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Natural gas — Gas sampling

Gaz naturel — Échantillonnage de gaz

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 193, *Natural Gas*, Subcommittee SC 1, *Natural gas analysis*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 238, *Test gases, test pressures and categories of appliances,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 10715:1997), which has been technically revised.

The main changes are as follows:

— This new edition has placed a significant relevance on regular service, maintenance and validation of installed sample systems which previously have not been given proper attention. Sample systems, or at least the fixed/installed portion of them, have all too often been installed and forgotten without realization that through use they become more and more contaminated leading to distortions of the composition of the gas being sampled.

— Introduction of new sampling devices.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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Introduction

The composition, quality, and properties of natural gas vary according to amongst others its source, level of processing, natural mixing at interconnection points, storage facilities, blending stations, fluctuating demand for some of its derivatives such as LPG (Liquefied Petroleum Gases), and increasingly the need to transport unconventional and renewable gases in the same network etc.

The variations that occur are closely monitored and controlled to ensure safety of the general public as well as operational staff, plant, equipment and the gas infrastructures in general. Additionally and commercially critical the energy content of the gas differs with these variations and is very accurately monitored for billing and fiscal purposes because of the very large sums of money involved.

The variations that occur can be best collectively grouped under the generic term "Gas Quality" which is subsequently referred to as GQ in this document.

For monitoring and controlling GQ, samples are taken at many and various stages along the way and analysed. Such samples are taken under many different process parameters with a need to always ensure that any gas that is subsequently analysed for such monitoring purposes is truly representative of the bulk.

Methods of measuring GQ are well specified in numerous ISO standards as are the means of calibrating such measuring instruments, however all those measurements and calibrations are all but futile if the samples used for making such measurements are not representative.

This document provides means to ensure sampling systems and sampling processes are designed, located, installed, operated, and maintained such that samples obtained are representative of the bulk to which they are attributed. It also specifies comprehensive information on the way that samples can be contaminated, altered, modified or degraded and methods, means and procedures for ensuring that the sample remains representative from the start of the sampling process to the point where the sample is presented to the analytical device.

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Natural gas — Gas sampling

WARNING — General quality aspects of natural gas are detailed in ISO 13686[1]. However, it is possible that the standard does not cover all the trace constituents that are increasingly necessary to monitor for various reasons.

1 Scope

This document gives means for ensuring that samples of natural gas and natural gas substitutes that are conveyed into transmission and distribution grids are representative of the mass to which they are allocated.

NOTE To ensure that a particular gas is taken into account in the standard, please see Annex A.

This document is applicable for sampling at sites and locations where interchangeability criteria, energy content and network entry conditions are measured and monitored and is particularly relevant at cross border and fiscal measurement stations. It serves as an important source for control applications in natural gas processing and the measurement of trace components.

This document is applicable to natural dry gas (single phase - typically gas transiting through natural gas pipelines) sampling only. On occasion a natural gas flow can have entrained liquid hydrocarbons. Attempting to sample a wet natural gas flow introduces the possibility of extra unspecified uncertainties in the resulting flow composition analysis. Sampling a wet gas (two or three phases) flow is outside the scope of this document.

This document does not apply to the safety issues associated with gas sampling.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14532, *Natural gas — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions from ISO 14532 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
absorption
extraction of one or more components from a mixture of gases when brought into contact with a liquid

Note 1 to entry: The assimilation or extraction process causes (or is accompanied by) a physical or chemical change, or both, in the sorbent material.

Note 2 to entry: The gaseous components are retained by capillary, osmotic, chemical, or solvent action.

EXAMPLE Removal of water from natural gas using glycol.

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[SOURCE: ISO 14532:2014, 2.2.2.6]

3.2
adsorption
retention, by physical or chemical forces of gas molecules, dissolved substances, or liquids by the surfaces of solids or liquids with which they are in contact

Note 1 to entry: For example, retention of methane by carbon.

[SOURCE: ISO 14532:2014, 2.2.2.7]

3.3
contaminant
constituent in very low levels, such as particulates, glycol, compressor oil, etc., that are assumed to be intrusive and not part of the gas to be sampled

Note 1 to entry: Such contaminants are generally harmful to the analytical equipment and if they enter the sampling process they need to be removed from the sample before it enters the analyser. However, once the contaminants enter the sampling process they continue to influence any following sample that come into contact with them. Over a period of time the accumulation of contamination in the sampling system can have a profound effect on the sample such that it is no longer representative of the mass.

Note 2 to entry: Contaminants are not to be confused with trace components that are inherent to the gas to be sampled.

3.4
desorption
removal of a sorbed substance by the reverse process of adsorption or absorption

Note 1 to entry: From solution in a liquid phase for example.

[SOURCE: ISO 14532:2014, 2.2.2.8, modified — Note 1 to entry added.]

3.5
direct sampling
sampling in situations where there is a direct connection between the natural gas to be sampled and the analytical unit

3.6
floating-piston cylinder
container which has a moving piston separating the sample from a buffer gas, where the pressures are in balance on both sides of the piston

3.7
gas sorption effect
physical process whereby some gases are adsorbed onto or desorbed from the surfaces of a solid without transformation of the molecules

Note 1 to entry: The force of attraction between some gases and solids is purely physical and depends on the nature of the participating material. Natural gas can contain several components that exhibit strong sorption effects. Special care should be taken when determining trace concentrations such as heavy hydrocarbons, water, sulfur compounds, mercury and hydrogen.

[SOURCE: ISO 14532:2014, 2.3.4.6]

3.8
high-pressure natural gas
natural gas with a pressure exceeding 0,2 MPa

3.9
hydrocarbon dew point
temperature, at a given pressure, at which hydrocarbon vapour condensation begins

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3.10
incremental sampler
sampler which accumulates a series of spot samples into one composite sample

3.11
indirect sampling
sampling in situations where there is no direct connection between the natural gas to be sampled and the analytical unit

3.12
liquid separator
unit, in the sample line, used to collect liquid fall-out

3.13
purging time
period of time during which a sample purges a piece of equipment

3.14
representative sample
sample having the same composition as the natural gas it is attributed to, when the latter is considered as a homogeneous whole

[SOURCE: ISO 14532:2014, 2.3.4.2]

3.15
residence time
time it takes for a sample to flow through a piece of equipment

3.16
retrograde condensation
production of a liquid phase of heavy hydrocarbons at a particular pressure and temperature where, at that same temperature, the gas stays in a single phase at a higher pressure as well as at a lower pressure

Note 1 to entry: Retrograde behaviour describes the non-ideal phase properties of hydrocarbon gas mixtures, such as natural gas.

3.17
sample container
container for collecting the gas sample when indirect sampling is necessary

3.18
sample line
line provided to transfer a sample of the gas from the *sampling point* (3.21) to the sampling device or the analytical unit

Note 1 to entry: Devices necessary to prepare the sample for transportation and analysis (conditioning unit) can be part of it.

3.19
sample probe
device inserted into the gas source, used to extract a sample and to which a *sample line* (3.18) is connected

3.20
sampling place
whereabouts along the gas pipeline or on the process plant where the *sample probe* (3.19) is located

3.21
sampling point
exact point in space defined by the *sampling place* (3.20), the *sampling position* (3.22) and by the location of the inlet on the *sample probe* (3.19)

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3.22
sampling position
location within the cross-sectional area of the gas pipeline or process plant at the *sampling place* from where a sample is taken

3.23
spot sample
sample of specified volume taken at a specified place at a specified time from a stream of gas

3.24
trace component
component present at very low levels

Note 1 to entry: Trace components generally include hydrocarbons or groups of hydrocarbons above n-pentane and other components listed in ISO 14532.

3.26
wetted surface
surface of the material in contact with the sampled gas

4 Safety considerations

The use of this document can involve working with high pressure flammable gases and other hazardous materials which can be located in areas designated as hazardous (potentially explosive and or toxic atmospheres). This document does not address the safety issues associated with such situations. It is the user's responsibility to establish appropriate design rules, installation, operating, testing and maintenance procedures for pressurized equipment, equipment located in potentially hazardous areas, the control, handling and transportation of substances potentially hazardous to health, etc.

International and national regulations on safety requirements should be followed closely and carry more weight than this document.

5 Principles of sampling

Natural gas sampling is the process of acquiring a sample from a source of interest, conditioning the sample (where necessary) and delivering the sample to an analytical instrument, either directly or indirectly via a vessel or other transport medium.

The methods and equipment for each of these steps are described within this document.

The purpose of the sampling system is to ensure that the sample acquired is representative of the source gas desired and that in the process of delivering the sample to the analytical instrument the chemical and physical state remain unchanged, even on a molecular level.

Considering the equipment is relied on to fulfil this purpose for many years of operation, careful consideration should be applied to the design (considering application-specific conditions and measurement objectives), manufacturing, operation, maintenance and performance evaluation of the system.

6 The concept of representative sample

In order to show that any information gained from a sample of natural gas is truly representative of the whole quantity to which the information is to be attributed we use the term "representative sample"

A representative sample is established by two main criteria:

a) The sample is not altered in any way, or more realistically in any avoidable way, during the process of collecting, handling, containing or preparing the sample for analysis or measurement. The condition of the sample being the same in composition and phase -absolute or essential sameness

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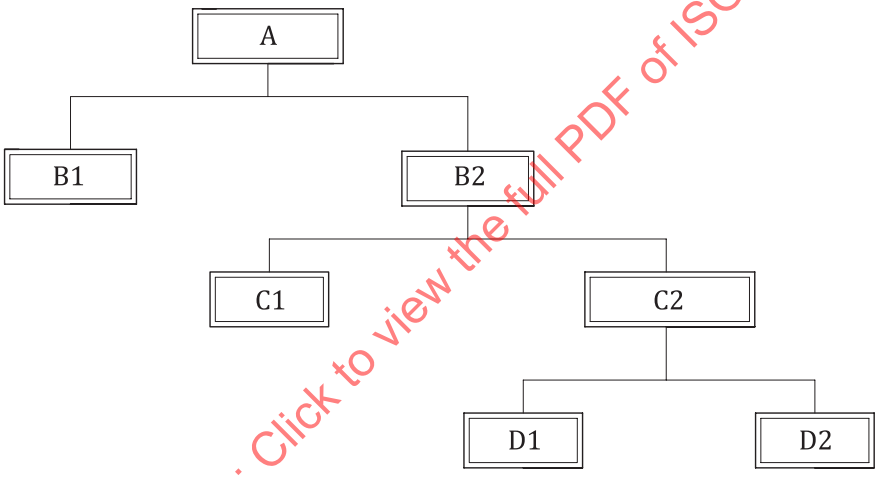
as the mass from which it was taken for the quality/analyte under consideration - is considered as being identical.

b) The sample is taken at a sample point where we can be sure that it is actually from the bulk to which the information is to be applied at a known time or time period. This requires a matching in time or a synchronization of analytical results to the mass. This is considered as being pertinent.

7 Types of sampling

7.1 Sampling method considerations

The main function of sampling is to take an adequate sample that is representative of the gas. The main distinction in sampling is between direct and indirect sampling methods. In the direct sampling method, the sample is drawn from a stream and directly transferred to the analytical unit. In the indirect sampling method, the sample is stored in a sample container before it is transferred to the analytical unit. The main classifications of the indirect sampling method are spot sampling or incremental sampling. Incremental sampling regarding regasified LNG is described in ISO 8943[17].



Key

A sampling
B1 direct
B2 indirect
C1 spot
C2 incremental
D1 time
D2 flow

Figure 1 — Survey of direct and indirect sampling methods

The information needed from the analysis of natural gas falls into two basic categories: averaged and limit values.

— Averaged values:

A typical example is the calorific value. Custody transfer requires the time- or flow-averaged calorific value. Commercial agreements determine the period and method of averaging.

— Limit values:

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Most gas custody transfer contracts contain specification limits on composition or on gas properties. Direct sampling can be applied, but often the requirements are such that also indirect sampling has to be applied.

7.2 Spot sampling

7.2.1 General

This clause specifies a method of indirect sampling in which a suitable container is filled with the sample. The sample is subsequently transported to the place of analysis.

Spot sampling is a form of sampling that is representative of what is in the pipeline at the moment that the sample is being taken. Spot sampling may be used for well or feed assessment, periodic stream assessment, result verification, process verification, trouble shooting and auditing purposes.

Spot sampling is a form of sampling that is taken from a single location and a single point in time and provides a sample of what was in the pipeline when the technician extracted the sample.

The interval between samples should be specified by the user, based on safety or process criticality of the results and stability of the gas quality (see 7.2.8).

