from this, having observed the proper mixing procedures described in clause 12.

14.2.1.2 Practical considerations

For illustrative purposes only the following operating parameters for an intermittent fixed-grab-volume sampling system are used within the examples of table 2:

a) required sample volume 5 to 20 l;

b) sample grab volume 1 to 1,5 ml;

c) maximum operating frequency 30 grab/min.

A further consideration is the flow turndown which in continuous pipeline applications is typically 10 : 1 and in marine applications is typically 30 : 1.

14.2.2 Intermittent variable-grab-volume samplers

The operating criteria for variable-grab-volume samplers differ from those of fixed-grab-volume samplers, although the total volume of sample collected will be about the same. Variable-grab-volume samplers collect samples on a fixed time rate but the volume of each grab is in proportion to the pipeline flow rate. Calculations and checks should be made to ensure that

a) the maximum operating frequency of the sampler is not exceeded;

b) the sample volume required per grab does not exceed the rangeability of the sampler at the maximum and minimum flow rates;

c) the total sample volume collected does not exceed the sample receiver volume.

14.2.3 Continuous samplers

Although continuous samplers are now being developed, they have not been used extensively and operating criteria have therefore not yet evolved.

Table 2 — Typical operating parameters for intermittent fixed-grab-volume samplers

Application	Transfer period	Total number of grabs	Grab volume ml	Sample volume l	Average sampling interval s	Average sampling ratio (expressed in terms of pipeline length) m/grab	Pipeline flow rate (linear) m/s
Continuous pipeline (CP)	30 d	10 000	1	10	260	260	1
CP and marine	7 d	10 000	1	10	60	60	1
CP and marine	24 h	10 000	1	10	8,6	25	3
Marine	6 h	10 000	1	10	2,15	6,45	3
Marine	3 h	5 000	1	5	2,15	6,45	3
Marine	1 1/2 h	2 500	1	2,5	2,15	6,45	3

NOTES

1 Pipeline pumping rates may be reduced for long pipelines.

2 For short transfer periods, i.e. less than three hours, table 2 shows that it may not be possible to achieve 5 l of sample and consideration should be given to a larger grab volume, for example 4 ml, which will provide a sample volume of 20 l.

3 The number of grabs should be maximized for each sampling operation, within the practical limitations of maximum grab frequency and size of receiver.

14.3 Operating checks

During operation of the sampler the following checks should be carried out periodically.

14.3.1 At the control equipment:

a) that the flow meter is operating;

b) that the sample counter is operating;

c) that the low-flow alarm in the main pipeline has not been energized;

d) that the receiver high-level alarm has not been energized;

e) that proportionality exists between the sample volume collected and the cumulative pipeline throughput.

14.3.2 At the sampler:

a) that the sample is entering the receiver;

b) that there are no leaks in the system;

c) that heat tracing, if necessary, is on;

d) that there is a full flow in the circulating loop if used.

14.4 Record sheet

A record sheet should be completed for each sampling operation and a typical example is shown in table 3. If the batch is split the documentation should be completed for each crude oil. Copies of the record sheet should be sent to the laboratory and to the department(s) responsible for operating the pipeline.

The following data should be included:

a) location and date;

b) identification of shipment or transfer;

c) crude oil type and batch size;

d) record of flow rate during the sampling operation;

e) number and volume of grabs (if appropriate);

f) calculated sample volume;

g) accumulated sample volume (if known);

h) any failures of the automatic sampler during the sampling operation;

j) evidence that proportionality existed between sampling rate and main line flow rate.

14.5 Sampler maintenance

14.5.1 Automatic samplers should be isolated and sampling probes removed from the pipeline on a regular basis. The equipment should then be cleaned and inspected for excessive wear or damage. It is particularly recommended to check the automatic sampler whenever the volume of sample collected does not agree with the volume expected.

14.5.2 Flowmeters, especially if operating on crude oil, may be vulnerable to fouling by line debris. A high level of maintenance will be required.

14.5.3 Sample lines from the automatic sampler to the sample receiver or container should be cleaned with solvent, and then blown clear or flushed with the material to be sampled.

14.5.4 A record of all flowmeter, sampler, and associated equipment failures, and the causes and actions taken should be kept as a means of adjusting maintenance frequency and to identify basic problems.

14.6 Checks of sample acceptability

14.6.1 In order to determine the acceptability of a sample obtained in a sampling operation, for example a cargo discharge or a pipeline batch transfer, the following requirements should be met.

a) The sampler performance factor (3.22) should be within the range 0,9 to 1,1.

b) The proportionality of the sampling ratio and the main line flow rate as recorded during the sampling operation should be checked and confirmed.

c) There should be no interruption in the sampling operation sufficient to affect the performance factor beyond the limits of a).

14.6.2 Unless all of the requirements in 14.6.1 are satisfied, the sample is not acceptable unless the discrepancy can be satisfactorily explained.

If the sample is not acceptable, a back-up sample obtained by the manual procedures laid down in ISO 3170 should be made available.

15 Proving the sampling system

15.1 Introduction

A field test to prove the sampling system should be carried out after a new automatic sampler has been installed. The following procedure is intended to test the total sample system by injecting a volume of water for a period of time and confirming that the sample taken represents the total volume of water injected plus the baseline water. This procedure is a volume balance test.

Table 3 — Typical sampler maintenance and performance report for an intermittent grab sampler

Sampler identification:

Location:

Date			
Identification of crude shipment			
Crude type			
Batch or parcel size (m³)		V	
Maximum loading rate (m³/h)		$Q_{\max}$	
Sampling ratio (m³/grab)		B	
Number of grabs		N	
Calculated sample volume[1] (l)		C	
Accumulated sample volume (l)		A	
Performance factor, A/C		PF	
Without failure[2]		S	
With failure[3]		F	
Give reasons why — **Not available** — **Not used** — **Failed**			
Maintenance	**Preventive**	P	
	Corrective	c	

[1] Calculation of sample volume:

a) for a flow-proportional sample,

$$C = \frac{V}{B} \times \frac{b}{1\ 000} \text{ litres}$$

b) for a fixed-rate sample,

$$C = \frac{f \times T \times b}{1\ 000} \text{ litres}$$

where

b is the sample grab volume, in millilitres, determined from a bench test;

f is the sampling frequency, in grabs per second;

T is the total sampling time, in seconds.

[2] Sampled "without failure"

Performance factor (PF) is within 0,9 to 1,1 range and all mechanical parts of the crude oil sampling system (flowmeter, controller, sampling valve, counter, etc.) functioned without mechanical breakdown. Proportionality existed between sampling rate and main line flow rate.

[3] Sampled "with failure"

Performance factor (PF) is outside 0,9 to 1,1 range or any one of the mechanical parts of the crude oil sampling system failed. Proportionality did not exist between sampling rate and main line flow rate.

15.2 Water injection facilities

These should be arranged as follows.

a) Connection valves, strainer, pressure gauges, piping, pump and a flowmeter are required to inject known amounts of water into the pipeline ahead of the sampler during the test transfer.

b) Locate the water injection point as far upstream as practicable of the piping elements that are expected to produce the required mixing.

c) Water injection flow rates should be between 1,0 % and 5,0 % of the crude oil flow rate during the test.

NOTE — If for operational reasons the water injection flow rates have to be less than 1 %, then the measurement of injected water quantity and the accuracy of the laboratory analytical procedure become critical in the assessment of sampling system acceptability.

d) Water should be injected for at least 1 h or for sufficient time to accumulate a sample volume that can be properly mixed.

e) Water should be injected into the bottom or the side of the pipe at a velocity which does not produce any significant additional mixing. This may be accomplished by introducing the injected stream through an elbow or bend so that its velocity is parallel to that of the main flow and in the same direction.

f) The volume of injected water should be measured with an accuracy better than ± 2 %.

15.3 Testing procedure

NOTE — It is usually required to test the sampling system under worst-case conditions, but these should be realistic with regard to the importance (i.e. total value) of the material being transferred. In some circumstances, the worst case will not be easy to define; in this instance, more than one test will be required in order to demonstrate satisfactory performance over the full range of working conditions.

The following procedure is recommended.

a) Select a test period when pipeline conditions can be held steady.

b) Select, from the range of oils normally sampled, an oil with the lowest viscosity and the lowest density at the operating conditions.

c) Adjust the oil flow rate to give the minimum velocity to be used in the pipeline. The volume of oil during the test period should be measured with an accuracy better than ± 2 %.

d) Collect three separate samples, i.e. "before", "test" and "after". In order to make efficient homogenization possible, use test receivers of small capacity and increase the sampling frequency to give an adequate volume. Operate the sampler for at least 1 h to collect the "before" sample, change the receiver and then inject water as described in 15.2 for at least 1 h. When all the injected water has passed the sampler, change the receiver again and collect the "after" sample for a further hour. Determine the water content of the samples collected "before" and "after" (see figure 6). The differences between the water content of the "before" and "after" samples should not exceed 0,1 %.

e) Operate the sampler to collect the test sample during the total time period that the injected water is passing. Allow for the time lag between water injection and arrival at the sampling location (see figure 6). At low flow rates, the injected water may move at a lower flow rate than the crude oil, therefore continue sampling into the test receiver for some time after the end of the expected passing of the injected water. After sampling is completed, the normal procedures should be used for sample handling, mixing and analysis for water.

f) As the performance of some sampling equipment can be affected by the sampling frequency, the effect should be verified for each sampler design and installation as follows:

1) for fixed-grab-volume samplers, measure the size of the sample delivered by 100 grabs at both the minimum and the maximum sampling frequency;

2) for variable-grab-volume samplers, measure the ratio of the sample volume to the batch volume at both the minimum and the maximum flow rate.

For both 1) and 2), the values so obtained at minimum and maximum conditions should be within ± 5 % of the calculated values.

15.4 Calculations

The deviation between the average water content in the test sample minus the baseline water content, and the average water injected should be calculated from the following equations:

$$W_{\text{dev}} = (W_{\text{test}} - W_{\text{base}}) - W_{\text{inj}} \qquad \ldots (1)$$

and

$$W_{\text{inj}} = \frac{V_1}{V_2} \times 100 \qquad \ldots (2)$$

where

V_1 is the total volume, in cubic metres, of the injected water;

V_2 is the total volume, in cubic metres, of the oil and water that passes the sampling location during the period when the sampler is in operation collecting the "test" sample;

W_{dev} is the deviation of the percentage water in the "test" sample from the average injected water with an allowance for baseline water;

W_{test} is the percentage of water in the test sample [see 15.3e)];

W_{base} is the average percentage of water in the baseline samples "before" (W_{bef}) and "after" (W_{aft}) the "test" [see 15.3 d)], but adjusted to the "test" conditions by the equation

$$W_{base} = \frac{(W_{bef} + W_{aft})}{2} \times \frac{V_2 - V_1}{V_2}$$

W_{inj} is the percentage of water injected into the oil.

Calculate the ratio

$$\frac{W_{dev}}{W_{inj} + W_{base}}$$

and obtain the rating of the sampling system under the test condition from table 4.

Table 4 — Sampling test ratings for injected water concentrations of 1 % and above

Rating	$\frac{W_{dev}}{W_{inj} + W_{base}}$
A	not greater than ± 0,05
B	greater than ± 0,05 but not greater than ± 0,10
C	greater than ± 0,10 but not greater than ± 0,15
D	greater than ± 0,15

15.5 Assessment of results

Sampling systems which perform in accordance with rating A of table 4 meet the highest requirements of this International Standard. If the performance is to the lower ratings B, C and D consideration should be given to whether improvements can be made to design and operating criteria to raise the rating to a higher level. If this is not possible or not justified on economic grounds, the sampling system may be satisfactory depending on the circumstances and/or the application.

15.6 Corrective action

If the sampling system needs to be uprated, the first corrective action should always be a thorough examination of the test procedure and reverification of sampling, sample mixing, sample handling and laboratory procedure.

If these appear to be satisfactory, further steps should be taken to recheck the profile and the performance factor, as well as the flowmeter and all the components of the sampling system.

16 Estimation of overall sampling system uncertainty

16.1 Introduction

This clause provides a mathematical procedure for estimating the overall uncertainty of the sampling system, taking into account the uncertainty of each element of the sampling and analytical sequence. The procedure uses an approximate formula (16.3) that can be applied in most cases.

The formula should be used by the design engineer to obtain information, at an early stage, concerning the overall uncertainty of the sampling system and the impact of each element on the final result. It thus provides an opportunity for technical and economic optimization.

The majority of the coefficients are determined by the construction characteristics of the system. These are not variable. The variables are the number of grabs taken N and the number of analyses n.