The sample is extracted by utilizing one of several approved methods for taking spot samples, such as: the fill and empty method, the Helium pop method, the continuous purge, constant pressure method or another proven and tested method of extraction. Most samples are gathered in a standard, single cavity sample cylinder or a constant pressure piston style sample cylinder.

While valuable information can be gathered by this method, it shall always be noted that the sample represents what was present at the time of sampling. It is not representative of the sample location for the next week or month, unless it is from a single gas well that has a long history of producing the same gas and gas content. It is worthy to note that an older field begins to get richer and richer near the end of its life. The gas quality could stay the same for 10 years and then begin to change near the end of its field production life.

Annex B on low pressure sampling describes a method of obtaining spot samples from a low pressure natural gas distribution system using a glass vessel. Other specialist vessels such as inert polymeric bags are available for niche applications.

Methods suited for high and low pressure spot sampling are:

— fill and empty;

— controlled rate;

— evacuated container;

— helium pre-fill – (helium pop);

— floating-piston cylinder;

— single cavity sample cylinder.

7.2.2 Fill-and-empty method

This method is applicable when the sample container temperature is equal to or greater than the source temperature. The source pressure shall be above atmospheric pressure. A detailed example procedure is given in B.2.

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7.2.3 Controlled-rate method

In this method, a needle valve is used to control the sample flow rate. This method is applicable when the sample container temperature is equal to or greater than the source temperature. The source pressure shall be above atmospheric pressure. B.3 gives a detailed example of this method.

7.2.4 Evacuated-cylinder method

In this method, a previously evacuated cylinder is used to gather the sample. This method is applicable when the source pressure is above or below atmospheric pressure and the source temperature is greater or less than the sample container temperature. The valves and fittings on the sample cylinder shall be in good condition and there shall be no leaks. B.4 gives an example of a detailed procedure.

7.2.5 Helium pre-fill method

This is similar to the evacuated-cylinder method except that a helium pre-fill is used to keep the container "air free" prior to sampling. It is used in those cases when helium is not to be measured, and preferably can be ignored, for example analysis by gas chromatography with helium carrier gas.

7.2.6 Floating-piston cylinder method

By this method, a sample is drawn into a floating-piston cylinder maintained at pipeline pressure and with heat-traced sample lines.

7.2.7 Single cavity sample cylinder

A single cavity cylinder used for the collection of a sample for analysis. Typically, the cylinder is stainless steel and formed with spun ends and tapped at each end of the cylinder. Some designs can only have a single tapped end. The most common sizes are 300 ml, 500 ml and 1 000 ml, with other volumes available. The cylinder has a valve and a safety relief at one end and a valve at the other end.

7.2.8 Sampling frequency

7.2.8.1 General considerations

Information on the properties of the gas stream in the past and about expected (systematic) future changes determines the sampling frequency. Generally, pipeline gas composition can have daily, weekly, monthly, semi-annual and seasonal variations. Compositional variations can also occur because of gas treatment equipment and reservoir changes. All of these environmental and operational considerations shall be taken into account when selecting a sampling interval.

These considerations may be supported by the statistical approach given below.

An appropriate number of samples may be calculated based on the required (target) uncertainty of the averaged quantities. (Strictly speaking, the approach takes into account the precision constituents of the combined measurement uncertainty).

Formula (1) for calculating the appropriate number of samples is as follows (details are described in Annex I):

$$n = \left(t \times \frac{s}{U_{\mathrm{tg}}} \right)^2 \tag{1}$$

Where

U_{tg} is the target expanded uncertainty of the average quantity value;

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n is the number of samples to be taken in a defined period;

s is the experimental standard deviation of the individual measurements;

t is Student's t-statistic.

This formula shall be solved by iteration: an initial value of n is chosen together with the respective t value for $(n - 1)$ degrees of freedom, this t value is used to calculate a revised value of n, which is used, in turn, to give a new value of t. The level of uncertainty, the number of samples and the standard deviation shall be taken over the same period of time.

7.2.8.2 Acceptable target uncertainty

There are two different situations with regard to the target uncertainty.

In the first case a target uncertainty related to the averaged quantity values is explicitly specified in the custody transfer contract. A typical example is the calorific value.

In the other situation only limit values are specified for the gas composition or property, but not an uncertainty. In these cases, the target uncertainty may be evaluated based on the decision rule used while assessing compliance with the specified limits, which, in turn, depends upon the acceptable risk level. For example, when the decision rule involves a guard band equal to the expanded uncertainty and it should ensure a low probability of incorrect statement of compliance, the difference between the last measured value, or the last year's average, and the limit value may be taken as a target expanded uncertainty.

More details on setting the target uncertainty may be found in the Eurachem/CITAC Guide[9].

7.2.8.3 Student's t-statistic

Student's t-statistic allows for the finite sample size, and is to be found in standard statistical tables. The value depends on the claimed confidence interval (typically 95 %) and the "degrees of freedom", here to be taken as the number of measurements minus one $(n - 1)$.

EXAMPLE 1

Determination of the monthly average caloric value:

d = 0,4 % (level of uncertainty required from custody transfer contract for monthly averaged value) s = 0,6 % (estimated variation over a one-month period) First estimate, taking n = 7

t = 2,45 for 6 degrees of freedom and a confidence level of 0,975 single-sided (equals 0,95 double-sided)

$$n^{\frac{1}{2}} = 2,45 \times \frac{0,6}{0,4}$$

n = 14

First iteration, taking n = 14:

recalculate for t = 2,16 for 13 degrees of freedom, and a confidence level of 0,975 single-sided (equals 0,95 double-sided)

$$n^{\frac{1}{2}} = 2,16 \times \frac{0,6}{0,4}$$

n = 11

Second iteration, taking n = 11:

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recalculate for t = 2,23 for 10 degrees of freedom, and a confidence level of 0,975 single-sided (equals 0,95 double-sided)

$$n^{\frac{1}{2}} = 2{,}23 \times \frac{0{,}6}{0{,}4}$$

n = 11

EXAMPLE 2

Total sulfur determination:

Last measured concentration 20 mg/m^3 and the contract limit value 50 mg/m^3.

d = 30 mg/m^3 (difference between limit value from custody transfer contract and last measured value)

s = 10 mg/m^3 [standard deviation in spot sample results (in the past year)] t = 4,30 n – 1 taken as 2, level of certainty 95 % n = 2

Three samples are enough. Recalculation indicates that two samples are not enough.

7.3 Incremental sampling (continuous or composite)

7.3.1 General considerations

Flow rates and compositions can vary with time, so the interval between the sampling increments shall be carefully chosen so that the collected sample reflects these changes.

Incremental, or composite sampling is a sampling method that occurs over a specified time or batch quantity, thereby taking a representative composite sampling that catches a snapshot of the changes in the sample stream during that time frame or for the batch quantity. A typical system has a sample probe, a sampling pump system that is rated for the pipeline pressure of the installation, a sample grab mechanism, a timing mechanism that is tied to the flow rate device at the location, a regulated external instrument supply source or a regulator that takes the gas pressure in the pipeline and regulate that supply to the pressure needed for the sample pump, and a solenoid to activate the sample pump. The system can be direct mounted or installed with an external sample loop.

7.3.2 Intervals

If possible, flow-rate-proportional sampling shall be used for incremental-sampling systems. It is especially important to use flow-proportional sampling if both the flow rate and the composition change. For example, if the flow is stopped and the sampler continues to collect a sample, then the composite sample has some part of its gas collected when no gas flow was present. If the composition during this period is different from the average composition, the sample is not representative.

Time-proportional sampling may be used and provides representative samples only if the flow rate is steady over the sampling interval or if the composition is stable over the sampling interval.

There are several incremental samplers commercially available. Such units can be controlled by a timer or a flow proportional signal from the flow computer.

7.3.3 System considerations

A recommended incremental sampler is the displacement type which pumps a sample into a floating-piston cylinder at constant and at or slightly above line pressure, or a standard cylinder that builds to line pressure at the end of the pre-determined sample period. The sample line between the sampling device and the collection cylinder shall be of minimum length. Except for very dry, lean or low dew point

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gases, the sample line and sampler shall be heat-traced and insulated to avoid sample condensation. Samplers shall be designed so that they either

a) allow a continuous and uninterrupted flow of gas through them, or

b) completely self-purge before each sample, and thus pump a representative sample increment into the sample container.

7.3.4 Monitoring the filling process

The filling process shall be monitored by a local or remote indicator on a regular basis.

7.3.5 Cylinder tracking

All information important to the laboratory shall be on a label with the cylinder. Labels shall be securely attached to the sample cylinders, but shall not interfere with the utilization of the cylinder.

Information attached should preferably include:

— the cylinder number;

— the cylinder type;

— the location of sampling;

— all details necessary for identification of the pipe sampled;

— the date and time, or period, of sampling;

— the method of sampling;

— the actual destination of the cylinder;

— any need for maintenance on the cylinder (e.g. leakage);

— any information relevant to the analytical lab concerning the sample;

— the sample pressure, if a pressure gauge is not an integral part of the sampling cylinder;

— the line static pressure;

— the temperature of the gas stream;

— any field remarks.

7.3.6 Overpressure protection

If needed, safety valve or equivalent (pressure release device) shall be installed in order to protect system for overpressure in a failure situation (e.g. blocked pump outlet).

7.4 Online or direct sampling

7.4.1 General considerations

A third method of sampling is an online or direct sampling system. A sample conditioning system has to be located as close as possible to the sampling point, and if possible at the sampling point, downstream of the sampling probe to reduce the pressure for direct feed into the analyser (e.g. online GC). This conditioning system should integrate heating to offset JT effects, or due to ambient conditions that would cause liquid fallout due to the phase envelope for that gas and the cold temperature. It is recommended to also have additional regulation, filtration, phase separation, protection for the GC, and other critical features for a given location. For the system supplier to make a proper design, all

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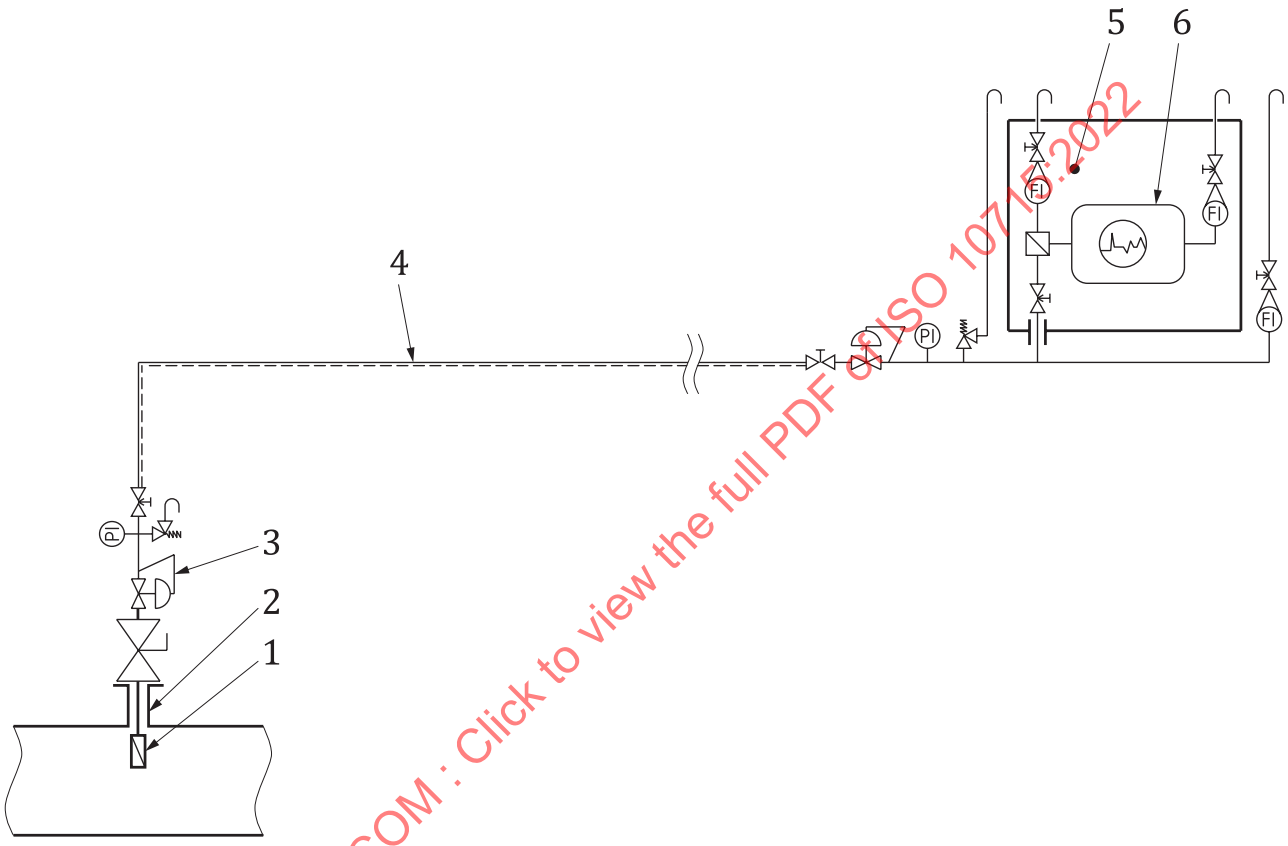
information concerning the system purpose, all gas constituents including water, contaminants, liquid, phase envelope, etc. shall be made available.

Figure 2 and Figure 3 show examples of a direct-sampling system as described in this document; a number of other different configurations exist.

Additional information can be found in ISO/TR 14749[2] which concerns the determination of hydrocarbon components by online gas chromatograph and provides guidelines for selection, evaluation and factors impacting such system.



Key

1 sampling point
2 sampling place
3 sampling probe including membrane, filtration, pressure reducer and outlet manifold
4 electric heated sample line
5 analyser building
6 analyser

Figure 2 — Example of sampling with direct regulated probe

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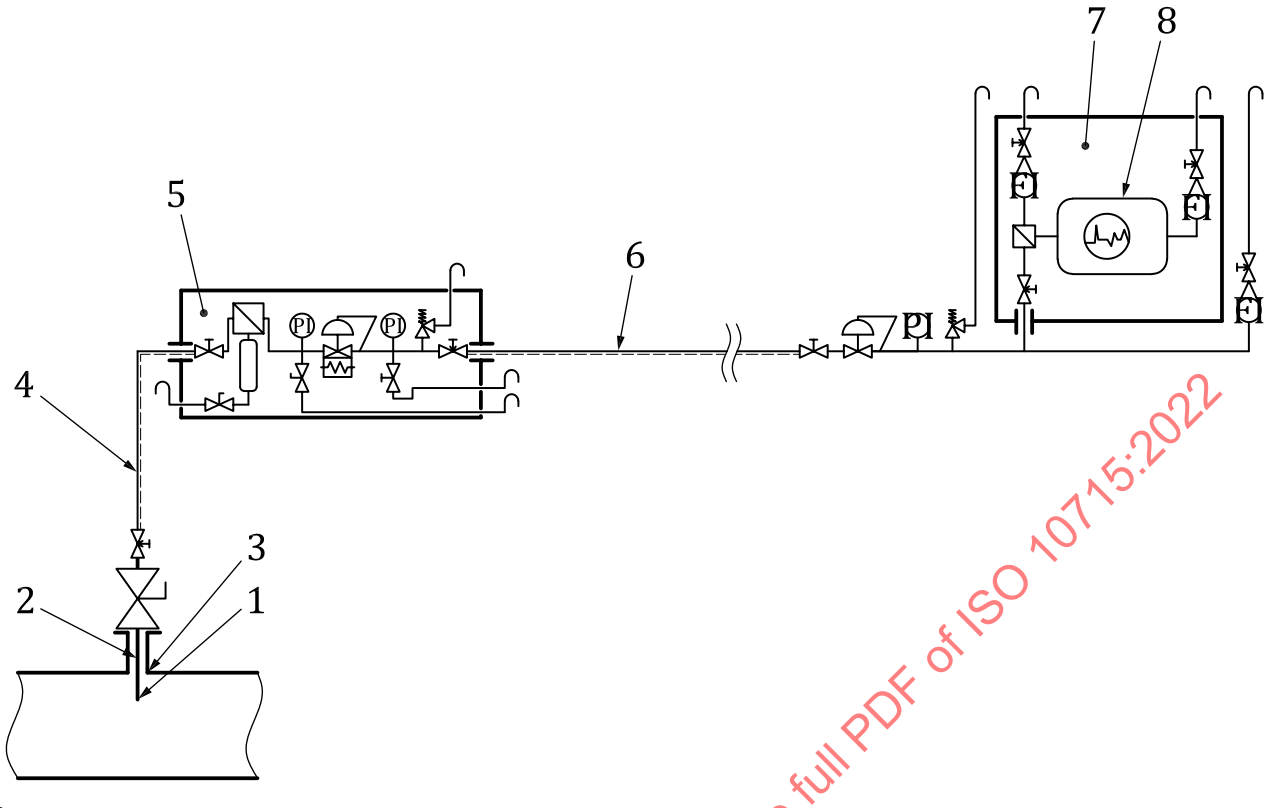

Key

1 sampling point
2 sampling probe without membrane and filtration
3 sampling place
4 sample line (to be as short as possible)
5 conditioning enclosure with filtration/separation and electric heated regulator
6 electric heated sample line
7 analyser building
8 analyser

Figure 3 — Example of sampling with non-regulated non-pressure reduced probe with conditioning enclosure

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7.4.2 Automatic drainage

Automatic drainage involves the collection and periodic drainage of liquids from a trap in the sample system. This method is generally not acceptable as the intermittent vaporization of the accumulated liquid between drainage cycles can bias the analytical result.

7.4.3 Reducing the pressure

Depending on the analysis performed, the gas sample has to be carried out of the sampling point at full line pressure or reduced pressure.

Reducing pressure can be necessary for the safety or integrity of the downstream sampling equipment or analyser, as well as reducing the sample transfer time from the sample point.

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7.4.4 Inert-gas purging

The system shall be equipped with facilities for inert-gas purging. Purging of the sample system is required if, for some reason, condensation has taken place and also to remove air (oxygen) from the system prior to introducing process gas to avoid a hazardous condition.

7.4.5 Safety/pressure relief valve

This shall be an automatic pressure-relieving device, which opens in proportion to the increase in pressure over the opening set pressure and has a rapid full opening or pop action characteristic and is actuated by the static pressure upstream of the valve. The device automatically closes when the upstream pressure is reduced below the set pressure. These devices are considered to be tight shutoff when closed and are normally used in gas, vapour or liquid service.

A pressure relief valve shall be installed downstream of the pressure reducer, in order to protect the analyser from an uncontrolled increase in pressure should the reducer fail.

7.4.6 Heating of sample line

The sample line shall be maintained at a temperature of approximately 10 °C above dew points (i.e. water, hydrocarbon) to avoid condensation and creation of droplets or mist, and adsorption/desorption of compounds. This type of temperature stability might be achieved by self-regulated electric traced tubing. Further details are described in 10.10.

8 Sampling location

8.1 General

The probe should be located at least 5 pipe diameters downstream of any obstruction in the pipe. That may be 5 diameters downstream of the diameter of an orifice plate, elbow, valve, thermowell, etc.

It should be located in an active stream of the pipeline (not in a blow-down stack, not in a dead leg, etc,) in which a representative gas stream is flowing. In theory, in clean and dry natural gas streams, the probe can be installed from the top of the pipeline, the side and even in the bottom. Nevertheless, probes have to be preferentially installed vertically on the top of a horizontal pipeline or with at least, a maximum angle of +45° (the probe pointing downwards) to enable liquid droplets to drain into the stream and avoid ingress or accumulation of undesirable contaminants or particles.

It is important to note that these considerations are for clean, dry, single phase pipelines with a very small, occasional presence of liquid

The probe shall be located directly in the gas stream in such a way that problems of aerosols and dust are eliminated. The probe shall be externally equipped with adequate valving. This makes it possible to disconnect the sample line from the process line. The probe can be of a stationary or removable type depending on location and operating condition.

Sample probe in vertical pipes is acceptable if installed horizontal or inclined without any possibility to allow ingress or accumulation of undesirable material in the sampling system.

8.2 Sampling place

8.2.1 General

The location along the length or run of the pipeline where a sampling point is installed needs to be chosen carefully.

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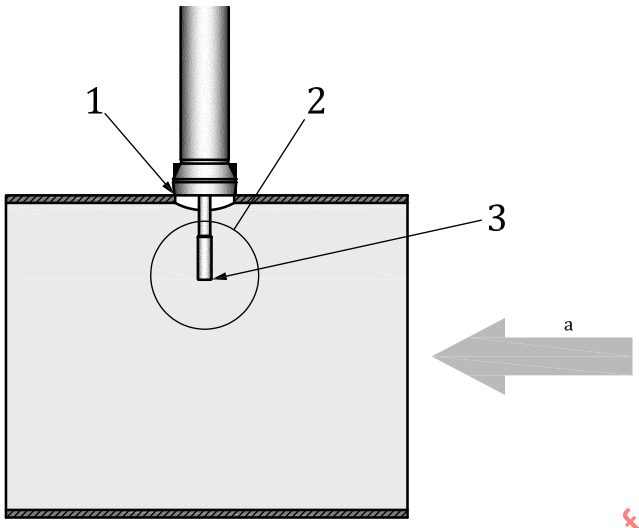
For small diameter pipelines below 50 mm (e.g. biomethane), a probe may not be required. It can cause issues such as pressure drops, blocking the flow, etc. For small diameter pipelines a specific probe may be used to be in conformity with these types of conditions.



Key

1 sampling place
2 sampling position
3 sampling point
[a] Gas flow.

Figure 4 — Example of sampling place

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8.2.2 Relevant gas

Critically a place shall be chosen such that gas passing that sample place is a gas to which the results of any subsequent analysis are applicable. The sample place shall always be chosen such that it is not in a dead end and that all gas to which the analysis results are applied actually flow past that sample place.

8.2.3 Undisturbed gas

The sample place shall be chosen such that it is in a location where the sample cannot be affected by flow disturbing elements. Flow disturbing elements are such things as control valves, elbows, tees, orifice plates, flow metering equipment, thermowells, processing equipment etc.

Such flow disturbing elements can cause momentary and local changes in the pressure and temperature of the gas. This in turn can cause the phase equilibrium of the gas to change by creating momentary liquid droplets etc. Further these flow disturbing elements usually creates momentary aerosols which are undesirable for sampling purposes.

8.2.4 Access

The sample place should be chosen where it can be readily accessed for operation and maintenance purposes. Personnel access ways/platforms to allow inspection and maintenance should be installed in a way to carry out the work safely on a routine basis.

Sometimes the conditions of 8.2.2 and 8.2.3 cannot be achieved by a single sample place for certain configurations/geometries of pipe runs in which case multiple sample places shall be used.

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8.3 Sampling position

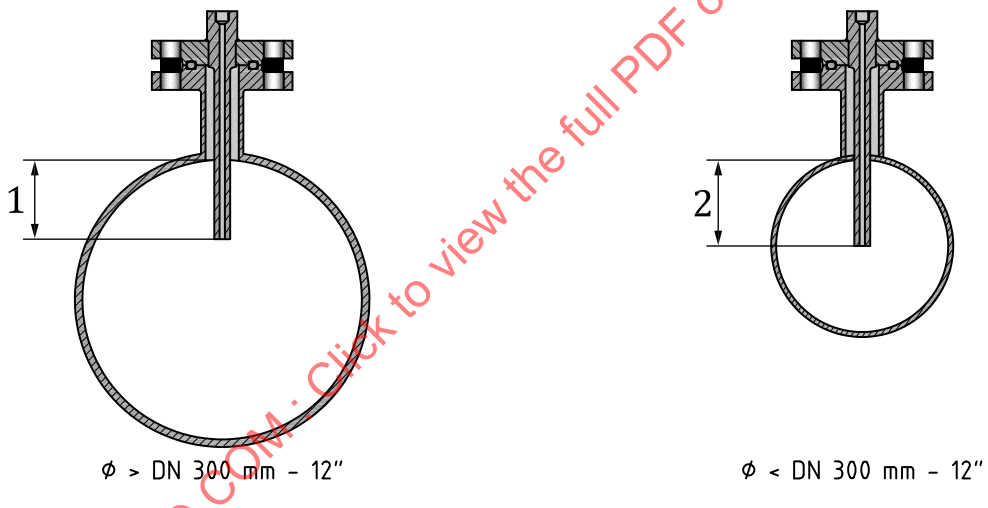
The sample position is referenced to a cross-sectional area of the pipe at the sample place.

The sample position shall be within the cross-sectional area of the main pipe. Therefore, a sample probe is a pre-requisite of correct sampling.