NOTES

1 A fundamental difference between error and uncertainty should be noted, which is that the former is by definition unknown, whereas the latter is an estimate.

2 Detailed information on how the formula is obtained will be given in ISO/TR 9494 (to be published).

16.2 Characteristics of sampling systems

The representativity of the sample obtained using an automatic sampler during a transfer depends on the arrangement and characteristics of the various elements used at different stages in the sampling sequence.

16.3 Formula for uncertainty calculations

The approximate formula referred to in 16.1 is as follows:

$$D = \frac{1}{N} + w\,(S + L) + $$

$$+\ 2\sqrt{\frac{1}{N}(1{,}2 \times 10^{-2} + \sqrt{wR})^2 + w^2\left(\frac{h_r^2}{4} + P\right)}$$

where

w is the water content, as a percentage by volume;

D is the combined uncertainty associated with the random and systematic errors in w (95 % confidence level);

n is the number of analyses;

N is the number of grabs;

S, R, L and P are derived coefficients (see 16.3.1).

16.3.1 The derived coefficients are as follows:

Sampling

$S = a_s + b_s + h_s$ (relative systematic uncertainties)

$R = \frac{1}{4}(a_r^2 + b_r^2 + c_r^2 + d_r^2)$ (relative random uncertainties)

Laboratory

$L = f_s + g_s$ (relative systematic uncertainties)

$P = \frac{1}{4}\left(f_r^2 + \frac{g_r^2}{n}\right)$ (relative random uncertainties)

where

$a_s, b_s, \ldots, g_s, h_s$ are the relative systematic uncertainties in the factors influencing the measurement of w (see 16.3.2);

$a_r, b_r, \ldots, g_r, h_r$ are the relative random uncertainties in the factors influencing the measurement of w.

NOTE — The relative uncertainty of x is $\frac{\text{uncertainty of } x}{\text{value of } x}$

16.3.2 The factors influencing the measurement of w are as follows:

a) non-homogeneity of the water content as described in clause 5 and annex A (for example poor dispersion):

relative systematic uncertainty a_s;

relative random uncertainty a_r;

b) changes caused in the water content by the sampling system as described in clause 8 (for example non-isokinetic):

relative systematic uncertainty b_s;

relative random uncertainty b_r;

c) uncertainty in the volume of each grab:

relative systematic uncertainty d_s (not used, but see 16.4),

relative random uncertainty d_r;

d) uncertainty in the flow rate caused by the flowmeter (degree of non-proportionality) as described in clause 10 (for example turbine meter factor variations):

relative systematic uncertainty c_s (not used, but see 16.4),

relative random uncertainty c_r;

e) changes in the water content during sampling as described in clause 11 (for example contamination or water vapour loss):

relative systematic uncertainty h_s;

relative random uncertainty h_r;

f) changes in the water content caused by sample handling and mixing as described in clause 12 (for example poor homogenization in the laboratory):

relative systematic uncertainty f_s;

relative random uncertainty f_r;

g) changes in the water content caused by transfer to laboratory glassware and analysis (for example centrifuge tube error):

relative systematic uncertainty g_s;

relative random uncertainty g_r.

16.4 Limitations of the formula

It is essential that the following conditions apply for the formula to be valid.

a) The number of grabs N is greater than 1 000.

b) The relative systematic uncertainty c_s of the flowmeter in the working range is less than ± 0,1 (i.e. less than 10 %).

c) The relative systematic uncertainty in the volume of the grab d_s is less than ± 0,1 (i.e. less than 10 %).

16.5 Examples

The examples which follow are designed to assist in applying the formula. The values used are typical ones taken from normal industrial practice.

16.5.1 Example 1

a) Values used

$N = 10\ 000$

$w = 1\ \%$

$\quad = 0{,}01$

$n = 2$

$a_s = 1\ \%$

$\quad = 0{,}01$

$a_r = 5\ \%$

$\quad = 0{,}05$

$b_s = 1\ \%$

$\quad = 0{,}01$

$b_r = 2\ \%$

$\quad = 0{,}02$

$d_s = 10\ \%$

$\quad = 0{,}10$

$d_r = 10\ \%$

$\quad = 0{,}10$

$c_s = 10\ \%$

$\quad = 0{,}10$

$c_r = 2\ \%$

$\quad = 0{,}02$

$h_s = 2\ \%$

$\quad = 0{,}02$

$h_r = 2\ \%$

$\quad = 0{,}02$

$f_s = 1\ \%$

$\quad = 0{,}01$

$f_r = 1\ \%$

$\quad = 0{,}01$

$g_s = 1\ \%$

$\quad = 0{,}01$

$g_r = 8\ \%$

$\quad = 0{,}08$

b) Calculation

$$\begin{aligned} S &= a_s + b_s + h_s \\ &= 0{,}01 + 0{,}01 + 0{,}02 \\ &= 0{,}04 \end{aligned}$$

$$\begin{aligned} R &= \frac{1}{4}(a_r^2 + b_r^2 + c_r^2 + d_r^2) \\ &= \frac{1}{4}(0{,}002\ 5 + 0{,}000\ 4 + 0{,}000\ 4 + 0{,}01) \\ &= 0{,}003\ 3 \end{aligned}$$

$$\begin{aligned} P &= \frac{1}{4}\left(f_r^2 + \frac{g_r^2}{n}\right) \\ &= \frac{1}{4}\left(0{,}000\ 1 + \frac{0{,}006\ 4}{2}\right) \\ &= 0{,}000\ 8 \end{aligned}$$

$$\begin{aligned} L &= f_s + g_s \\ &= 0{,}01 + 0{,}01 \\ &= 0{,}02 \end{aligned}$$

$$D = \frac{1}{10\ 000} + 0{,}01\ (0{,}04 + 0{,}02) +$$

$$+ 2\sqrt{\frac{1}{10\ 000}(0{,}012 + 0{,}005\ 7)^2 + 10^{-4}(10^{-4} + 8 \times 10^{-4})}$$

$$D = 10^{-4} + 6 \times 10^{-4} + 2\sqrt{3{,}15 \times 10^{-8} + 9 \times 10^{-8}}$$

$$D = 7 \times 10^{-4} + 2 \times 3{,}48 \times 10^{-4}$$

$$D = 14 \times 10^{-4}$$

Hence

$$w = (1 \pm 0{,}14)\ \%$$

16.5.2 Example 2

a) Values used

$N = 20\ 000$

$w = 2\ \%$

$\quad = 0{,}02$

$n = 2$

$a_s = 1\ \%$

$\quad = 0{,}01$

$a_r = 5\ \%$

$\quad = 0{,}05$

$b_s = 1\ \%$

$\quad = 0{,}01$

$b_r = 4\ \%$

$\quad = 0{,}04$

$d_s = 10\ \%$

$\quad = 0{,}10$

$d_r = 10\ \%$

$\quad = 0{,}10$

$c_s = 10\ \%$

$\quad = 0{,}10$

$c_r = 4\ \%$

$\quad = 0{,}04$

$h_s = 1\ \%$

$\quad = 0{,}01$

$h_r = 1\ \%$

$\quad = 0{,}01$

$f_s = 0{,}5\ \%$

$\quad = 0{,}005$

$f_r = 1\ \%$

$\quad = 0{,}01$

$g_s = 0{,}5\ \%$

$\quad = 0{,}005$

$g_r = 4\ \%$

$\quad = 0{,}04$

b) Calculation

$$\begin{aligned} S &= a_s + b_s + h_s \\ &= 0{,}01 + 0{,}01 + 0{,}01 \\ &= 0{,}03 \end{aligned}$$

$$\begin{aligned} R &= \frac{1}{4}(a_r^2 + b_r^2 + c_r^2 + d_r^2) \\ &= \frac{1}{4}(0{,}002\ 5 + 0{,}001\ 6 + 0{,}001\ 6 + 0{,}01) \\ &= 0{,}003\ 9 \end{aligned}$$

$$\begin{aligned} P &= \frac{1}{4}\left(f_r^2 + \frac{g_r^2}{n}\right) \\ &= \frac{1}{4}\left(0{,}000\ 1 + \frac{0{,}001\ 6}{2}\right) \\ &= 0{,}000\ 2 \end{aligned}$$

$$\begin{aligned} L &= f_s + g_s \\ &= 0{,}005 + 0{,}005 \\ &= 0{,}01 \end{aligned}$$

$$D = \frac{1}{20\ 000} + 0{,}02\ (0{,}03 + 0{,}01) +$$

$$+ 2\sqrt{0{,}5 \times 10^{-4}(0{,}012 + 0{,}008\ 8)^2 + \text{---}}$$

$$\overline{\text{---} + 4 \times 10^{-4}(0{,}25 \times 10^{-4} + 2 \times 10^{-4})}$$

$$D = 0{,}5 \times 10^{-4} + 8 \times 10^{-4} +$$

$$+ 2\sqrt{2{,}2 \times 10^{-8} + 9 \times 10^{-8}}$$

$$D = 8{,}5 \times 10^{-4} + 2 \times 3{,}34 \times 10^{-4}$$

$$D = 15{,}2 \times 10^{-4}$$

$$D = 0{,}15\ \%$$

Hence

$$w = (2 \pm 0{,}15)\ \%$$

16.5.3 Example 3

a) Values used

N = 1 000 (borderline value for N)

w = 0,5 %
= 0,005

n = 2

a_s = 1 %
= 0,01

a_r = 5 %
= 0,05

b_s = 1 %
= 0,01

b_r = 2 %
= 0,02

d_s = 10 %
= 0,10

d_r = 5 %
= 0,05

c_s = 10 %
= 0,10

c_r = 1 %
= 0,01

h_s = 1 %
= 0,01

h_r = 1 %
= 0,01

f_s = 0,5 %
= 0,005

f_r = 1 %
= 0,01

g_s = 0,5 %
= 0,005

g_r = 4 %
= 0,04

b) Calculation

$$S = a_s + b_s + h_s$$

$$= 0{,}01 + 0{,}01 + 0{,}01$$

$$= 0{,}03$$

$$R = \frac{1}{4}\left(a_r^2 + b_r^2 + c_r^2 + d_r^2\right)$$

$$= \frac{1}{4}(0{,}002\,5 + 0{,}000\,4 + 0{,}000\,1 + 0{,}002\,5)$$

$$= 0{,}001\,375$$

$$P = \frac{1}{4}\left(f_r^2 + \frac{g_r^2}{n}\right)$$

$$= \frac{1}{4}\left(0{,}000\,1 + \frac{0{,}001\,6}{2}\right)$$

$$= 0{,}000\,2$$

$$L = f_s + g_s$$

$$= 0{,}005 + 0{,}005$$

$$= 0{,}01$$

$$D = \frac{1}{1\,000} + 0{,}005\,(0{,}03 + 0{,}01) + 2\sqrt{\frac{1}{1\,000}(0{,}012 + 0{,}002\,6)^2 + 0{,}25 \times 10^{-4}(0{,}000\,025 + 0{,}000\,225)}$$

$$D = 10^{-3} + 0{,}2 \times 10^{-3} + 2\sqrt{0{,}2 \times 10^{-6} + 0{,}006\,25 \times 10^{-6}}$$

$$D = 1{,}2 \times 10^{-3} + 2 \times 0{,}454\,1 \times 10^{-3}$$

$$D = 2{,}1 \times 10^{-3}$$

$$D = 0{,}21\ \%$$

Hence

$$w = (0{,}5 \pm 0{,}21)\ \%$$

17 Bibliography

ISO 3534, *Statistics — Vocabulary and symbols.*

ISO 3733, *Petroleum products and bituminous materials — Determination of water — Distillation method.*

ISO 3734, *Crude petroleum and fuel oils — Determination of water and sediment — Centrifuge method.*

ISO 3735, *Crude petroleum and fuel oils — Determination of sediment — Extraction method.*

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

ISO/TR 9494, *Petroleum liquids — Automatic pipeline sampling — Statistical study of performance of automatic samplers*