There exists along the pipe wall a boundary layer in which the gas composition may not be representative of the gas flowing through the pipe. Additionally contamination products that are carried in the pipe such as compressor oils, valve lubricants, glycol, dust, etc gradually build up on the pipe wall over a period of time and sampling close to this contamination allows wall effects to become a significant factor in the quality of gas sampled.

In order to avoid the wall effects and ensure representative sample; while considering mechanical resistance, standard industry practice is to locate the sample probe within the centre one third. For pipes larger than DN 300 mm (12”) it is necessary to insert beyond a minimum 100 mm from the pipe wall, but it is not necessary to insert beyond 10 % to achieve a representative sample.

For more information about the mechanical considerations see Annex F. Consult the manufacturer on the definitive sample position within the pipe cross-section depending on the specific design of the probe.



Key

1 over DN300 –12 ” - 100 mm insertion or 10 % of the size of the pipe

2 below DN300 –12” - Location in the centre one-third

Figure 5 — Sample position

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8.4 Sampling point

The sampling point is a position in space (actually a position within the pipeline) that is established by a set of three-dimensional coordinates. The actual sample point is established by the sampling place and sampling position but is further established by the centre of the inlet at the tip or opening on the sampling probe where sampled gas enters the probe.

NOTE 1 The design of the sampling probe and the dynamics of how it interacts with fast flowing gas when installed can alter the physical state of the gas at the sampling point.

The term sampling point is used and it should not be confused with the sample place or sample position.

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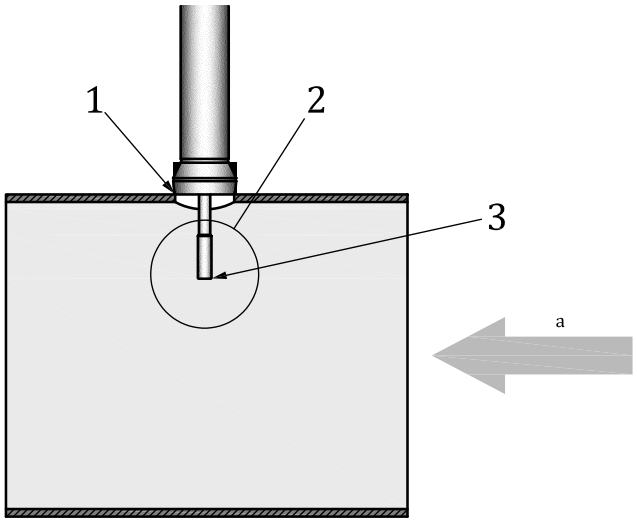

Key

1 sampling place
2 sampling position
3 sampling point
a Gas flow.

Figure 6 — Example sample point

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9 Ideal implementation of gas sampling

9.1 General

To ensure that a representative sample is used for measurement and attribution, careful consideration needs to be given to the

— location of the sampling point,

— process and flow conditions at the sampling point,

— methods of sample collection, conditioning, transportation and storage,

— materials of the sampling system,

— surfaces and/or contaminants that the sample contacts,

— temperature of the sampling system,

— cleanliness, servicing and maintenance of the sampling system, and

— attribution of the information gained from the sample to the mass.

The main technical issues are listed in the following subclauses:

9.2 Gas sorption

9.2.1 General

A number of the constituents of natural gas are highly susceptible to gas sorption effects with materials normally thought of as inert. The surfaces of the materials can become active because of a build-up of contaminants. It is therefore necessary to choose very carefully the materials and the condition of the

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surface of such materials that come into contact with the sample. This not only applies to the main body of material/component but also to seats, seals, diaphragms etc. Filters and separators of all types are of particular interest because of their inherent very large surface area and intimate interaction with the gas. For this reason, minimizing surface area and the use of inert materials are recommended. For more information about filters and separator see 10.4.

Special attention to sorption effects should be observed in sampling systems for trace analysis.

9.2.2 Surface treatment

The sorption effects exhibited by some materials can be modified and often reduced by surface treatment. A clean, grease-free surface shows less adsorption. Rough surfaces provide a nucleus for gases to adsorb and accumulate.

Polishing techniques are now available and can be used to minimize sorption effects and reduce the conditioning time required to bring the sampling equipment to equilibrium. Other processes are also available to reduce sorption effects. Some materials can be electroplated with an inert material such as nickel to reduce adsorption. Passivation of aluminium using proprietary techniques is available to inhibit adsorption.

Chemical treatment such as silanization is also available for eliminating surface adsorption of active compounds.

Be aware if you want to determine siloxanes, silanization is not the best technique.

9.2.3 Sorption considerations regarding sampling equipment

There are numerous features of a sampling system that encourage preferential sorption and consequently affect the ability to provide a representative sample to the analyser and an accurate analytical result.

The preferential sorption is caused by rough surface finish, dissimilar materials and dead spaces where analytes can become trapped and unable to re-enter the sample stream.

In general, the number of features that the sample will pass, before reaching the analyser, should be minimized. The use of metallic compression-type fittings and face seals minimize the sample exposure to rough surfaces.

Minimization of sample exposure to pressure and flow control features of a sample system should be achieved by using a fast loop, bypassing the live analytical stream.

9.2.4 Equilibrating of sampling equipment

In new sampling equipment, initially a high amount of sorption takes place before stabilizing. Therefore, equilibrating of sampling equipment entails exposure to sample gas components for a certain period of time in such a way that the amount of sorptive components remains stable in the gas sample during analysis.

This may be achieved by purging the sampling equipment with the sample gas until gas samples taken in sequence show analytical consistency. The final assessment that equilibrium has been achieved and the sampling equipment conditioned can initially be determined by analysis using a reference gas mixture of known composition.

Conditioning times may be reduced by the initial evacuation of the equipment prior to purging with the sample. Several sequences of evacuation and purging may be advantageous in reducing conditioning time and achieving equilibrium.

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9.3 Materials used in sampling

9.3.1 General considerations

The suitability of materials used in a sampling system depends on the gas being sampled.

Because of the possible presence of small amounts of sulfur compounds, mercury, carbon dioxide, etc., in natural gas, all equipment and fittings shall preferably be made of stainless steel or, for low pressure, glass. However, possible alternative materials are listed in ISO 16664:2017[3], Table 1.

Valve seats and piston seals shall be made of (elastic) material appropriate for the intended service. Sampling of wet or high-temperature gases, or gases containing hydrogen sulfide or carbon dioxide, presents additional material problems. These types of gas can require special materials and coatings in the sampling system. It is recommended that sample cylinders used in sour-gas service shall be either titanium, polytetrafluoroethylene (PTFE) coated, epoxy coated, chemically inert coated or mirror polished stainless steel. Depending on the concentration target, additional surface treatments should be considered. Reactive components such as hydrogen sulfide and mercury shall be analysed on site using direct sampling methods when practical since even coated vessels may not eliminate absorption of these components.

The use of soft metals such as brass, copper and aluminium shall be avoided where corrosion and metal fatigue problems are likely to occur. Aluminium can, however, be used for sample containers in some applications where the sample container reactivity is critical. Generally, materials coming into contact with samples or calibration gases shall have the following characteristics:

— impermeability to all gases;

— minimum sorption;

— chemical inertness to the constituents being transferred. Any new or alternative cylinder material should first have been tested for the interaction with gas compounds and stability an over period greater than the expected use of a sample to show that the targeted compound's amount fraction remains stable. Table 1 gives further guidelines.

Table 1 — Compatibility of sampling-system materials with gas components

Material	Compatibility[ab] with gas components							
	C_nH_m	COS CO_2	CH_3OH O_2	H_2S RSH THT	H_2O	He	Hg	H_2 CO
Stainless steel	a	a	a	b	b	a	b	a
Glass[2)]	a	a	a	a	a	a	a	a
PTFE[3)]	b	b	b	a	c	c	a	b
Polyamide	a	a	b	a	a	a	c	a
Aluminium	a	a	a	b	b	a	c	a
Titanium	a	a	a	a	a	a	a	a
polyvinilfluoride (Tedlar)	a	a	a	a	a	a	b	a

[a] a= suitable.

[a] b = with reservations.

c = not recommended

2) Glass is highly inert material, but subject to breakage and unsafe for sampling above atmospheric pressure.

3) PTFE is inert but can be adsorptive. It is permeable to e.g. water, He and H_2. PTFE coatings can have imperfections, and parts of the interior surface may therefore not be protected.

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9.3.2 Steel grades

Carbon steel and other relatively porous materials may retain heavier components and contaminants such as carbon dioxide and hydrogen sulfide in the natural-gas stream and shall not be used in a sampling system.

Although stainless steel is generally a good material for use in sampling equipment, the user is recommended to consult corrosion experts, as well as ISO 15156-1[18] before using it.

Stainless steel is not generally suitable for trace water measurements without additional inert coating. Aluminium or other cylinder materials are better suited to this application.

9.3.3 Epoxy coatings

Epoxy (or phenolic) coatings reduce or eliminate adsorption of sulfur compounds and of other minor constituents. It is not practical to coat small fittings, valves and other small areas. Losses of gas components from such unprotected areas can however be detectable and can be measured if concentrations are in the ppb(nmol/mol) or ppm (µmol/mol) range (see also 7.2).

9.3.4 Other polymers

The use of other polymers shall be limited to tubing or connectors joining items of equipment, where there is little or no direct contact with the sample. Special care shall be taken in the case of water or sulfur-compound analysis. However, good results can be obtained using polyamide material for short tubing lengths. In some cases, soft PVC can be used at low pressures. Before any new polymer material is used in a sampling system, it shall be tested using certified blends at expected concentrations to verify that it does not cause any change in the sample composition.

9.3.5 Rubbers

Rubber tubing or connections are not recommended, even at low pressure, because of the high reactivity and permeability of rubber. Silicon rubbers are known for their high absorption and permeability for many components.

9.3.6 Bimetallic corrosion

Using dissimilar metals in contact with each other in a sample system can cause increased rates of corrosion and result in sampling errors and/or safety problems.

9.4 Sample contamination

9.4.1 Cleanliness

The sample wetted surfaces of components of a sampling system need to be rigorously cleaned prior to use. In use these surfaces can become contaminated as natural gas often contains particulates, droplets and aerosols etc. which if they enter the sampling system are generally deposited on the cleaned surfaces or filters etc. Such contaminants have a huge gas sorption effect on processes and mitigate the care taken in material selection and initial cleaning.

9.4.2 Cleaning sampling systems

All parts of the sampling and sample lines in contact with gas shall be free from grease, oil, mould or any polluting products. Sample containers shall be cleaned and purged prior to each collection of samples, unless they are special passivated cylinders used to sample streams containing highly reactive components (see also Annex D). They shall be cleaned properly, e.g. with a volatile solvent, and dried to avoid absorption phenomena, particularly those caused by sulfur compounds and heavy hydrocarbons.

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Solvents, such as acetone, that do not leave a residue after drying are generally acceptable for removing heavy-ends contamination, although they can present hazards such as flammability and toxicity in some cases. Steam cleaning is generally acceptable only if the steam itself is clean and does not contain corrosion inhibitors, boiler water treating chemicals or other substances that can contaminate the sample cylinder.

Special care shall be taken in cleaning cylinders that contain deposits.

If analysis of sulfur components is intended, steam shall not be used to clean stainless-steel cylinders. Sulfur species are readily absorbed by the cylinders and the analysis underestimates sulfur levels. Samples to be analysed for their sulfur content need to be collected in special lined cylinders or passivated cylinders dedicated to that purpose. It is important to note that the entire wetted surface of the sample container and its secondary components shall be coated. Coating the cylinder, but not the valves, fittings, relief devices, etc., may not be sufficient protection. In certain cases, suitable coating (see Table 1), or surface treatment is recommended

9.4.3 Pre-charging of sample cylinders

Nitrogen, helium, argon and dry, instrument-quality air are good examples of gases used to dry or purge cylinders which are free of deposits and heavy-ends contamination. In order to avoid interference, the drying or purging gas used shall not contain any of the constituents to be analysed. Many laboratories leave a blanket of nitrogen, helium or other gases in sample cylinders in order to protect the cylinder from air contamination. The blanket gases and gases used to recharge or back-pressure sample cylinders shall be carefully selected so that, if leakage does occur within the cylinder or the sample is contaminated by these gases, the analytical system is not interpreting the contamination by these gases as being a part of the sample being analysed. For example, chromatography using helium as a carrier gas does not detect helium left over from the recharge of a single-cavity cylinder or helium leaking past the piston in a floating-piston cylinder.