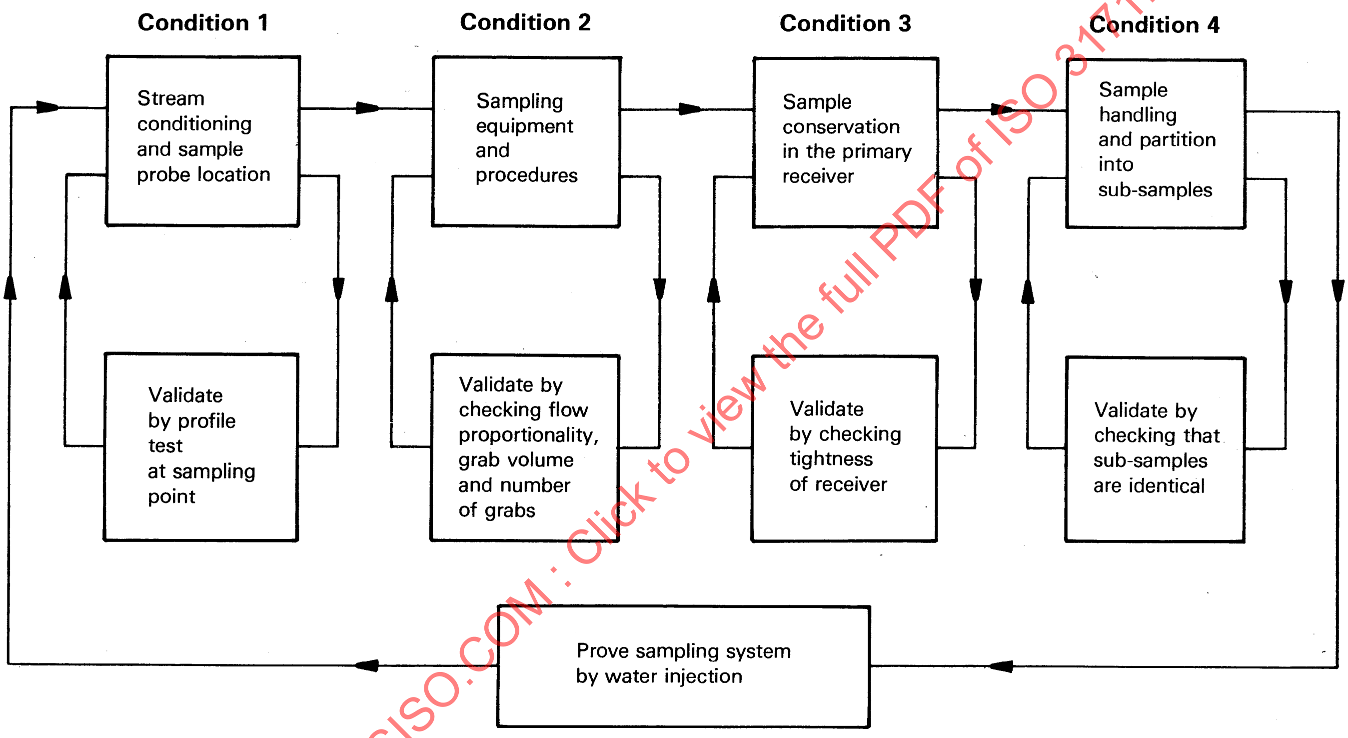
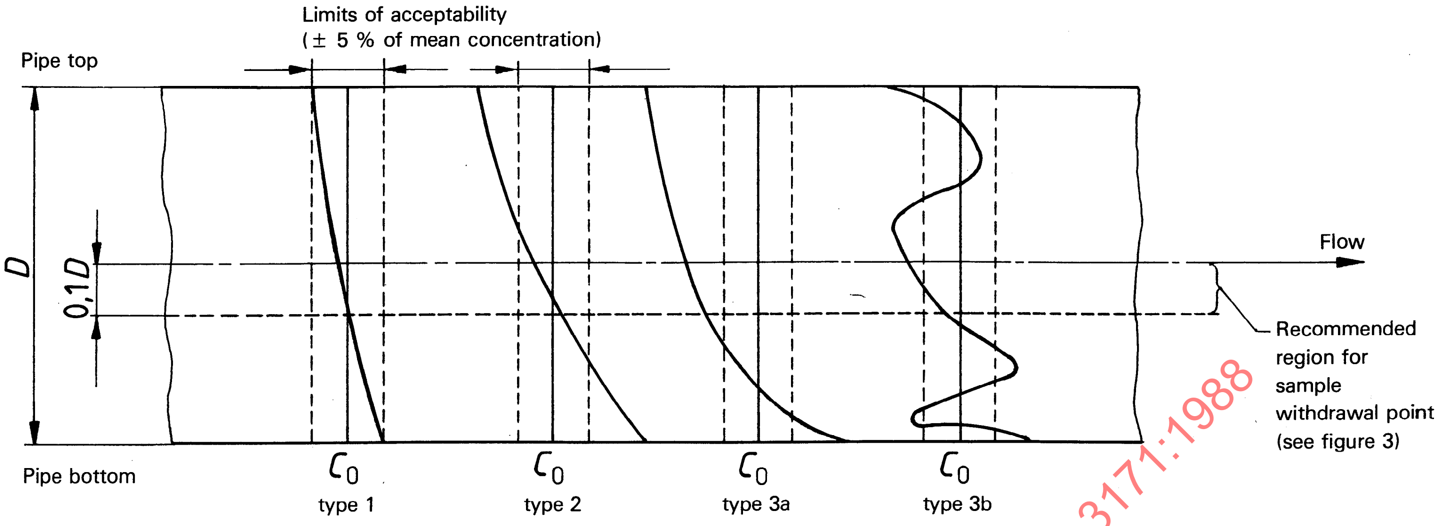


Figure 1 — Initial or periodic validation of a sampling system

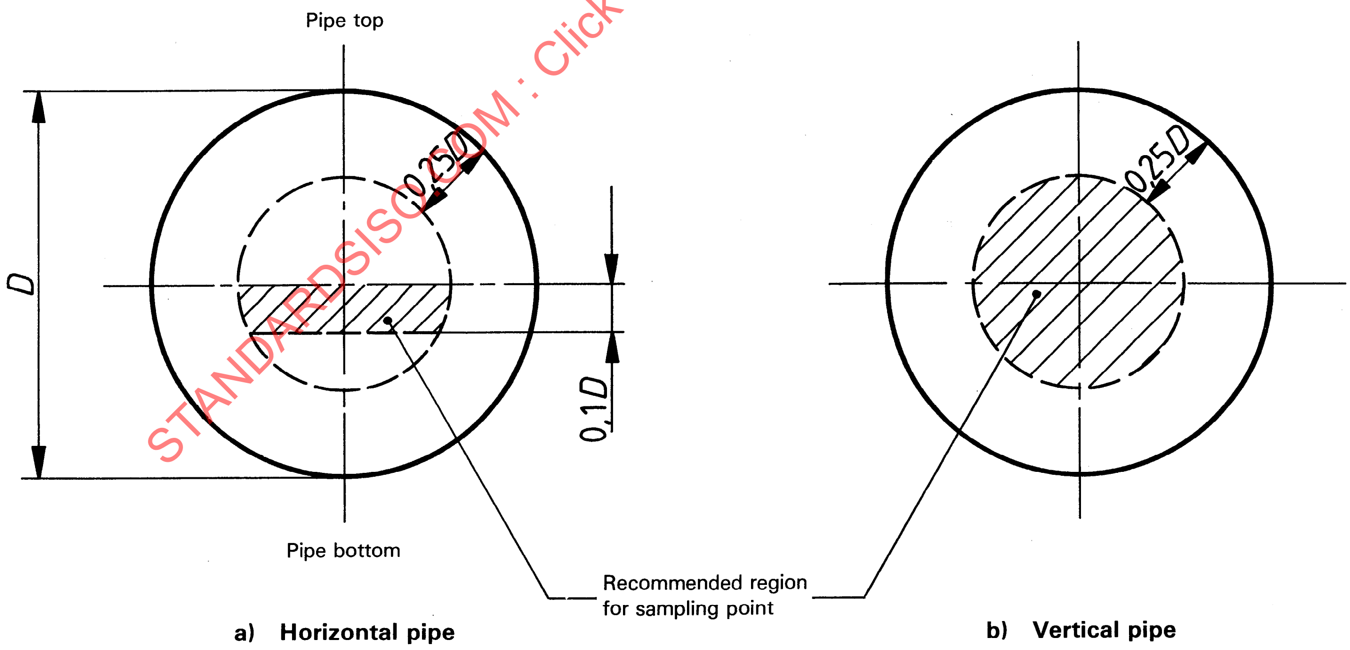


NOTES

1 Vertical lines marked "C_0" represent the mean water concentration in each case.

2 Water concentration increases along the abscissa, which is parallel to the pipe centreline. The abscissa starts again from zero for each type of profile

Figure 2 — Graphical representation of concentration profiles in a horizontal pipe



a) **Horizontal pipe**

b) **Vertical pipe**

Figure 3 — Location of sampling point

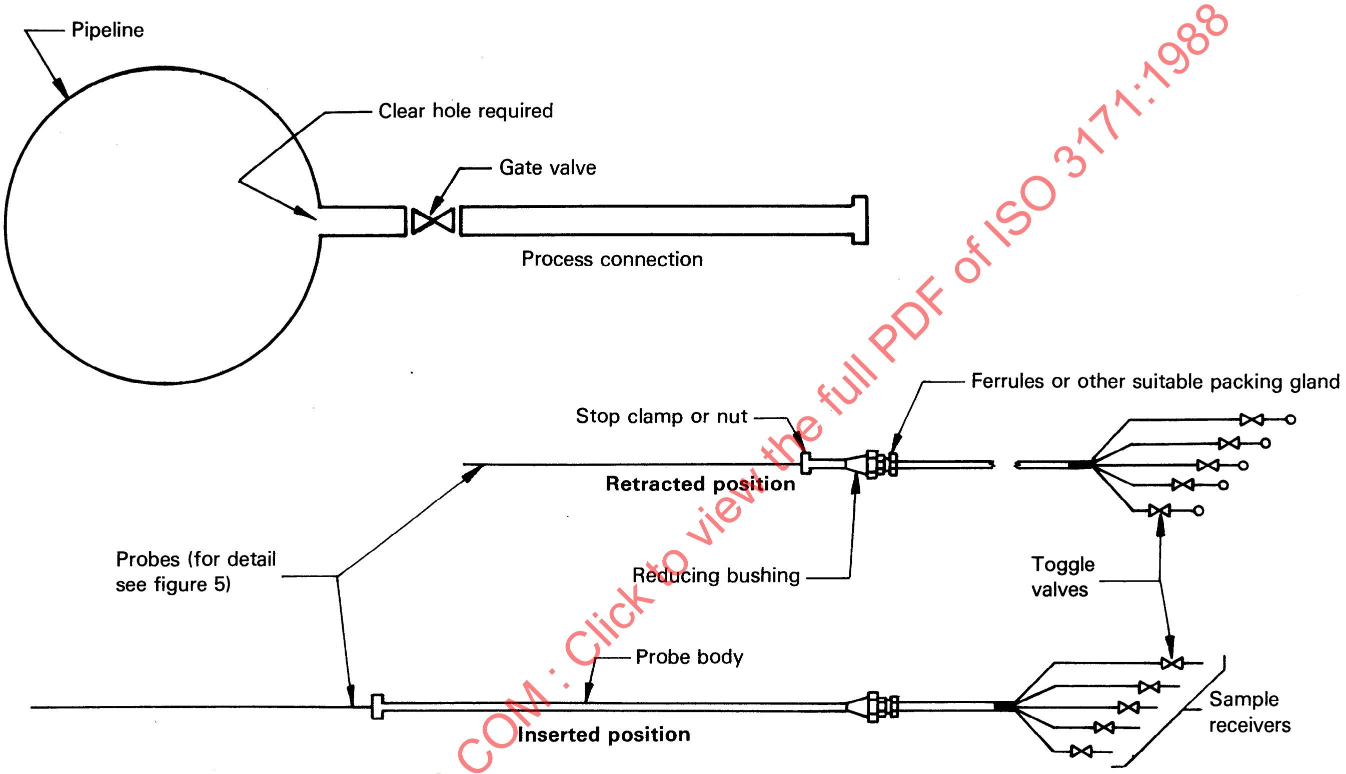


Figure 4 — Multipoint probe for profile sampling

Dimensions in millimetres

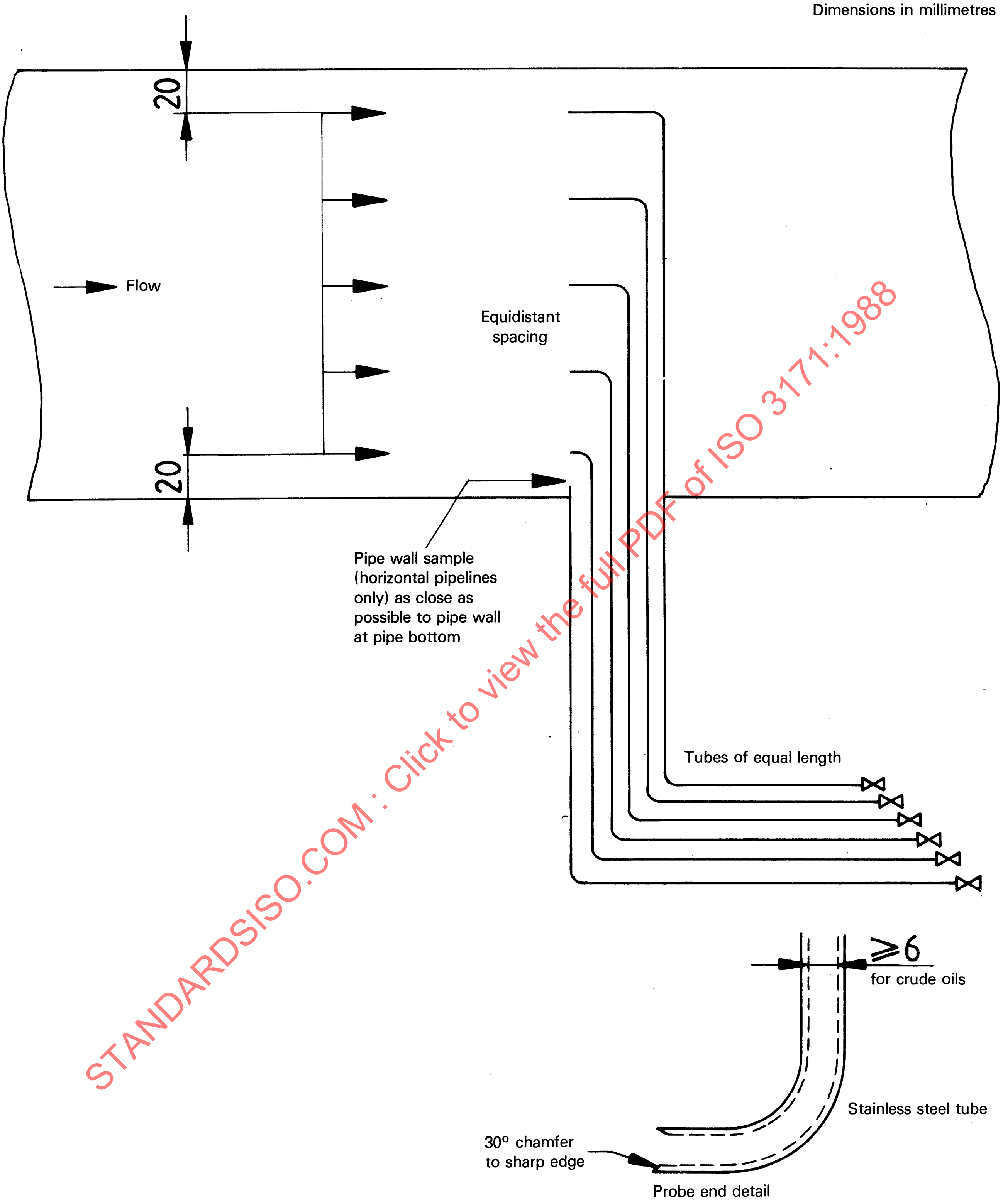


Figure 5 — Arrangement of multipoint probe in horizontal pipeline for 300 mm diameter pipelines or larger (see 6.4.1.1)

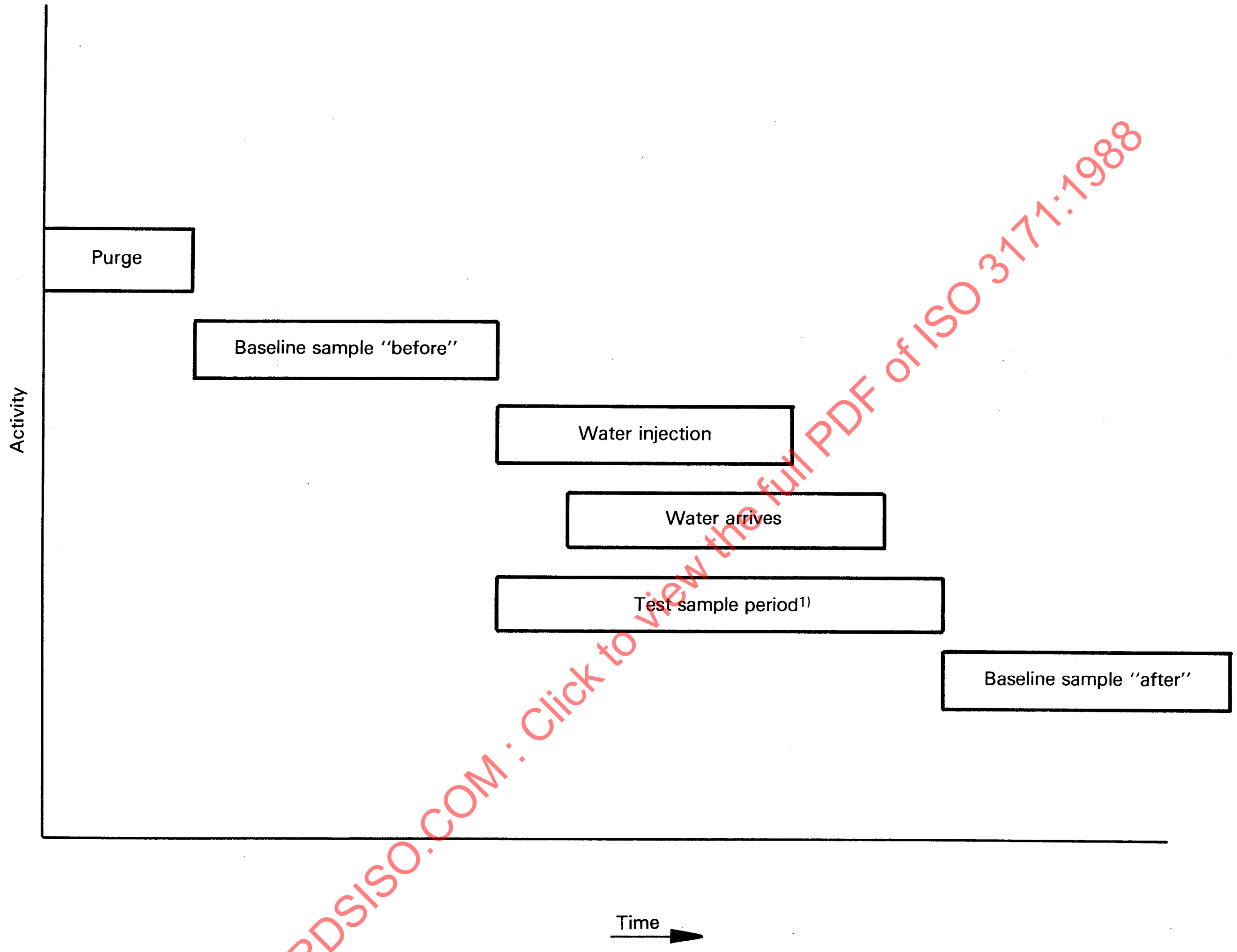


Figure 6 — Typical timing diagram for sampler system testing

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[1] Each sample period should be at least 1 h. The test sample period should overlap both ends of the "water arrives" period.

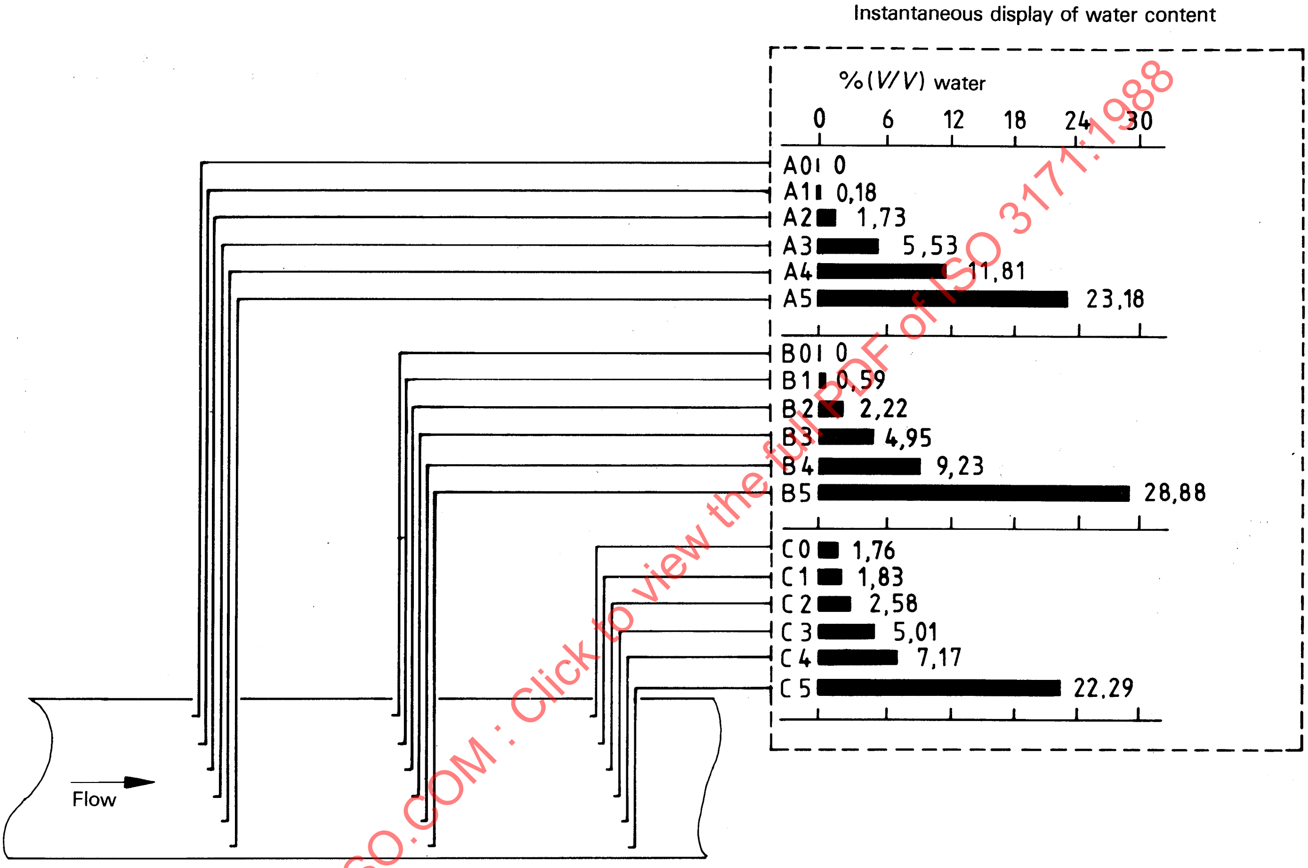
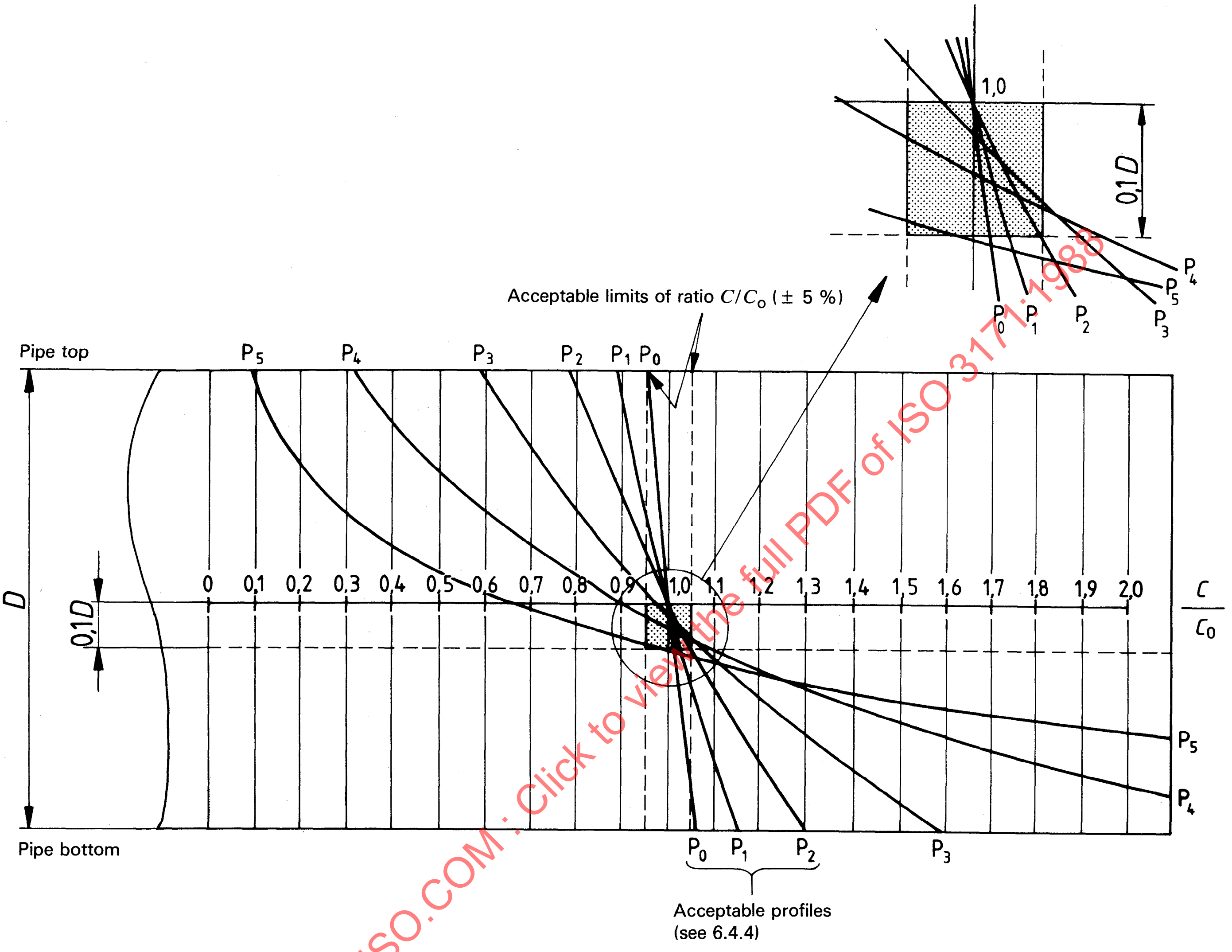