9.5 Sample condensation

9.5.1 Temperature

All component parts of a sampling system shall be kept at a minimum 10 °C above dew point temperatures of possible gas mixtures. If necessary, keep the sampling place under constant temperature by using thermal insulation in conjunction with heat tracing. It is necessary to keep the temperature as constant as possible as fluctuations in temperature cause different gas sorption effects. It is often possible to see a rise in the level of reactive components during daytime with a fall during night-time due simply to changes in temperature of the sampling system.

9.5.2 Pressure reduction and Joule Thomson cooling

The condensation behaviour of natural gas is complex, owing to it being a mixture of compounds and elements with differing boiling points. In collecting and preparing a sample for analysis it is very easy to stray into and through the liquid/vapour phase boundary. If this happens, the integrity of the sample becomes questionable, so should be avoided as far as reasonably practicable. This is particularly important for calculating hydrocarbon dewpoint, or other measurement applications where accounting for higher hydrocarbons is critical.

The Joule Thomson effect describes the instantaneous cooling that occurs in a gas when its pressure is reduced (the gas is expanded). The amount of cooling is proportional to the pressure drop, and the coefficient between the pressure and temperature relationship is dependent on the element or compound in question.

Joule Thomson cooling can take place at any point in a sampling system where a pressure drop occurs. Sometimes pressure drops are inadvertently created due to a poor choice of component parts, through a valve not being properly opened, or other unintended situations, such as lack of operation and maintenance. Even opening a valve can have significant detrimental effects (see Annex E). The

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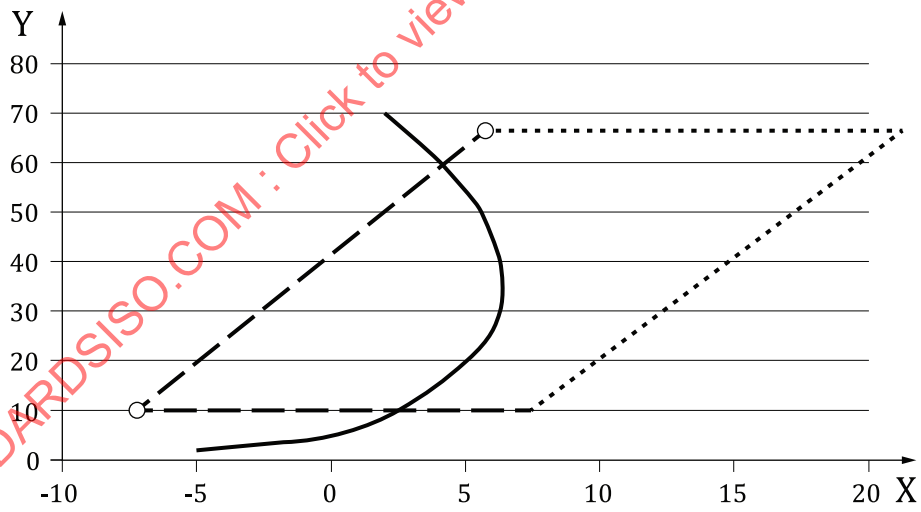
reduction in gas temperature caused by the actual pressure drop is known as primary cooling. The cooling of the gas sample in this manner can alter the condition of the gas long before the cooling effects (symptoms) are visible or noticeable on equipment parts.

When pressure drops are large and gas is cooled and compromised as a result, items of plant/parts both upstream and, more readily, downstream from the pressure reducing constriction also become cooled. As these items of plant/parts become increasingly cooled they further add to the cooling of the gas by conduction, convection and radiation and increase the overall magnitude of the temperature drop of the gas. The reduction in gas temperature caused by these means is known as secondary cooling.

Secondary cooling can be avoided by providing a sufficient source of external heat such as temperature compensated regulating probes, heated pressure regulators, trace heating etc. However, this is only treating the secondary cooling (a symptom of primary cooling) as well as preventing items of plant and equipment becoming frozen.

Primary cooling cannot be avoided and therefore if the composition of the gas is such that the possible temperature drop from primary cooling could cause the sample to cross a phase boundary then protection of the gas sample needs to be considered in a different way.

One way of negating the primary cooling effects is to pre-heat the gas prior to any reduction in pressure. The amount of pre-heating should be determined by calculating the maximum cooling (drop in temperature) that is likely to take place according to the composition of the gas and the reduction in pressure required at that point in the sampling system, and by adding a minimum margin of 10 °C, to allow for uncertainties in conditions and fluctuations in properties of the sample gas. The design of the heating arrangement and sampling system shall be such that it ensures the gas is at the required temperature right up to the inlet of the restricting orifice over which the pressure drop occurs. If this method of negating the primary cooling effect is used, the need for protecting against secondary cooling is removed. Figure 7 is an annotated phase diagram for Natural Gas, that illustrates these phenomena



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Key

X	temperature (°C)
Y	pressure (bar = 0,1 MPa)
———	shows the gas vapour phase boundary for a typical Natural Gas mixture
— — —	shows the temperature profile of a Natural Gas mixture when taking a high pressure sample from a pipeline and reducing it to suitable (low) pressure for analysis. Joule Thomson primary cooling is evident, until the pressure reduction ceases and the gas temperature changes to match ambient conditions.
----------	illustrates the described method of avoiding problems associated with Joule Thomson cooling (and secondary cooling), whereby the high pressure sample is pre-heated prior to pressure reduction, so that when Joule Thomson (primary) cooling occurs during pressure reduction, the gas sample remains safely above the phase boundary throughout transition to lower pressure (suitable for analysis).

Figure 7 — Phase diagram for a typical natural gas mixture

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NOTE In this document, the unit used for pressure is "bar" where 1 bar = 0,1 MPa, as bar is the common unit used in the gas industry.

9.5.3 Condensation and revaporization

9.5.3.1 General

To avoid the potential negative effects of retrograde condensation during any sampling procedure and to maintain the precision of the sample, heat traced and insulated sample lines, and heated sampling equipment may be required to ensure sample integrity.

Cases where all aspects of the single-phase natural gas sampling process are naturally maintained at least 10° C above the hydrocarbon dewpoint in all environmental conditions, may not need additional heating.

The condensation behaviour of natural gas is rather complicated. Figure 7 gives an example of a pressure/temperature phase boundary diagram for a natural gas. The shape of the curve depends on the composition of the gas.

As Figure 7 shows, the phase boundary is a complex function between the critical point and normal operating conditions. Retrograde condensation can occur when the phase boundary is encountered in an unexpected manner while adjusting the pressure or temperature of the gas.

9.5.3.2 Example of a condensation problem

An example of how this problem can occur is shown in Figure 8. The pipeline contains gas at pressure p_0 If the initial temperature is –10 °C, and the gas is expanded (i.e. has its pressure reduced) isothermally, it follows the vertical line in the figure as it approaches the pressure at which it can be analysed, p_1. The gas is a stable single phase at p_0 and continues to be so until it reaches pressure p_2 which is on the boundary of the two-phase region.

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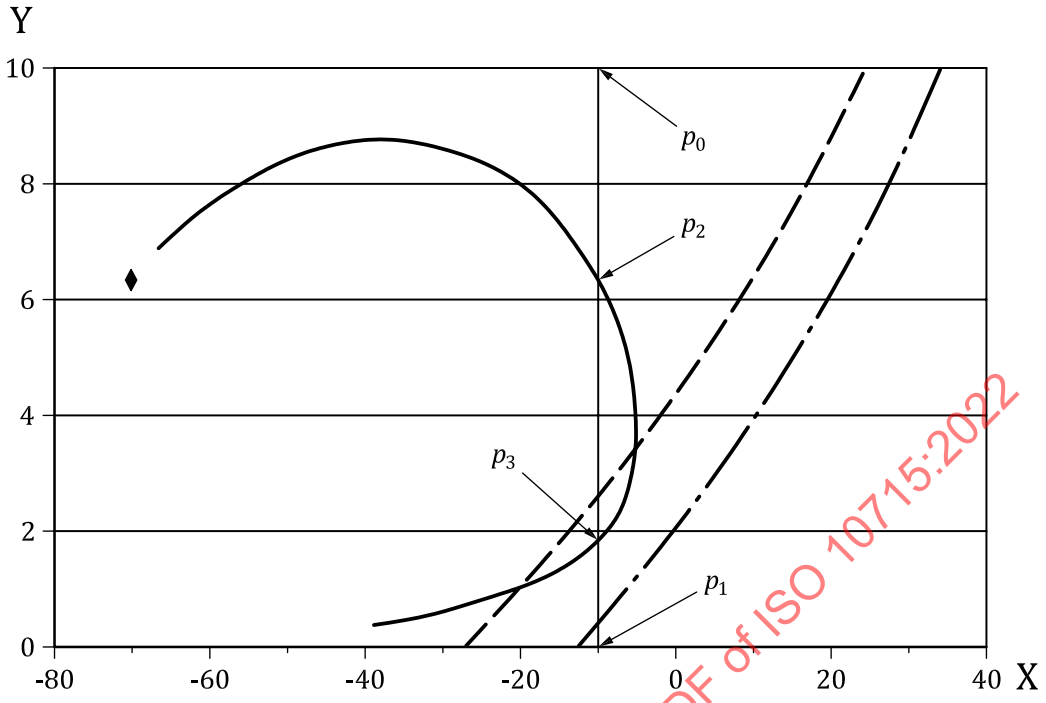

Key

X	temperature (°C)
Y	pressure (MPa)
———	dewline
—·—	cooling from 35 °C
– – –	cooling from 25 °C
♦	critical point
———	isothermal

Figure 8 — Example of a pressure/temperature diagram for natural gas

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Between p_2 and the lower pressure p_3, both gas and condensed liquid are present. The relative quantities of the gas and liquid phases, and their compositions, vary continuously over this range. At pressures below p_3, and down to the analysis pressure p_1, a single-phase gas exists once more.

Conversely, a cylinder with an initial pressure of p_1, filled isothermally to p_0, is, as the pressure passes through p_3, two phases. These recombine at p_2, but this process is slow, and any gas sampled from the cylinder while two phases are present is unrepresentative, and furthermore its removal alters the composition remaining in the cylinder.

The use of pressurized piston cylinders is a way to avoid these problems, keeping the sample in a state where no fall-out occurs.

In fact, as a gas is expanded, its temperature falls due to the Joule-Thomson effect. The gas whose behaviour is shown in Figure 8, starting from a temperature and pressure of 25 °C and 10 MPa, cool to below −10 °C at p_3, and hence suffer condensation. The initial temperature needed is 35 °C to reach p_1, without encountering the two-phase region.

9.5.3.3 Condensation after sample has been collected

A gas sample could partially condense in the sample container when it is being transported or is awaiting analysis in a lab. High-pressure gas sample containers and the lines to an analytical unit shall always be heated prior to analysis (except for gas that is not passing through a phase boundary). Heating

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times and temperatures shall be sufficient to ensure that any condensed hydrocarbons are revaporized before an analysis is started.

9.6 Disturbance of the flow through the sampling system

For the flow circulation, components should be chosen so that internal flow circulation is avoided within the whole wetted sample pathway. The most important consideration is to avoid dead volumes in the sample system, where mixing and stagnation occur. Flange and screwed connections can be particularly bad as are step changes in internal diameters. Needle and globe type valves and designs of pressure reducing regulators cause flow circulation. Some designs of particulate filters and membrane separators can cause exceptional amounts of flow circulation within a sampling system.

9.7 Delay time

9.7.1 Direct sampling method

The delay time in obtaining the analytical results is the addition of sampling system residence times and the instrument cycle time.

The instrument cycle time is assumed to be known.

In order to obtain a representative sample, the time delay calculation shall be included in system design. Calculation shall include all internal volumes from the probe to the analytical instrument. Delay time should be minimized and balanced against need for minimizing sample waste and system complexity. For applications where fast response is required, such as process control or combustion control, the sample system delay time should not negatively impact the ability of the overall system to achieve the desired outcome. For example, the action of adjusting a valve position or ignition control to optimize gas turbine combustion performance should occur within a few seconds. The transit time needs to be coherent with the final application of the sampling (i.e. gas quality tracking, trace components monitoring etc.) and the flow of gas in the sample line has to be higher than the flow required by the analyser. There is also a compromise to be found between short transit time and limiting GHG emissions.

Pressure drop, cooling/JT effects and need for heating trace/heated regulators and cabinet heater shall be considered.

Delay time is controlled by and depends on following factors:

— Distance between sampling point and analyser input: Distance should be as short as practical from sample probe to pressure reduction system, or if possible at the sampling point, in order to reduce the delay time (by avoiding high-pressure sampling line from the sampling point to the conditioning unit.). Normally this section is subject to the longest transport time. Distances furthest from any sample conditioning is less critical, as the pressure is lower, hence a low transport time is achievable, due to there being physically less gas in the sample system

— Sample line volume should be kept to the minimum possible; therefore the smallest viable diameter tubing should be used. The sample line tubing diameter has to be in accordance with sampling and flow conditions for fast loop sampling and take account of analyser requirements. It has to be consistent with best practices and take in consideration minimizing atmospheric emissions.

  Consider the following criteria for determining the internal diameter of the sample line:

  a) length of the line;

  b) pressure drop calculation;

  c) flow required by analysers.

— Internal dead volumes: Internal volumes from system components such as sampling probe, sampling lines filters, regulators, flowmeters, etc. shall be considered in delay time calculation Such volumes should be kept as low as possible and dead volumes should be avoided.

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— Purge flow-rate: Flow meters (for all relevant streams) should be installed in order to monitor flowrates in order to verify the actual delay time.

— Use of slip stream/bypass (waste stream): Slip stream flow can be routed to atmospheric disposal system (flare) or can be compressed for injection back to process. For environmental purposes, slip stream quantity to atmosphere should be minimized.

— A fast-loop configuration (sample return to process) can be used, where sample is extracted at high-pressure and returned at slightly lower pressure, subject to suitability for process conditions and analytical requirements. The benefit of this method is the reduction of emissions to atmosphere or flare.

— Pressure levels in sampling system: By reducing the pressure of the sample gas over a heated pressure regulator close to the sample point, a lower transport time can be achieved.

— Sorption effects: For components that tend to sorption effects, an equilibrium occurs in the gas sampling system in a time that depends on the amount fraction of the component of interest. This equilibrium time cannot be reduced and needs to be considered. See Annex C for details and 'surface treatment' methods.

— Time matching: If the sampling system is feeding a GC as part of a metering system, matching between GC results (taking into account sample system delay time and analyser cycle time) and the instantaneous bulk gas flow-rate should be considered.

Delay time is the sum of residence time in each sections of the sampling line calculated from the actual volume flow rates in each of the sections, and shall include the residence time in volumes of filters, valves and dead ends.

Actual volume flow rates in each of the sections is shown in the example of a block diagram for delay time calculation (see Figure G.4) dictated by the volume flow rate through the analyser and the by-pass flow rate (by-pass flow rate can be required to obtain acceptable low delay times) taking each section's pressure and temperature into account.

In the example/block diagram, fast loop is considered, resulting in an increased volume flow rate in the sampling probe up to and including the filter (the 100 ml volume) compared to the flow rate only made up by the analyser flow rate and by-pass flow rate.

The purge time of trace analytes like H_2S, do not follow the same rules and the sorption effect needs to be taken into account (see Annex C).

Residence times and delay times with and without fast loop are shown in Tables G.1 and G.2.

A detailed method for the calculation of residence time is given in Annex G.

9.7.2 Indirect sampling method

The delay in time in obtaining the analytical results is the sum of the sampling system residence times and the transport time from the sampling area to instrument. A time stamp shall be recorded for such a method.

The purging time for spot sampling shall be at least 10 times the residence time. The purging shall ensure representativity and system equilibrium with respect to temperature and flow.

The delay in time in obtaining the analytical results being an accumulation/addition of:

a) Online Instruments: The analytical instrument cycle time plus the sampling system transit/purge time.

NOTE The sample system transit/purge time can be many times that of the analytical instrument cycle time in poorly designed, integrated and/or installed sampling systems. Locating the analytical instruments remotely from the sampling place can further increase this problem.

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b) Offline Instruments: As a) plus any time delays in transporting the sample from the collection point to the location of the analytical instrument and introducing it to the analyser at the start of any analytical process.

c) The sample container should be time stamped and the lifetime of the sample inside needs to be assessed.

10 Sampling equipment

10.1 General

Equipment used in the sampling of high-pressure natural gas shall be inspected to ensure it still meets the site-or application-specific requirements and standard engineering practice, if required. Documentation shall be available and up to date. Equipment shall be designed to meet relevant sampling conditions, e.g. pressure, temperature, corrosivity, flow, chemical compatibility, vibration, thermal expansion and/or thermal contraction. Permanent transfer and sampling lines shall be properly secured. Breakable connections shall have easy access for leak-testing. Outlets shall be equipped with double block and bleed valves. End caps shall be connected to fittings when the cylinders are not in use.

The use of flexible high-pressure tubing shall be limited and manufacturers' instructions for safe application shall be strictly followed. Sample lines can be blocked by solid or liquid contaminants. Special precautions shall be employed when trying to "reopen" such lines. Only qualified personnel may do this.

Sample lines shall have shut-off valves located as close to the source stream as possible. The sampling probe shall be equipped with a shut-off valve. Electrical equipment shall be approved for the relevant sampling application. Equipment which can create static electricity shall be avoided. Use of equipment or tools which creates sparks shall be avoided.

It is the sampling system with the smallest amount of equipment that is the best for representative sample. However sufficient equipment shall be installed to ensure compliance with respect to sampling system functionality

A good design of a sample probe take the local conditions into account but balance this with any negative effects of the probe itself.. Designing a probe to meet such conditions can often lead to it becoming a significant flow disturbing element altering both the sample that is extracted and the precision of local flow measurement equipment. Furthermore such probes also become inconsistent with good sampling practice because of internal volume and surface conditions. Also the effects of vortex shedding vibration need to be considered on the design of the item of process plant to which the probe is connected.

NOTE See Annex F on vortex shedding and associated problems as well as Reference [10].

Branch connections to such items as pressure measuring devices, pressure relief devices, vent lines, standby/duplicate sample ways etc. should be avoided unless they are continually swept out by flowing sample gas. Also tee connections for the introduction of test or calibration gases etc. should be kept to a minimum and should be designed in such a way to avoid any dead volume in order to reduce dilution effects.

If provided for, end caps shall be installed on cylinders during transportation and storage.

Cylinders shall have volume, working pressure and test pressure permanently stamped.

Cylinders shall have a test pressure of at least I,5 times the working pressure.

Cylinders shall be protected against damage during transportation and storage. Transportation boxes or cartons designed for the individual type of cylinder shall be available.

Cylinders shall be accompanied by labels or paperwork with relevant information protected against damage.

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Cylinders and associated accessories shall be inspected and leak-tested periodically.

Electrical equipment shall be approved for the relevant sampling application.

Equipment shall be earthed as necessary and that which can create static electricity shall be avoided.

Use of equipment or tools which may create sparks shall be avoided.

10.2 Probes

10.2.1 General

A sampling probe shall be designed to meet the process conditions of the item of plant/gas grid to which it is connected as well as the environmental conditions to which it is subjected.

Furthermore, the probe needs to be designed to be resistant to the vibrational effects of vortex shedding. Designing a probe to meet such conditions can under certain conditions lead to it becoming a significant flow disturbing element altering both the sample that is extracted and the precision of local flow measurement equipment. The vortex shedding and associated problems is described in Annex F.

Gas lines with streams free of entrained liquids and at flow conditions well above their dewpoint temperatures may be sampled with any probe design. However, lines that are operating at or near the gas stream dewpoint requires a special probe designed to overcome the problems of condensation. To avoid altering the gas composition, any extra liquids in the sample source shall be separated at the source temperature and pressure.

A probe in the pipeline is typically inserted in accordance with 8.3. This is to ensure that the sample is not being taken off the wall of the pipeline where liquids tend to accumulate and would be ingested into the sample. Use of a probe shall ensure getting a sample from the active part of the flowing stream and not from a dead-end source (see 8.1 for probe location). Adding membrane phase separator at the probe tip location or at the outlet of the sampling probe will also help to reject liquids, hydrocarbon liquids and contaminants. The probe may be of a stationary or removable type depending on location and operating condition, especially if pigging and inspection works can be conducted on the considered pipeline.

10.2.2 Straight-tube probe

The most basic sample probe design is the straight-tube probe shown in Figure 9. The end can be flat or angle-cut.

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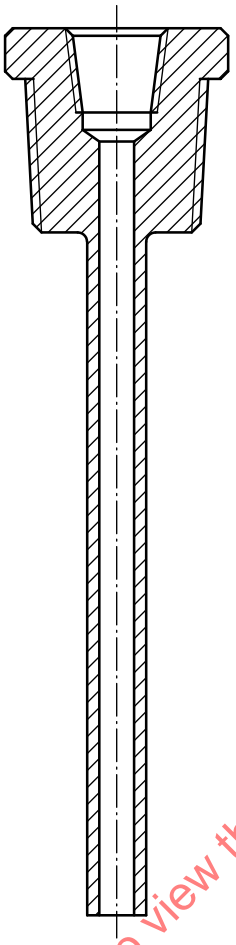

Figure 9 — Straight-tube probe

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10.2.3 Probe regulator

The other type of probe design in common use in the gas industry is the probe regulator. These probes are commonly used with continuous analyser systems and are designed to deliver the gas to the system at reduced pressure. The diaphragm and control spring are mounted externally to the pipe wall and connected by an internal rod to the point at which the pressure reduction occurs, which is at the lower end of the probe which is inserted into the gas stream. This lower end is often finned, so that the temperature drop on expansion is compensated for by the thermal mass of the gas stream. An illustration of a typical probe regulator is shown in Figure 10. The intended design is to use the heat of the process gas to offset the Joule Thomson cooling effect.

CAUTION — Some regulated probes might need a specific extraction tool. Refer to the manufacturer instruction notice.

WARNING — Most important risk with probe regulators: not advised for wet gases because of hydrates formation – blockage of the pressure drop system.

Probe regulator:

— normally need extraction tool for removal at line pressure and maintenance,

— not suitable for wet gas due to risk of liquid drop-out.

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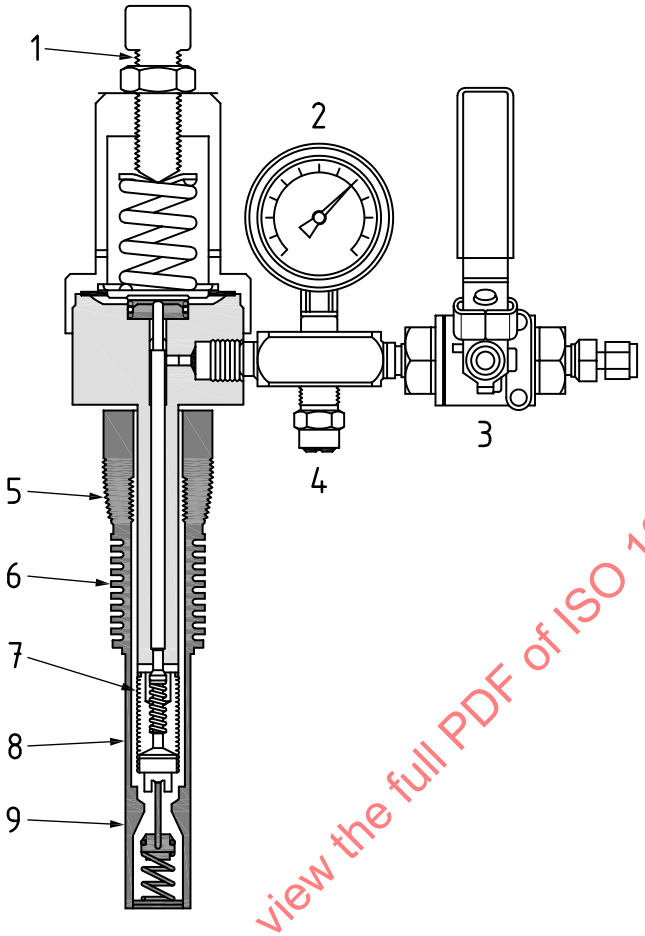

Key

1 outlet pressure adjustment
2 gauge, typical
3 sample isolation valve, typical
4 relief valve, typical
5 sample tap connection
6 fins optional
7 membrane optional
8 regulator valve seat in probe stern
9 foot valve housing optional

Figure 10 — Probe regulator

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10.2.4 Pitot probe

A pitot probe (Figure 11) is commonly used to create a fast loop or slip stream outside of the main pipeline. p_1 or upstream pressure is diverted from the pipeline, through the instrument or fast loop and returned to p_2 or downstream pressure. The probe flow is dependent on differential pressure and pipeline flow velocity to create the flow from the entrance to the probe to the return port of the probe.