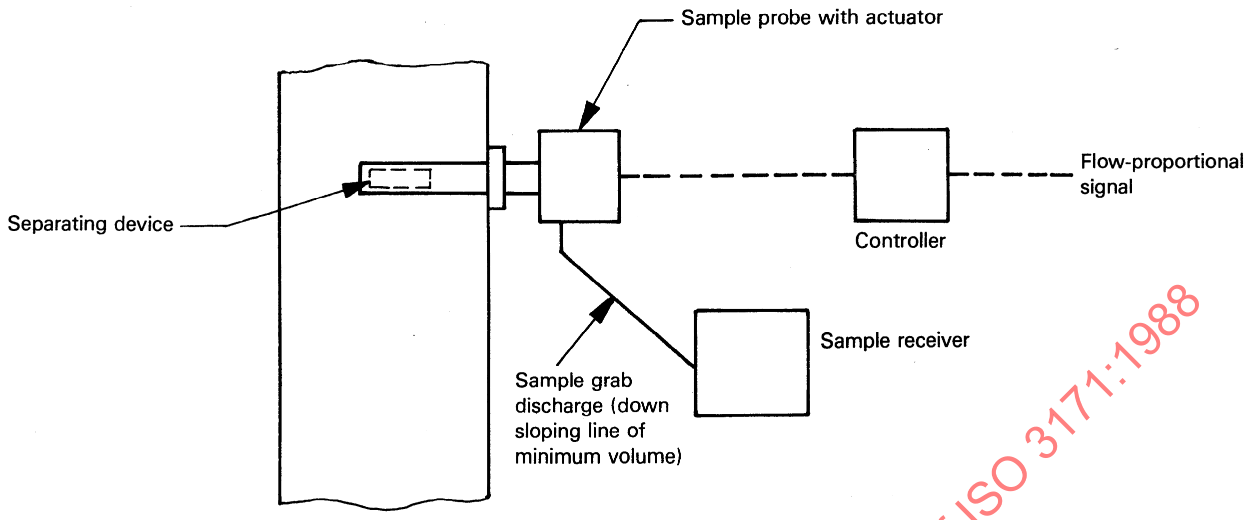
Figure 7 — Bar graph presentation of automatic profile test at three locations



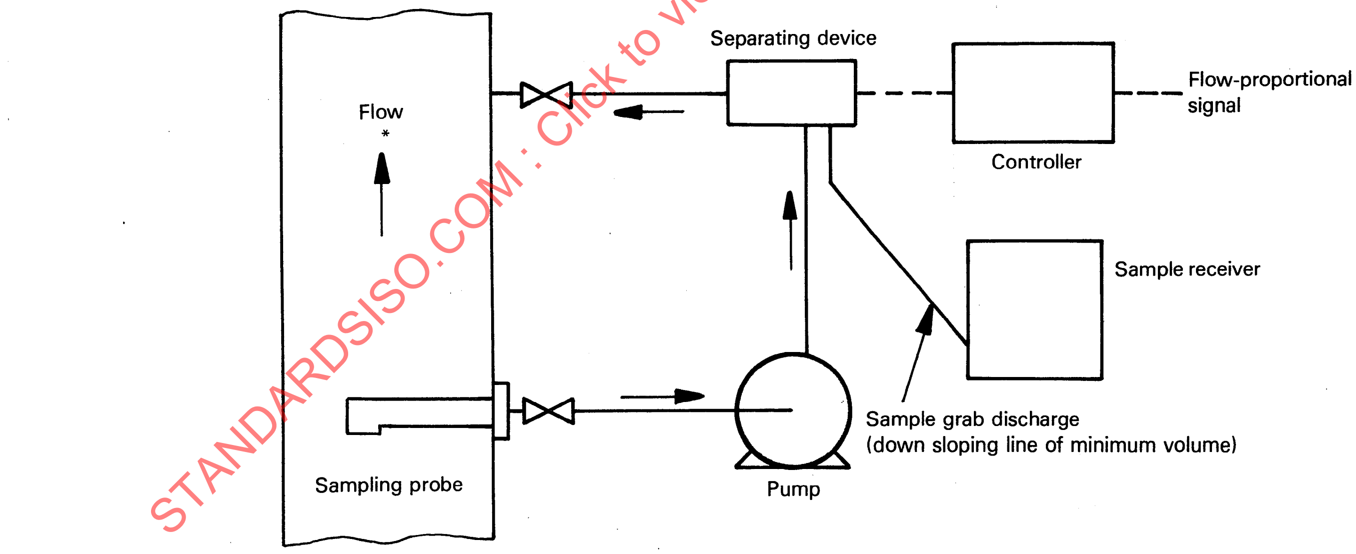
NOTE — The ratio C/C_0 is the ratio of the water concentration at a point to the mean water concentration at the the sampling location.

Profiles P_3, P_4 and P_5 are not acceptable because the ratio C/C_0 is outside the range 0,95 to 1,05 for at least part of the recommended region for the sample withdrawal point (see figures 2 and 3).

Figure 8 — Results from profile tests (typical profiles)



a) **Automatic sampler in line**



* Arrow does not indicate pipe orientation

b) **Automatic sampler with an external sample loop**

Figure 9 — Typical sampling systems

Annex A

Estimating water-in-oil dispersion

(This annex forms an integral part of the Standard.)

A.1 Introduction

This annex sets out calculation procedures based on a simplified theory to give some indication of the dispersion of water in oil at proposed or existing sampling locations. These procedures should be used with extreme caution in any practical application.

The theoretical basis for these procedures is given in clause A.3 in a simplified version.[1]

The results of the calculations may deviate widely from some experimental values for the following reasons.

a) The values of some of the constants are very difficult to determine because of a lack of experimental data. In particular the value of ΔX [equation (12) et al.] is not known in many cases.

b) Some of the fundamental equations used in the calculations are subject to limitations (see clause A.3).

Consequently, a conservative approach is strongly recommended when estimating the acceptable limits for adequate dispersion.

A.2 General

The dispersion of oil and water at the sampling location has to be sufficient to give representative sampling, i.e. the water concentration at the sampling probe entry point should be within the limits for acceptance given in 4.4.

A.2.1 Horizontal piping

A.2.1.1 Adequate oil and water mixing for representative sampling is characterized by uniform dispersion ($C_1 = C_2$ in A.2.1.2). Dispersion of oil and water is promoted by a high flow rate, high oil viscosity, high oil density, small pipe diameter and upstream mixing.

Oil and water stratification is characterized by coarse dispersion, i.e. large-diameter water droplets with a relatively high settling rate W, resulting in an increase in water concentration towards the bottom of the pipe and a decrease towards the top. This condition is promoted by minimum upstream mixing, a low flow rate, low oil viscosity, low oil density and large pipe diameter.

A.2.1.2 The degree of dispersion in horizontal pipes can be estimated using the equation

$$\frac{C_1}{C_2} = \exp\left(\frac{-W}{\varepsilon/D}\right)$$

where

C_1/C_2 is the ratio of water concentration at the top (C_1) to that at the bottom (C_2);

W is the settling rate of the water droplets;

ε/D is the turbulence characteristic, where ε is the eddy diffusivity and D the pipe diameter.

A C_1/C_2 ratio of 0,9 to 1,0 indicates very good dispersion. A ratio of 0,4 or smaller indicates poor dispersion with a high potential for water stratification.

A.2.1.3 Four calculation procedures are provided:

Procedure 1: to indicate whether dispersion is likely to be adequate for sampling (see clause A.4);

Procedure 2: to indicate whether enough energy for proper sampling is likely to be available (see clause A.5);

Procedure 3: to select a suitable sampling location (see clause A.6);

Procedure 4: to determine a system constant from profile test data (see clause A.7).

A.2.1.4 In addition to the assumptions and limitations discussed in clause A.3, the following should be noted.

a) The analysis is based on the assumption that the concentration profiles are fully developed. Thus, profiles taken too close to a mixing element (where swirl effects may distort the dispersion) or profiles taken too far downstream (where settling may dominate, particularly at low velocity) may not be properly described by the analysis.

b) Water injection during profile or proving tests may produce additional mixing and subsequently a better dispersion

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[1] For further information, see:

a) HAYWARD, P. Conditions hydrauliques minimales pour l'échantillonnage automatique. *Pétroles et Techniques,* 295, 1983.

b) HAYWARD, P. Étude d'un projet de poste d'échantillonnage. *Pétroles et techniques,* 332, 1987.

than otherwise would be expected from the system. The mixing energy produced by the jet should be less than half the mixing energy produced by the most critical mixing element upstream of the sampling location [see clause A.3 and procedure 1 in clause A.4, equations (12) to (26)].

c) The water concentration level in the crude oil has some effect on the profile. If that concentration varies with time and reaches 10 % to 20 % the method should not be used.

d) The main purpose of the calculation procedures is to select potential locations for sampling, to evaluate whether changes in operating conditions might adversely affect the dispersion, to estimate the amount of additional mixing energy needed to improve dispersion, as a diagnostic tool in the evaluation of questionable performance, and in the analysis of profile test data.

e) Sampler proving and profile testing are recommended to validate or discredit the location of a sampling system. The calculations give assistance for evaluating the improvements needed by unacceptable systems (see procedure 2 in clause A.5).

f) When evaluating whether dispersion is adequate or not in a given system, it is recommended to use the worst-case conditions expected, for example the lowest flow rate and the lowest oil viscosity or density.

g) When calculating the energy dissipation rate E, it should be noted that the dissipation energies of different piping elements are not additive in regard to dispersion, i.e. when a series of elements is present, the element that should be considered is the one that dissipates energy the most. A procedure to determine which is the most critical piping element is presented in procedure 3 (see clause A.6).

A.2.2 Vertical piping

In vertical lines, the dispersion is usually better than in horizontal lines because gravity does not promote settling as it does in a horizontal line. However, if the water droplet settling rate is more than 5 % of the crude oil flow rate, the water concentration will be noticeably higher in an upwards flow and lower in a downwards flow than the mean concentration.

NOTE — The droplet settling rate W can be estimated from figure 11 or equation (8).

The sampling probe should be located at a minimum distance of 3, but preferably greater than 5, pipe diameters from any upstream bend and a minimum distance of 0,5 diameters from any downstream bend, to avoid a distorted profile.

A.2.3 Units

The parameters considered in this annex are generally expressed in SI units. However, when other units are used a special mention is given following the equations concerned.

A.2.4 Nomenclature

The symbols and units employed for the terms used in this annex are given in table 5.

A.3 Principles

Many of the following equations are not strictly applicable to these circumstances, but are useful because they offer a simplified approach to a complex problem.

As already stated in A.2.1.2, the relation between water concentration at the top of a horizontal pipe C_1, to the concentration at the bottom C_2, is given by the equation

$$\frac{C_1}{C_2} = \exp\left(\frac{-W}{\varepsilon/D}\right) \qquad \dots (3)$$

This formula is only valid for

$$\frac{W}{\varepsilon/D} < 1,$$

where

W is the settling rate of a water droplet with a diameter d;

D is the pipe diameter;

ε is the particle eddy diffusivity. This characterizes the pipe turbulence and is given by the equation

$$\varepsilon = \zeta R U^* \qquad \dots (4)$$

where

ζ is a dimensionless constant;

R is the radius of the pipe;

U^* is the pipe friction velocity.

An adequate estimate for ζ is 0,36. U^* is related to the Fanning friction factor f and the mean flow rate in the pipe V by the equation

$$U^* = V\left(\frac{f}{2}\right)^{1/2} \qquad \dots (5)$$

The Fanning friction factor for smooth pipes is given by the equation

$$f = \frac{0{,}079}{Re^{0{,}25}} \qquad \dots (6)$$

where Re is the flow Reynolds number.

The Blasius friction factor λ is related to f by the relation $\lambda = 4f$ and it can be used equivalently in the expressions to follow.

Table 5 — Symbols

Symbol	Term	Unit
C	Water concentration (water/oil ratio)	Dimensionless
D	Pipe diameter	m
d	Average diameter of water droplet	m
E	Rate of energy dissipation	W/kg
E_a	Available energy dissipation from critical element	W/kg
E_o	Energy dissipation in straight pipe	W/kg
E_r	Required energy dissipation	W/kg
f	Fanning friction factor	Dimensionless
G	Parameter, defined in equation (27)	Dimensionless
g	Gravitational acceleration (= 9,81)	m/s^2
K	Resistance coefficient	Dimensionless
ΔP	Pressure drop	Pa 1)
Q	Volumetric flow rate	m^3/s
R	Radius of pipe	m
Re	Reynolds number	Dimensionless
U^*	Friction velocity	m/s
V	(linear) flow rate	m/s
$\overline{V}$	Volume	m^3
W	Settling rate of water droplets	m/s
ΔX	Dissipation distance	m
Y	Distance between top and bottom profile probes	m
β	Parameter, defined in equation (21)	Dimensionless
γ	Ratio between small and large diameter where pipe diameter changes	Dimensionless
λ	Blasius friction factor (= $4f$)	Dimensionless
ε	Eddy diffusivity	m^2/s
ζ	Eddy diffusivity constant	Dimensionless
ϑ	Kinematic viscosity	m^2/s 2)
ϱ	Crude oil density	kg/m^3
ϱ_d	Water density	kg/m^3
σ	Surface tension	N/m 3)
τ	System constant, defined in equation (16)	m^{-1}

1) 1 Pa = 10^{-5} bar

2) 1 m^2/s = 10^6 cSt = 10^6 mm^2/s

3) 1 N/m = 10^3 dyn/cm

Substitution of equations (5) and (6) into equation (4) with $\zeta = 0{,}36$ gives:

$$\frac{\varepsilon}{D} = 6{,}313 \times 10^{-3} \vartheta^{0{,}125} V^{0{,}875} D^{-0{,}125} \qquad \ldots (7)$$

where

V is the flow rate, in metres per second, at the sampling section;

ϑ is the kinematic viscosity, in square millimetres per second (centistokes).

This equation may be solved either numerically or by use of the nomogram in figure 12.

The other important parameter in equation (3) is the settling rate of the average-sized particle. According to Stokes law, settling rate is described by

$$W = \frac{g}{18} \left(\frac{\varrho_d - \varrho}{\varrho} \right) \frac{d^2}{\vartheta} \qquad \ldots (8)$$

where

g is the gravitational acceleration;

ϱ_d and ϱ are the densities of water and crude oil, respectively;

d is the average diameter of the water droplets given by

$$d = 0{,}362\,5 \left(\frac{\sigma}{\varrho} \right)^{0{,}6} E^{-0{,}4} \qquad \ldots (9)$$

or by following the sequence E, ϱ, d in figure 10

where

σ is the droplet surface tension between water and oil;

E is the energy dissipation rate in the flow.

Substituting equation (9) into equation (8), and assuming that $\sigma = 0{,}025$ N/m:

$$W = 855 \left(\frac{\varrho_{\mathrm{d}} - \varrho}{\vartheta \varrho^{2{,}2}} \right) E^{-0{,}8} \qquad \dots (10)$$

where ϑ is in square millimetres per second (centistokes).

This equation may be solved either numerically or by using the nomogram in figure 11 (see note 1).

The dissipation energy E is related to the pressure drop ΔP by the equation

$$E = \frac{\Delta P \, Q}{\varrho \bar{V}} \qquad \dots (11)$$

where

Q is the volumetric flow rate;

$\bar{V}$ is the volume of liquid subjected to the dissipation action.

Thus:

$$E = \frac{\Delta P \, V}{\Delta X \, \varrho} \qquad \dots (12)$$

where

V is the flow rate at the pipe section in which energy is dissipated;

ΔX is a characteristic length that represents the distance in which energy has been dissipated, i.e. the notional distance over which the water phase within the crude oil breaks up into small globules.

In most cases, ΔX is not known. Wherever possible the value to be used should be supported by experimental data. For specially designed high-efficiency static mixers, the value ΔX will be small and should be obtained from the designer.

For some piping elements (such as valves, pumps, etc.) the pressure drop is normally known and equation (12) can be easily applied. For those cases where ΔP is not known, it can be calculated using the equation

$$\Delta P = \frac{K \varrho \, V^2}{2} \qquad \dots (13)$$

where K is the resistance coefficient of the piping element under consideration.

Equation (12) thus becomes

$$E = \frac{K \, V^3}{2 \Delta X} \qquad \dots (14)$$

For profile data analysis (see procedure 4 in clause A.7), it is more convenient to write equation (14) in the form

$$E = \tau V^3 \qquad \dots (15)$$

where τ is the system constant, defined as

$$\tau = \frac{K}{2 \Delta X} \qquad \dots (16)$$

In the special case of a long straight unobstructed pipe, the pressure gradient is calculated using the equation:

$$\frac{\Delta P}{\Delta X} = \frac{2 f \varrho \, V^2}{D} \qquad \dots (17)$$

where f is given by equation (6).

Substituting equation (17) into equation (12) gives the energy dissipation rate for a pipe E_{o} as

$$E_{\mathrm{o}} = \frac{2 f \, V^3}{D} \qquad \dots (18)$$

or, by substituting equation (6) for f

$$E_{\mathrm{o}} = 0{,}005 \, \vartheta^{0{,}25} D^{-1{,}25} V^{2{,}75} \qquad \dots (19)$$

where ϑ is in square millimetres per second (centistokes).

It can be shown from equations (17) and (18) that E from equation (14) can also be presented as

$$E = \beta E_{\mathrm{o}} \qquad \dots (20)$$

where

$$\beta = \frac{K D}{4 \, \Delta X \, f} \qquad \dots (21)$$

This optional presentation is useful in developing a simpler and faster method for calculating E [see procedure 1 — method b) in clause A.4]. (See note 2.)

NOTES

1 Interfacial tension values may be significantly affected by additives and contaminants. If it is known that the surface tension value is other than 0,025 N/m the settling rate relation given in equation (10) should be modified. Multiply the right-hand side of equation (10) by

$$\left(\frac{\sigma}{0{,}025} \right)^{1{,}2}$$

2 The calculations described above are applicable only if the size distribution of the water particles can be approximated by an average value (the "Sauter mean"). If the actual droplet size distribution is wide, the predicted concentration ratio may deviate from the actual ratio. This is because droplets smaller than the average size will be dispersed more easily while droplets larger than the average size will settle faster.

Also, actual profiles found by tests may not agree with the concentration ratio predicted because of unmeasurable parameters such as ΔX and f. For this reason, the system constant τ and the characteristic parameter of a mixing element β are given for predicting concentration ratios at different flow conditions (V, ϱ, ϑ) for a given system.

A.4 Procedure 1

A.4.1 Objective

To indicate whether dispersion is likely to be adequate for sampling in a system with a given piping element.

A.4.2 Step 1

Estimate the energy available for dispersion, E, in the piping element under consideration by the method given in A.4.2.1 or that given in A.4.2.2.

A.4.2.1 Method a)

Calculate E by the relation

$$E = \frac{\Delta P\, V}{\Delta X \varrho} \qquad \ldots (12)$$

where

ΔP is the pressure drop across the piping element;

ΔX is a characteristic length which represents the distance in which energy has been dissipated.

NOTES

1 If ΔX is not known, a substitutive value of $\Delta X = 10D$ may be used as a very rough approximation for devices of low mixing efficiency such as those in table 6.

2 If ΔP is not known, calculate it using the equation

$$\Delta P = \frac{K \varrho V^2}{2} \qquad \ldots (13)$$

where K is the resistance coefficient of the piping element under consideration. Suggested values of K for different piping elements are given in table 6.

3 E can also be described as

$$E = \tau V^3 \qquad \ldots (15)$$

where τ is a system constant that can be evaluated for a given system by procedure 4 given in clause A.7 if a set of profile test data is available.

A.4.2.2 Method b)

An alternative method for calculating E may be used. It is simpler and faster but less accurate than method a). This method is based on the equation

$$E = \beta E_o \qquad \ldots (20)$$

where

β is a characteristic parameter of a mixing element;

E_o is the rate of energy dissipation in a straight pipe and is calculated from figure 10 or from the equation

$$E_o = 0{,}005\, \vartheta^{0{,}25} D^{-1{,}25} V^{2{,}75} \qquad \ldots (19)$$

where ϑ is in square millimetres per second (centistokes).

NOTE — For certain piping elements, the following tentative relationships for E are suggested:

1) Bends

$$E = \beta E_o \qquad \ldots (20)$$

where β is given in table 7.

The spacing between the bends may affect the degree of dispersion. For the values in table 7 to hold, the distance between each bend should not exceed 30 pipe diameters.

2) Change of diameter

$$E = \beta E_o \qquad \ldots (20)$$

— Contraction:

$$\beta = 2{,}5\,(1 - \gamma^2) \qquad \ldots (22)$$

— Enlargement:

$$\beta = 5\,(1 - \gamma^2)^2 \qquad \ldots (23)$$

where γ is the ratio small diameter/large diameter.

Table 6 — Suggested resistance coefficients[1]

Contraction	$K = 0{,}5\,(1 - \gamma^2)$	$0 \leqslant K \leqslant 0{,}5$
Enlargement	$K = (1 - \gamma^2)^2$	$0 \leqslant K \leqslant 1{,}0$
Orifice	$K = 2{,}8\,(1 - \gamma^2)\left[\left(\frac{1}{\gamma}\right)^4 - 1\right]$	
Circular mitre bends	$K = 1{,}2\,(1 - \cos\theta)$ where θ = turn angle	$0 \leqslant K \leqslant 1{,}2$
Swing check valve	$K = 2$	
Angle valve	$K = 2$	
Globe valve	$K = 6$	
Gate valve	$K = 0{,}15$	

1) γ is the ratio small diameter/large diameter and K is based on the velocity in the smaller pipe.

Table 7 — Values of β for bends

r/D	1	1,5	2	3	4	5	10
n[1)] = 1	1,27	1,25	1,23	1,22	1,18	1,15	1,07
n = 2	1,55	1,50	1,48	1,45	1,38	1,30	1,13
n = 3	1,90	1,80	1,75	1,70	1,56	1,44	1,18
n = 4	2,20	2,10	2,00	1,93	1,72	1,56	1,23
n = 5	2,60	2,40	2,30	2,20	1,90	1,70	1,28

1) n is the number of bends of radius r in a pipe of diameter D.

3) Centrifugal pump

$$E = 0{,}012\,5\,\frac{\Delta P\,Q}{\varrho\,D^3} \qquad \ldots (24)$$

where

Q is the volumetric flow rate;

D is the diameter of the pump discharge pipe.

4) Throttling valve

$$E = \frac{\Delta P\,V}{20\,\varrho\,D} \qquad \ldots (25)$$

5) Flow nozzle

$$E = 0{,}022\,\frac{V_{\mathrm{j}}^3}{\phi} \qquad \ldots (26)$$

where

ϕ is the nozzle diameter;

V_{j} is the flow rate at the nozzle exit.