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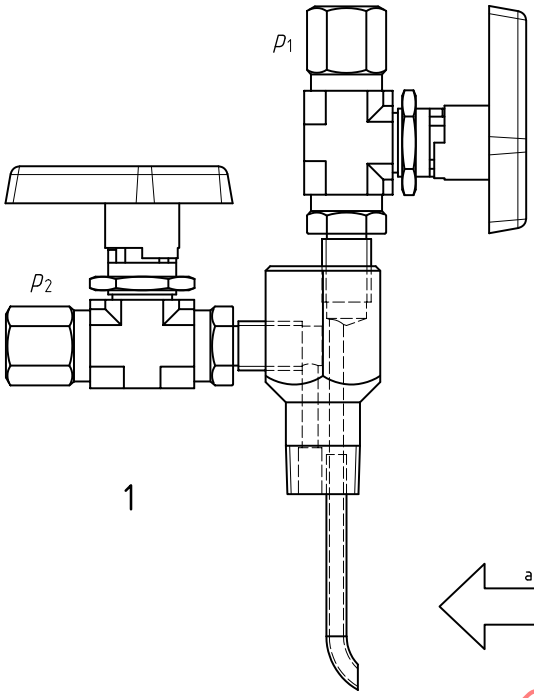

Key

1 pilot probe
p_1 outlet
p_2 return
a Flow.

Figure 11 — Pitot probe

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10.3 Tubings

10.3.1 Sampling and sample lines

10.3.1.1 General

Branch connections to such items as pressure measuring devices, pressure relief devices, vent lines, standby/duplicate sample ways etc. should be avoided unless they are continually swept out by flowing sample gas. Also tee connections for the introduction of test or calibration gases etc should be kept to a minimum and should be designed in such a way to avoid any dead volume in order to reduce dilution effects.

Sampling lines shall be as short and as small in diameter to decrease the residence time but not so small in diameter that they excessively restrict the flow. Sample lines should travel up or slope up from the sample point in the pipeline to the sampler or analytical system located at a higher elevation. Loops, dips and low points should be avoided as they present a collection point for contaminants and any condensed liquids formed during malfunction of the sampling system. Sample lines venting to the atmosphere shall be minimized. In addition, high-pressure drops can cause cooling and condensation, which affects the representative nature of the sample. The purging time for spot samples shall be at least 10 times the residence time. Annex G gives guidelines for the calculation of the residence time. All connections between the sample point and the sample container shall be such that sample contamination cannot occur. Where necessary and allowed, threaded connections shall be made using PTFE tape. Only pipe thread sealing compounds with no effect on the sample shall be used Poorly selected compounds can contaminate the sample and/or absorb components from the sample, resulting in erroneous results.

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10.3.1.2 Pressure drop in a sample line

Proper operation of a sample line requires a pressure differential from the collection point to the discharge. This pressure drop can be provided by an orifice plate, regulator or other appropriate device in the flow line.

10.3.2 Bypass constructions

10.3.2.1 General

When using a bypass, closed loops are preferred due to environmental and safety considerations.

10.3.2.2 Bypass loop

The bypass loop, also known as a “fast loop” or “hot loop”, shall be of the closed configuration; it shall return to the process line. Stainless steel tubing measuring 3 mm to 10 mm should preferably be used. The loop requires a pressure differential, from collection point to discharge, to ensure a constant and steady flow rate through the sampling equipment located in the loop. The fast loop contains pressure and flow monitoring and control components, such as a flow meter, pressure gauge and back pressure regulator

10.3.2.3 Bypass line

Where it is impractical to provide a sufficient pressure differential, thought can be given to the use of an open-ended bypass line which is ultimately vented to the atmosphere or to a flare. The flow rate and pressure loss in an open-ended line needs to be controlled to limit any cooling and condensation which affects sample integrity.

10.4 Filters, membranes and separators

Filters and membrane separators can be necessary to obtain a clean, dry sample. It has to be kept in mind that systems shall not alter the representativeness of the sampled composition. If the liquid being removed to protect the GC is hydrocarbon liquid, the heating value and the composition of the sample of the stream could be changed. Some gas processing units, for example scrubbers, separators, amine contactor, compressors, can release or carry-over contaminants in the form of liquid, oil, aerosol etc. Filter or filter membranes (self-cleaning type) devices is therefore normally installed in order to protect sampling equipment and analytical instruments connected to the sampling system.

It might sometimes be necessary to control some characteristics of the gas at the outlet of process units (for example, water content after dehydration, hydrogen sulfide content after desulfurization, dewpoint after compression). Some units, because of the nature of the process, can release some contaminants in the form of liquid, aerosols or froth (glycol, amine, oils, etc.). In that case, it is necessary to protect the pressure reducer and also the analytical units from contact with any liquid sampled with the gas. If the probe cannot be installed downstream of a gas/liquid separator in the line, the devices presented in Figures 6 and 7 may be used to stop non- gaseous materials.

Separators, drip pots or spot sampling manifolds are not recommended nowadays in sampling systems. They can however, still be in use on site to ensure that any free liquids that have been collected by the sample probe do not enter the analyser or sample cylinder. Care shall be taken whenever one is used. The pressure and temperature of such devices shall match the pressure and the temperature of the source to avoid altering the sample composition during the sampling process. If possible, no mechanical devices, filter or absorptive material that promote condensation or absorption shall be used.

A spot sampling manifold system, is used for taking spot samples from the pipeline that takes into consideration the potential for small, occasional amounts of liquid present during the sampling process. Flow is diverted from the pipeline via a probe. From the probe, the gas flow enters a separator that allows the free liquid to impinge on the side of the separator, collect and fall to the bottom of the separator. The gas exits the separator at the top and enters the top of the sample cylinder. On the opposite end of the

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cylinder is a coiled extension tube with a valve on the end. That valve, rather than the cylinder valve, is used to assist in the filling and emptying of the cylinder while isolating the Joule-Thomson cooling effect from the cylinder. That valve can also be fitted with a restriction fitting to govern the exit flow rate, if the operator prefers a pre-set flow rate. This apparatus should always be warmed to pipeline flowing temperature or above, and pressure, to avoid temperature generated condensation. The Spot sampling manifold can be used with all the spot sampling techniques.

Separators (or drip pots) are generally not recommended in sampling systems. They may however be used to ensure that any free liquids that have been collected by the sample probe, do not enter the analyser or sample cylinder. Care shall be taken whenever one is used.

If possible, no mechanical devices, filter or absorptive material that promote condensation or absorption shall be used.

Filters are a significant feature of a sampling system with regard to sorption effects, owing to the huge surface area required to achieve their principal function of contamination capture. Filter surfaces can directly trap analytes of interest and can also indirectly capture analytes by accumulation of highly sorptive particulates. Coalescing and/or membranes systems allow the rejection of liquid droplets present on the surface. Filters should minimize dead spaces around the filter element itself, as these are sources of potential contamination and analyte residence and should be designed to remove all contamination upon replacement of the filter element during maintenance.

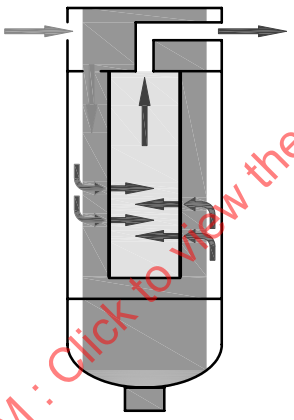

Figure 12 — Filter schematics

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10.5 Valves and safety valves

All manually operated shut off valves in the system shall have a proper open/close indication:

— service valves should be included at system inlet and outlet;

— valves for on/off function should be ball valve type.

— needle and globe type valves are for flow control and regulating purpose.

Ball valves also offer better flow paths than needle valves and other valve types, which improve flow characteristics and reduce contaminant residence.

Pressure reduction valves should include an integrated heating supply or be placed on a heated plate or in a heated cabinet as required. See also 10.8.

In order to minimize potential leak points; the number of valves and fittings should be minimized. Using elbows should be avoided; bended tubing is preferred. Valves with integrated fittings are generally preferred.

The location of drain and vent valves shall ensure that no liquid can enter backwards into the analyser vent line (analyser outlet).

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Safety valves: Pressure relief valves shall be installed in order to protect equipment and components accordingly.

10.6 Fittings

Tubing compression fitting and sealing compounds should be of common make for the complete sampling system.

Maximum allowable pressure ratings shall be in accordance with the tubing and tubing fitting manufacturer published design data.

Connectors to sample cylinders shall be designed for frequent use. Flexible hoses should be used and connected with O-ring seal fittings. Standard ferrule NPT-fitting should not be used.

If the material of the tubing and fitting is different, the combination shall be verified as acceptable by the fitting manufacturer.

10.7 Flow monitoring and control

Flow meters shall be used as necessary to ensure sample-/bypass-/vent-flows are according to design. To control the flow rate, a needle valve is normally installed in connection with flow-meter. Calibrated orifices might also be used to control the flow.

10.8 Pressure reducers

In order to supply the analytical unit with sample gas at the appropriate pressure, a pressure reduction device is often required.

Depending on the pressure in the pipe and the pressure drop along the sample line, it might be appropriate to reduce the pressure at the beginning of the line to allow reducing the delay time, or not to reduce the pressure at all

Pressure reducers should preferably be made of stainless steel and PTFE.

Pressure regulators shall have a pressure rating that exceeds the maximum expected line pressure of the gas- sampling system.

Due to the Joule-Thomson effect, the temperature falls by approximately 0,5 °C with a pressure reduction of 0,1 MPa, and consequently there is a potential for condensation of heavy hydrocarbons.

If this occurs, the sample is no longer representative, and shall consequently be rejected. The normal way of preventing this fall-out is by heating to compensate for the temperature drop. The heat is applied upstream of the pressure reduction device. The system shall be designed so that no condensation is taking place at any point. The amount of heat energy required is dependent on the gas composition, pressure reduction, pressure and temperature, flow rate, etc.

10.9 Pressure sensor/manometers

Pressure gauges should be installed as needed to monitor and control pressure in the system. Gauge size should be kept low in order to reduce dead volume.

Block and bleed manifold should be avoided.

10.10 Heating devices

Heating elements may be installed on the sample probe and sample lines. In some cases, heating the sample cylinder is also required. Electrical heating elements shall be of the self-limiting type. They shall also meet the requirements of electrical codes for the area in which they are used. These requirements

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are needed to ensure that a heating element does not overheat if a failure occurs in the electrical components.

The temperature in all parts of the sample lines including the sample conditioning equipment shall be kept at a temperature of at least 10 °C above the hydrocarbon dew point temperature. The dew point temperature shall be calculated by well recognized methods for every pressure level in the system. The temperature and pressure at critical points in the sampling system can be indicated.

Circulation of heated 'air' can be required to ensure an even temperature in the cabinet.

Heat tracing of tubing inside cabinet can be required if cabinet temperature is not high enough.

10.11 Seals and lubricants

There are a variety of seals for the equipment used in sampling systems. Compatibility with the sampled product is critical as well as choosing seals that meet the demands of temperature and pressure considerations of the equipment and sampling process. There are equally a variety of lubricants that are used with the seals and other points within the sample systems.

10.12 Sample containers or cylinders

10.12.1 General

Cylinders shall have a test pressure of at least 1,5 times the working pressure.

Cylinders shall be protected against damage during transportation and storage. Transportation boxes or cartons designed for the individual type of cylinder shall be available.

Cylinders shall be accompanied by labels or paperwork with relevant information protected against damage.

Glass containers shall not be exposed to pressure.

If provided for, end caps shall be installed on cylinders during transportation and storage.

Cylinders shall have volume, working pressure and test pressure permanently stamped.

Cylinders and associated accessories shall be inspected and leak-tested periodically.

All cylinders should meet any and all safety requirements for the area in which they are used. Many local and national governments have transportation requirements for these cylinders, since they are pressurized and are carrying hazardous materials within the public domain. Safety is a strong priority. Many countries accept other country approvals, rather than setting up their own rules and test requirements.

These cylinders can also be treated with coatings that assist in maintaining the integrity of the sample that is contained within them ensuring minimal reactivity with sulfur compounds. These internal coatings shall be specified.

The sample container shall not alter the gas composition in any way or affect the proper collection of the gas sample. The materials, valves, seals and other components of the sample container shall all be specified with this purpose in mind.

Containers for sampling are usually made of glass (for very low pressures, overpressure below 0,2 MPa), stainless steel, titanium alloy or aluminium alloy.

Unless the containers are vacuum-sealed, they shall be equipped with at least two valves, allowing purging of the gas sample. The container surface in contact with the gas shall be free from grease, oil or any other polluting product. They shall be carefully cleaned to avoid absorption phenomena. Annex D describes a cleaning procedure.