A.4.3 Step 2

Calculate the settling rate for the average-sized droplet from figure 11 or from the equation

$$W = 855\left(\frac{\varrho_{\mathrm{d}} - \varrho}{\vartheta\,\varrho^{2,2}}\right)E^{-0,8} \qquad \ldots (10)$$

where

E is the highest value among the figures obtained in step 1;

ϱ_{d} is the water density. For salt water (from wells or tankers), a suggested value is 1 025 kg/m^3 if the actual one is not available.

If the mean of C_1 and C_2 is higher than 5 %, multiply W by 1,2.

A.4.4 Step 3

Calculate the turbulence characteristic from figure 12 or using the equation

$$\frac{\varepsilon}{D} = 6{,}313 \times 10^{-3}\,\vartheta^{0,125}\,V^{0,875}\,D^{-0,125} \qquad \ldots (7)$$

A.4.5 Step 4

Calculate the value of the parameter G using the equation

$$G = \frac{\varepsilon/D}{W} \qquad \ldots (27)$$

from which the expected concentration ratio can be determined according to table 8.

NOTE — Because of the uncertainty of the calculations, errors in G of more than 20 % may result. These large errors occur at low values of G and for this reason, when values of G less than 2 in equation (27) are obtained, then sampling is not recommended.

Table 8 — Expected concentration ratio

G	C_1/C_2	C_2/C_1
10	0,90	1,11
8	0,88	1,14
6	0,85	1,18
4	0,78	1,28
3	0,71	1,41
2	0,61	1,64
1,5	0,51	1,96
1	0,37	2,70

A.5 Procedure 2

A.5.1 Objective

To indicate whether enough energy E_{r} for acceptable sampling is likely to be available in a given piping element for given flow conditions.

A.5.2 Step 1

Determine the value of G from table 8 for the required profile. For example, if a profile with a C_1/C_2 ratio of 0,90 is required, the corresponding value of G is 10.

A.5.3 Step 2

Calculate the turbulence characteristic from figure 12 or using the equation

$$\frac{\varepsilon}{D} = 6{,}313 \times 10^{-3}\,\vartheta^{0,125}\,V^{0,875}\,D^{-0,125} \qquad \ldots (7)$$

A.5.4 Step 3

Calculate the required settling rate from the equation

$$W = \frac{\varepsilon / D}{G} \qquad \text{. . . (28)}$$

A.5.5 Step 4

Calculate the required energy for an acceptable profile from figure 11 or using the equation

$$E_r = 4\,630 \left(\frac{\varrho_d - \varrho}{\vartheta\, W} \right)^{1{,}25} \varrho^{-2{,}75} \qquad \text{. . . (29)}$$

A.5.6 Step 5

Calculate the energy available for dispersion E_a by following step 1 in procedure 1 given in clause A.4. If $E_a < E_r$, then the energy available is not enough for acceptable sampling.

A.5.7 Step 6

One of the following alternatives may be used to increase the available energy:

a) add an additional upstream mixing element;

b) decrease the upstream pipe diameter (i.e. increase flow rate);

c) investigate an alternative location for the sampling probe (see procedure 3 given in clause A.6).

A.6 Procedure 3

A.6.1 Objective

To select a suitable sampling location.

A.6.2 Step 1

Select the worst-case conditions. Also, determine the desired concentration ratio C_1/C_2 and from table 8 find the corresponding value of G.

A.6.3 Step 2

Calculate ε / D from figure 12 or using the equation

$$\frac{\varepsilon}{D} = 6{,}313 \times 10^{-3} \vartheta^{0{,}125} V^{0{,}875} D^{-0{,}125} \qquad \text{. . . (7)}$$

A.6.4 Step 3

Calculate W using the equation

$$W = \frac{\varepsilon / D}{G} \qquad \text{. . . (28)}$$

A.6.5 Step 4

Calculate the required energy for the desired profile from figure 11 or using the equation

$$E_r = 4\,630 \left(\frac{\varrho_d - \varrho}{\vartheta\, W} \right)^{1{,}25} \varrho^{-2{,}75} \qquad \text{. . . (29)}$$

A.6.6 Step 5

Calculate the dissipation energy E_a for each piping element in the system by following step 1 in procedure 1 given in clause A.4 and determine which element has the largest energy dissipation rate. This element is the most critical element and the energy associated with it is the energy available for dispersion E_a.

A.6.7 Step 6

Compare E_a with E_r and determine from table 9 if the resulting profile is acceptable.

Table 9 — Acceptability of profile

Condition	Conclusion	Action
$E_a \geqslant E_r$	Profile satisfies criterion	No action needed
$E_a < E_r$	Profile does not satisfy criterion	Increase flow rate (by reducing the pipe diameter for at least 10 diameters upstream of the sampling location) and/or introduce a new mixing element. Go to step 7.

A.6.8 Step 7

If the flow rate has been increased by reducing the pipe diameter, repeat steps 2 to 6 and determine if the new E_a is larger than the new value of E_r.

If a new mixing element has been introduced into the system without changing the flow rate, check by following step 1 in procedure 1, given in clause A.4, whether its dissipation energy E is larger than E_a. If it is larger ($E \geqslant E_a$), then replace E_a with the value of E and go to step 6. If it is smaller ($E < E_a$), repeat step 7 for another piping element.

A.7 Procedure 4

A.7.1 Objective

To determine a system constant τ from profile test data.

A.7.2 Step 1

Determine the water concentration at the top probe location ($= C_A$) and at the bottom probe location ($= C_B$). Also determine the distance between these two probe locations ($= Y$) and the values of ϑ, V and D which were used in the profile test.

A.7.3 Step 2

Calculate the turbulence characteristic from figure 12 or using the equation

$$\frac{\varepsilon}{D} = 6{,}313 \times 10^{-3} \vartheta^{0{,}125} V^{0{,}875} D^{-0{,}125} \qquad \dots (7)$$

A.7.4 Step 3

Calculate the settling rate from the equation

$$W = \frac{\varepsilon}{D} \left(\frac{D}{Y} \right) \ln \left(\frac{C_B}{C_A} \right) \qquad \dots (30)$$

NOTE — $C_B > C_A$.

A.7.5 Step 4

Calculate E from figure 11 or using the equation

$$E = 4\ 630 \left(\frac{\varrho_d - \varrho}{\vartheta\ W} \right)^{1{,}25} \varrho^{-2{,}75} \qquad \dots (29)$$

A.7.6 Step 5

Calculate τ from equation (15) rearranged as

$$\tau = \frac{E}{V^3} \qquad \dots (31)$$

NOTE — The τ-value thus calculated for a given system is only valid for this specific system and generally cannot be applied to other piping configurations.

A.8 Calculation examples

A.8.1 Example of procedure 1

Using the guidelines associated with parameter G (see table 8) determine whether dispersion is adequate for sampling in a system that includes a contraction from a 1,0 m pipe to a 0,5 m pipe. Use the following additional information:

$V = 1{,}0$ m/s (in the small pipe)

$\varrho = 840$ kg/m^3

$\vartheta = 12$ mm^2/s (12 cSt)

$\varrho_d = 1\ 025$ kg/m^3

A.8.1.1 Step 1

Estimate the energy available for dispersion.

A.8.1.1.1 Method a)

a) default value for ΔX is $10D$

b) Calculate K (see table 6):

$$\begin{aligned} K &= 0{,}5\ (1 - \gamma^2) \\ &= 0{,}5\ [1 - (0{,}5/1{,}0)^2] \\ &= 0{,}375 \end{aligned}$$

c) Calculate ΔP:

$$\begin{aligned} \Delta P &= \frac{K \varrho\ V^2}{2} \\ &= \frac{0{,}375\ (840)\ (1{,}0)^2}{2} \\ &= 157{,}5 \text{ Pa} \end{aligned}$$

d) Calculate E:

$$\begin{aligned} E &= \frac{\Delta P\ V}{\Delta X\ \varrho} \\ &= \frac{157{,}5\ (1{,}0)}{10\ (0{,}5)\ (840)} \\ &= 0{,}037\ 5 \text{ W/kg} \end{aligned}$$

A.8.1.1.2 Method b)

a) Calculate E_o (see example 1 in figure 10):

$$\begin{aligned} E_o &= 0{,}005\ \vartheta^{0{,}25} D^{-1{,}25} V^{2{,}75} \\ &= 0{,}005\ (12)^{0{,}25} (0{,}5)^{-1{,}25} (1{,}0)^{2{,}75} = 0{,}022 \text{ W/kg} \end{aligned}$$

b) Calculate β:

$$\begin{aligned} \beta &= 2{,}5\ (1 - \gamma^2) \\ &= 2{,}5\ [1 - (0{,}5/1{,}0)^2] \\ &= 1{,}875 \end{aligned}$$

c) Calculate E:

$$\begin{aligned} E &= \beta E_o \\ &= 1{,}875\ (0{,}022) \\ &= 0{,}04 \text{ W/kg} \end{aligned}$$

A.8.1.2 Step 2

Using the value for E calculated by method a) (as it is a more accurate method), calculate the settling rate:

$$\begin{aligned} W &= 855 \left(\frac{\varrho_d - \varrho}{\vartheta \varrho^{2{,}2}} \right) E^{-0{,}8} \\ &= 855 \left(\frac{1\ 025 - 840}{12 \times 840^{2{,}2}} \right) 0{,}037\ 5^{-0{,}8} \\ &= 0{,}067\ 2 \text{ m/s (see example 1 in figure 11).} \end{aligned}$$

Calculate the droplet diameter as follows:

$$d = 0{,}362\ 5 \left(\frac{\sigma}{\varrho} \right)^{0{,}6} E^{-0{,}4} \qquad \dots (9)$$

$$\begin{aligned} &= 0{,}362\ 5 \left(\frac{0{,}025}{840} \right)^{0{,}6} (0{,}037\ 5)^{-0{,}4} \\ &= 2{,}59 \text{ mm (see example 1 in figure 10).} \end{aligned}$$

A.8.1.3 Step 3

Calculate the turbulence characteristic (see the example in figure 12):

$$\frac{\varepsilon}{D} = 6{,}313 \times 10^{-3}\,\vartheta^{0{,}125}\,V^{0{,}875}\,D^{-0{,}125}$$

$$= 6{,}313 \times 10^{-3}\,(12)^{0{,}125}\,(1{,}0)^{0{,}875}\,(0{,}5)^{-0{,}125}$$

$$= 0{,}009\,4 \text{ m/s}$$

A.8.1.4 Step 4

Calculate the value of G:

$$G = \frac{\varepsilon/D}{W} = \frac{0{,}009\,4}{0{,}067\,2} = 0{,}14$$

This value indicates that the concentration ratio C_1/C_2 is smaller than 0,30 (table 8) and therefore the dispersion in the given conditions is not adequate for acceptable sampling.

A.8.2 Example of procedure 2

For the conditions described in A.8.1, determine the additional energy required for proper sampling.

A.8.2.1 Step 1

From table 8, determine the desired value of G. For example, a ratio of $C_1/C_2 = 0{,}90$, and consequently $G = 10$, is required.

A.8.2.2 Step 2

Calculate ε/D:

$$\frac{\varepsilon}{D} = 6{,}313 \times 10^{-3}\,\vartheta^{0{,}125}\,V^{0{,}875}\,D^{-0{,}125}$$

$$= 6{,}313 \times 10^{-3}\,(12)^{0{,}125}\,(1{,}0)^{0{,}875}\,(0{,}5)^{-0{,}125}$$

$$= 0{,}009\,4 \text{ m/s}$$

A.8.2.3 Step 3

Calculate the required settling rate:

$$W = \frac{\varepsilon/D}{G}$$

$$= \frac{0{,}009\,4}{10}$$

$$= 0{,}000\,94 \text{ m/s}$$

A.8.2.4 Step 4

Determine the required energy E_r (see also example 2 in figure 11):

$$E_r = 4\,630 \left(\frac{\varrho_d - \varrho}{\vartheta\,W}\right)^{1{,}25} \varrho^{-2{,}75}$$

$$= 4\,630 \times \left(\frac{1\,025 - 840}{12 \times 0{,}000\,94}\right)^{1{,}25} 840^{-2{,}75}$$

$$= 7{,}80 \text{ W/kg}$$

Calculate the drop diameter as in A.8.1.2: $d = 0{,}3$ mm (see example 2 in figure 10).

A.8.2.5 Step 5

According to A.8.1, the available energy $E_a = 0{,}037\,5$ W/kg. Since $E_a \ll E_r$, increase the available mixing energy.

A.8.2.6 Step 6

If the pipe diameter is decreased to 0,25 m, the flow rate becomes 4,0 m/s and the following equations result:

$$\frac{\varepsilon}{D} = 6{,}313 \times 10^{-3}\,\vartheta^{0{,}125}\,V^{0{,}875}\,D^{-0{,}125}$$

$$= 0{,}034\,4 \text{ m/s}$$

$$W = \frac{\varepsilon/D}{G}$$

$$= 0{,}003\,44 \text{ m/s}$$

For these new conditions, the required energy is:

$$E_r = 4\,630 \left(\frac{\varrho_d - \varrho}{\vartheta\,W}\right)^{1{,}25} \varrho^{-2{,}75}$$

$$= 1{,}54 \text{ W/kg}$$

$$K = 0{,}5\,(1 - \gamma^2)$$

$$= 0{,}469$$

$$\Delta P = \frac{K\varrho\,V^2}{2}$$

$$= 3\,152 \text{ Pa}$$

$$E_a = \frac{\Delta P\,V}{\Delta X\,\varrho}$$

$$= 6{,}00 \text{ W/kg}$$

Thus $E_a > E_r$ (6,00 > 1,54), indicating that an adequate dispersion (i.e. $C_1/C_2 > 0{,}90$) exists in the new system.

A.8.3 Example of procedure 3

Select a suitable sampling location in a piping system that includes: a 4-bend loop ($r/D = 2$), a globe valve, a throttling valve with a measured pressure drop of 20 kPa (0,2 bar), and a centrifugal pump [$\Delta P = 80$ kPa (0,8 bar)]. The most severe flow conditions expected are:

$$V = 2{,}0 \text{ m/s}$$

$$\varrho = 840 \text{ kg/m}^3$$

$$\vartheta = 12 \text{ mm}^2\text{/s (12 cSt)}$$

$$\varrho_{\mathrm{d}} = 1\,025 \text{ kg/m}^3$$

$$D = 0{,}5 \text{ m}$$

A.8.3.1 Step 1

For example, if a value of $C_1/C_2 = 0{,}90$ is chosen, then from table 8, $G = 10$.

A.8.3.2 Step 2

Calculate ε/D:

$$\frac{\varepsilon}{D} = 6{,}313 \times 10^{-3}\, \vartheta^{0{,}125}\, V^{0{,}875}\, D^{-0{,}125}$$

$$= 6{,}313 \times 10^{-3}\, (12)^{0{,}125}\, (2{,}0)^{0{,}875}\, (0{,}5)^{-0{,}125}$$

$$= 0{,}017\,2 \text{ m/s}$$

A.8.3.3 Step 3

Calculate W:

$$W = \frac{\varepsilon/D}{G} = \frac{0{,}017\,2}{10} = 0{,}001\,72 \text{ m/s}$$

A.8.3.4 Step 4

Calculate E_{r}:

$$E_{\mathrm{r}} = 4\,630 \left(\frac{\varrho_{\mathrm{d}} - \varrho}{\vartheta\, W}\right)^{1{,}25} \varrho^{-2{,}75}$$

$$= 4\,630 \left(\frac{1\,025 - 840}{12 \times 0{,}001\,72}\right)^{1{,}25} 840^{-2{,}75}$$

$$= 3{,}67 \text{ W/kg}$$

A.8.3.5 Step 5

Calculate the dissipation energy E for each piping element in the system by following step 1 in procedure 1 (see A.4.2).

A.8.3.5.1 Straight pipe

According to equation (19):

$$E_{\mathrm{o}} = 0{,}005\, \vartheta^{0{,}25}\, D^{-1{,}25}\, V^{2{,}75}$$

$$= 0{,}005\, (12)^{0{,}25}\, (0{,}5)^{-1{,}25}\, (2{,}0)^{2{,}75}$$

$$= 0{,}149 \text{ W/kg}$$

A.8.3.5.2 Four-bend loop

According to equation (20):

$$E = \beta E_{\mathrm{o}}$$

where

β is calculated from table 7 ($n = 4$; $r/D = 2$):

$$\beta = 2{,}00$$

Thus

$$E = 2{,}00\,(0{,}149)$$

$$= 0{,}298$$

A.8.3.5.3 Globe valve

According to equations (12) and (13), taking $\Delta X = 10D$ and $K = 6$:

$$\Delta P = \frac{K \varrho V^2}{2}$$

$$= \frac{6\,(840)\,(2)^2}{2}$$

$$= 10\,080 \text{ Pa}$$

$$E = \frac{\Delta P\, V}{\Delta X\, \varrho}$$

$$= \frac{10\,080\,(2)}{10\,(0{,}5)\,(840)}$$

$$= 4{,}8 \text{ W/kg}$$

A.8.3.5.4 Throttling valve

According to equation (25):

$$E = \frac{\Delta P\, V}{20 \varrho D}$$

$$= \frac{20\,000\,(2)}{20\,(840)\,(0{,}5)}$$

$$= 4{,}76 \text{ W/kg}$$

A.8.3.5.5 Centrifugal pump

According to equation (24):

$$E = 0{,}012\,5 \frac{\Delta P\, Q}{\varrho D^3}$$

and taking $D = 0{,}5$ m and $Q = V \dfrac{\pi D^2}{4} = 0{,}393$ m³/s, then

$$E = \frac{0{,}012\,5\ (80\,000)\ (0{,}393)}{840\ (0{,}5)^3}$$

$$= 3{,}74 \text{ W/kg}$$

A.8.3.5.6 Summary

The calculated energies (in watts per kilogram) are:

- straight pipe: 0,149
- 4-bend loop: 0,298
- globe valve: 4,8
- throttling valve: 4,76
- centrifugal pump: 3,74

Thus, the most critical element is the globe valve and the available energy for dispersion is $E_a = 4{,}8$ W/kg.

A.8.3.6 Step 6

Thus, $E_a > E_T$ $(4{,}8 > 3{,}67)$, indicating that dispersion is adequate for sampling downstream of the globe valve.

NOTE — In the given system, the energies provided by the throttling valve and the centrifugal pump exceed the required energy, and therefore these elements can also serve as acceptable mixers.

A.8.4 Example of procedure 4

Profile tests have resulted in a profile where the top water concentration is 2,0 % and the bottom water concentration is 2,5 %. The distance between the top and bottom probes is 0,45 m. The flow conditions during the profile tests were

$V = 2$ m/s

$\varrho = 840$ kg/m³

$\vartheta = 12$ mm²/s (12 cSt)

$\varrho_d = 1\,025$ kg/m³

$D = 0{,}5$ m

Determine the system constant τ and evaluate the profile deviation if a crude oil with $\vartheta = 50$ mm²/s (50 cSt) and a flow rate of 1,5 m/s were tested.

A.8.4.1 Step 1

$C_A = 2{,}0$

$C_B = 2{,}5$

$Y = 0{,}45$

A.8.4.2 Step 2

Calculate ε/D:

$$\frac{\varepsilon}{D} = 6{,}313 \times 10^{-3}\, \vartheta^{0{,}125}\, V^{0{,}875}\, D^{-0{,}125}$$

$$= 6{,}313 \times 10^{-3}\, (12)^{0{,}125}\, (2{,}0)^{0{,}875}\, (0{,}5)^{-0{,}125}$$

$$= 0{,}017\,2 \text{ m/s}$$

A.8.4.3 Step 3

Calculate the settling rate:

$$W = \left(\frac{\varepsilon}{D}\right) \times \left(\frac{D}{Y}\right) \ln \left(\frac{C_B}{C_A}\right)$$

$$= 0{,}017\,2 \left(\frac{0{,}50}{0{,}45}\right) \ln \left(\frac{2{,}5}{2{,}0}\right)$$

$$= 0{,}004\,3 \text{ m/s}$$

A.8.4.4 Step 4

Calculate E:

$$E = 4\,630 \left(\frac{\varrho_d - \varrho}{\vartheta\, W}\right)^{1{,}25} \varrho^{-2{,}75}$$

$$= 4\,630 \left(\frac{1\,025 - 840}{12 \times 0{,}004\,3}\right)^{1{,}25} 840^{-2{,}75}$$

$$= 1{,}167 \text{ W/kg}$$

A.8.4.5 Step 5

Calculate τ:

$$\tau = \frac{E}{V^3}$$

$$= \frac{1{,}167}{2^3}$$

$$= 0{,}146 \text{ m}^{-1}$$

A.8.4.6 Step 6

Calculate the value of G for the increased viscosity and reduced flow rate, using the following steps from procedure 1.

a) Calculate E:

$$E = \tau V^3$$
$$= 0{,}146\ (1{,}5)^3$$
$$= 0{,}49 \text{ W/kg}$$

b) Calculate W:

$$W = 855 \left(\frac{\varrho_d - \varrho}{\vartheta \varrho^{2,2}}\right) E^{-0,8}$$
$$= 855 \left(\frac{1\,025 - 840}{50 \times 840^{2,2}}\right) \times 0{,}49^{-0,8}$$
$$= 0{,}002\,1 \text{ m/s}$$

c) Calculate the turbulence characteristic:

$$\frac{\varepsilon}{D} = 6{,}313 \times 10^{-3}\ \vartheta^{0,125}\ V^{0,875}\ D^{-0,125}$$
$$= 6{,}313 \times 10^{-3}\ (50)^{0,125}\ (1{,}5)^{0,875}\ (0{,}5)^{-0,125}$$
$$= 0{,}016 \text{ m/s}$$

d) Calculate the value of G:

$$G = \frac{\varepsilon/D}{W}$$
$$= \frac{0{,}016}{0{,}002\,1}$$
$$= 7{,}62$$

Therefore, at the new operating conditions, according to table 8, C_1/C_2 would become 0,87 compared with the ratio C_A/C_B of 0,80 for the original conditions.

A.8.5 Example of application to test data

The test data are taken from tables 10a and 10b in annex B for the profile tests Nos. 7 to 12 (set 1) and Nos. 13 to 18 (set 2), respectively.

The upstream mixing conditions are unknown and therefore the profiles obtained from tests cannot be predicted by calculations, but one of these sets can be predicted from the other by using calculations from procedures 1 and 4.

A.8.5.1 Step 1

Compare the dispersion energies E using equation (15):

given $V_1 = 1{,}84$ m/s (set 1)

and $V_2 = 2{,}38$ m/s (set 2)

$$\frac{E_1}{E_2} = \frac{\tau \times V_1^3}{\tau \times V_2^3}$$
$$= \left(\frac{1{,}84}{2{,}38}\right)^3$$
$$= 0{,}462$$

A.8.5.2 Step 2

Compare the settling rates using equation (10), in which all the variables except E are the same for sets 1 and 2:

$$\frac{W_1}{W_2} = \left(\frac{E_1}{E_2}\right)^{-0,8}$$
$$= (0{,}462)^{-0,8}$$
$$= 1{,}85$$

A.8.5.3 Step 3

Calculate the ratio C_A'/C_B' for set 1:

$$\frac{C_A'}{C_B'} = \frac{\dfrac{4{,}06}{4{,}7}}{\dfrac{5{,}38}{4{,}7}}$$
$$= 0{,}75$$

where

C_A' is the water concentration expressed as the point average value at the top sample probe relative to the mean value for set 1;

C_B' is the water concentration expressed as the point average value at the bottom sample probe (and labelled H in figure 13a) relative to the mean value for set 1.

The ratio corresponds to C_A/C_B in A.7.2 and A.7.4 and can be used in equation (30) to give

$$W_1 = \left(\frac{\varepsilon}{D}\right)\left(\frac{D}{Y}\right) \ln \left(\frac{1}{0{,}75}\right)$$
$$= \left(\frac{\varepsilon}{Y}\right) \times 0{,}288$$

Then, for set 2, it can be estimated by using the ratio calculated in step 2 that

$$W_2 = \left(\frac{\varepsilon}{Y}\right) \times 0{,}288 \times \frac{1}{1{,}85}$$
$$= \left(\frac{\varepsilon}{Y}\right) \times 0{,}156$$

Hence, using equation (3) for the conditions of set 2:

$$\frac{C''_A}{C''_B} = \exp\left[- \frac{\left(\frac{\varepsilon}{Y}\right) 0{,}156}{\frac{\varepsilon}{Y}} \right]$$

$$= 0{,}86$$

A.8.5.4 Comparisons

The prediction of C''_A/C''_B in A.8.5.3 compares with the corresponding value obtained from the measured water concentrations:

$$\frac{C''_A}{C''_B} = \frac{\frac{4{,}10}{4{,}23}}{\frac{4{,}58}{4{,}23}}$$

$$= 0{,}89$$

where

C''_A is the water concentration expressed as the point average value at the top sample probe relative to the mean value for set 2;

C''_A is the water concentration expressed as the point average value at the bottom sampling probe (and labelled H in figure 13b) relating to the mean value for set 2.