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Soft-seated valves are recommended over those having metal-to-metal seats.

There are basically two types of cylinders available in natural gas sampling:

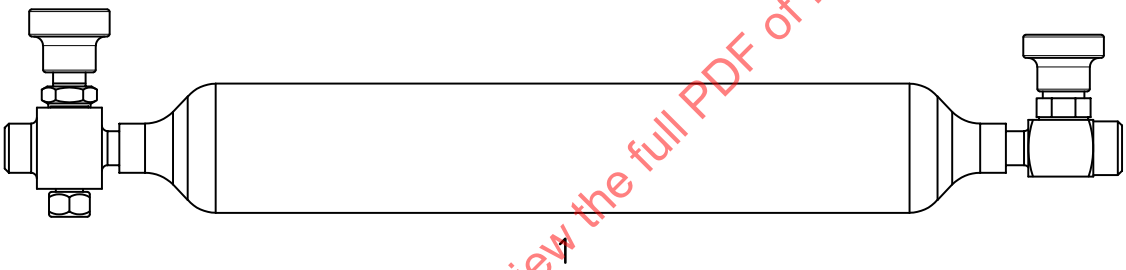
a) the single cavity, spun end cylinder is the most common cylinder used in the natural gas industry, and

b) the constant pressure or piston style cylinder.

10.12.2 Standard or single cavity cylinder

A standard (single cavity) cylinder used for the collection of a sample for analysis, such as described in Figure 13. Typically, the cylinder is stainless steel and formed with spun ends and tapped at each end of the cylinder. Some designs can only have a single tapped end. The most common sizes are 300 ml, 500 ml and 1 000 ml, with other volumes available.

The cylinder has a valve and a safety relief at one end and a valve at the other end. Spring type reliefs are acceptable, but they present an integrity problem, in that you do not know if some of the sample has escaped or not. If it did vent, the sample would be tainted. With the rupture disc, you know the cylinder was over pressured and vented, and now the tainted sample is gone.



Key

1 single cavity standard cylinder

Figure 13 — Single cavity standard cylinder

10.12.3 Floating-piston cylinders or Constant Pressure cylinders

The container required for this method is constructed of metal tubing, honed and polished on the inside surface. The cylinder is preferably closed with removable end caps to provide access for removal and servicing of the moving piston. The end caps are drilled and tapped for valves, gauges and relief valves. Figure 14 gives an example of a floating-piston sample cylinder showing a cylinder with an external apparatus to show the user when the cylinder has reached 80 % capacity. When item 5 reaches item 9 (80 % ring) the user should cease filling.

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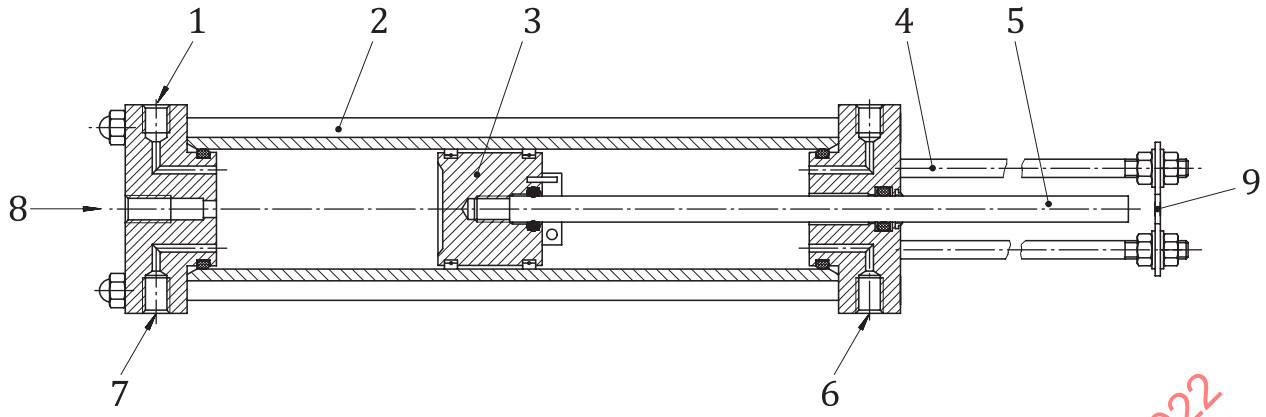

Key

1 relief port
2 tiebolts
3 piston
4 tripod
5 indicator rod
6 precharge
7 gauge and valve port
8 sample
9 80 % ring

Figure 14 — Floating-piston cylinder

This cylinder is normally constructed of stainless steel. The cylinder has a floating piston inside that allows the technician to pre-charge the back side of the cylinder to line pressure and take a sample at line conditions and not allow the gas to depressurize or flash in the process. Then, and very importantly, the cylinder can be taken to the lab and by connecting to a pre-charge gas at the line pressure of the sample, maintain the sample at line conditions during the analytical process. This maintains the integrity of the sample at a very high level. For gases that have higher calorific value values and are susceptible to a phase change due to temperature or pressure changes, this cylinder is preferred. It has inlet and pre-charge valves, a purge valve, safety reliefs and gauges.

Because this cylinder has seals, it is important that the seals are chosen correctly and are compatible with the product that is being sampled into it. Manufacturers' recommendations are very helpful in this area.

10.13 Concentration devices

Where an analyte of interest is present at extremely low levels, it may not be possible to directly analyse the sample to obtain an accurate and reliable evaluation of analyte concentration. In this case, it may be necessary to make use of a concentration device. The principle of such a device is to pass sample through it and accumulate a sufficient concentration of the analyte(s) of interest. This accumulated analyte captured within the concentration device can be subsequently liberated from the device using elevated temperature and a neutral gas such as nitrogen to deliver it to an analytical instrument that can accurately and reliably measure the concentration of the analyte.

The purge gas should be used so as not to cause cross interference with the analyte(s) of interest in the analytical instrument. For determining the concentration with a minimum uncertainty, it is necessary to accurately know how much sample gas was flowed through the concentration device to accumulate the amount of analyte used to generate the analytical result. This can be achieved by accurate flow measurement equipment or by calculation.

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Concentration devices are made of materials suitable for the service and analyte(s) of interest and are typically of glass or stainless steel construction and containing a medium that absorbs the analyte(s) of interest.

10.14 Number and sequence of equipment

The function of a sample system is to deliver a representative gas sample to an analytical vessel using methods earlier described. To minimize interaction of the sample system with the transiting gas sample, fewest possible pieces of equipment should be used, and they should be selected to minimize transit time and sorption effects. However, safety, source contamination and analytical protection criteria often necessitate addition of sample system equipment to fulfil additional requirements, such as liquid separation devices.

The optimum sequence of items can vary by application, but in general placing a filter close to the sample offtake reduces accumulation of contamination throughout the sample system, and pressure reduction close to the sample point minimizes sample lag time. The sample gas flowmeter needs to be located after the analyser otherwise it becomes a wetted surface as well (see Table 2).

Table 2 — Required equipment depending on the cases

Equipment per Application	Clean, dry gas being sampled at line pressure e.g. LP biomethane grab sample	Automatic samplers e.g. Incremental Sampler	Online sample system for gas property measurement e.g. gas chromatograph	Online trace analyte sampling in HP stream e.g. mercury in gas processing plant
Sample probe	R	N	N	N
Isolation valve	N	R	N	N
DBB (double block and bleed)	U	U	R	N
Valve heater	O	U	O	R
Particulate Filter	O	O	N	N
Sample tubing	N	N	N	N
Heated tubing	O	O	O	N
Coated tubing	O	O	O	R
Sample pump	U	N	U	U
P regulation	O	U	N	N
Heated P reg	U	O	R	N
P gauge	U	O	R	N
Flow meter	U	U	R	N
PSV/SRV (pressure safety valve/ safety relief valve)	O	N	N	N
Heated enclosure	O	O	O	O
Sample cylinder	N	N	O	O
N = Necessary, R = Recommended, O = Optional, U = Unnecessary				

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Table 2 *(continued)*

Equipment per Application	Clean, dry gas being sampled at line pressure e.g. LP biomethane grab sample	Automatic samplers e.g. Incremental Sampler	Online sample system for gas property measurement e.g. gas chromatograph	Online trace analyte sampling in HP stream e.g. mercury in gas processing plant
Comments	Probe recommended for DN70/3" line and above Heating and coating are subject to analyte of interest P regulation and safety subject to process conditions and sample capture equipment requirements	A programmable logic controller (PLC) or other device can be required to ensure sampling according to appropriate flow/time	Heating and coating depends if the GC is being used to measure sulfur compounds	Ideally regulators, flow meters and PSV/SRV outside live measurement pathway
N = Necessary, R = Recommended, O = Optional, U = Unnecessary				

The table illustrates some necessary, recommended and optional items of sampling equipment for use in certain sampling applications. The examples shown are indicative only and not intended as a fixed rule for implementation.

11 Verification of the system

For certain safety- or process-critical measurement applications, verification of the sample system should be performed periodically to ensure no degradation of the sample system performance over time, at a period specified by the user according to their site and stream requirements. New designs and installations of sample systems should incorporate features to facilitate in situ verification.

Verification of the sampling system assesses function and performance and is necessary to identify and treat the contribution of sampling error to analytical systems.

During manufacture, pressure-retaining sampling assemblies should be pressure tested at 1,5 times design pressure to demonstrate strength of welds, joints and fittings. Management and execution of the specific pressure test procedure is the responsibility of the manufacturer. A leak test should also be performed, using leak detection fluid. This leak test should be repeated during commissioning to ensure that no joints have been compromised as a result of transportation or installation of the system.

If a filter is used in the sampling system, it is recommended to change this as part of a routine maintenance schedule, at a period specified by the user according to their site and stream requirements. This is necessary due to the impact the filter has on sorption phenomena and consequential impact on sampling performance.

To verify performance of the sampling system, a verification gas should be introduced into the sample system as close upstream to the sample point as practicable, typically at the head of the sample probe via a selection valve. For existing sampling systems that have not been designed to allow introduction of a verification gas, an additional selection valve may be added downstream (but close to) the sample probe or tapping point. The verification gas should be similar in content and properties to the gas being sampled and have known values or properties that can be verified by the analytical instrument, to demonstrate no alteration to the sample identity has occurred in the sample system.

A sample system verification method is described in Annex H

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12 Troubleshooting

In-service measurement issues can be caused by a malfunctioning sample system. Sample system issues can exhibit themselves in various forms or may not be immediately evident to the analyser or operator as they can still be receiving sample, albeit no longer representative. In general, the issues can be categorized by one of the following causes:

— Blockage or restriction of sample flow through a sample system component, caused by contamination of the gas stream entering the sample system

— A component malfunction or failure, caused by mismatch of design versus operating conditions (such as pressure, flow, process composition) or contamination issues or component fault

— A molecular-level fault in sampling handling, resulting in chemical or physical changes to the gas sample during sampling

External factors such as process upset and environmental impacts that effect the performance of the sample system are not covered by this summary of sample system specific issues. Appropriate environmental thermal and physical protection should be selected according to expected ambient conditions to minimize the impact of the environment. Process upset issues cannot be prevented from within the sample system, however remedial action can include backflush of the sample system (including sample lines and sample probe) and replacement of the filter element and other potentially contaminated sampling components.

Some common issues are listed below with some possible remedial actions and proactive, preventative actions that can be taken to reduce the risk of in-service issues in Table 3.

Table 3 — Examples of common issues in sampling

#	Sampling issue	Description of issue	Symptom	Remedy	Preventative action
1	**Blocked filter**	Contamination in the gas stream saturates the surface of the filter, preventing sufficient, stable flow through the sample system	Decline of flow through the system, tending to complete loss of flow. Filter appears heavily contaminated on inspection / changeout	Change filter, assess suitability of sample probe (position, point) for minimizing contamination ingress, check process stream behaving within normal operating parameters	Proactive filter change schedule (Note that larger filter capacity extends filter change schedule, but does not improve sampling performance), appropriate selection of sample position, point.
2	**Blocked probe sample line**	Accumulation of contamination drawn into the sample probe and subsequently sample lines due to poor probe tip design or poor selection of sampling point according to Clause 8	Decline of flow within the sampling system, tending to complete loss of flow	Backflush of sample line and/or probe using e.g. hexane over-pressurized (to above process pressure) with e.g. nitrogen.	Careful selection of sample probe to discourage ingress of contaminant particles/droplets and avoid localized aerosol formation at the sample point.
				Replacement of sample probe (with better tip design), if issue recurrent	See Clause 8 and 10.1
3	**Sample line, regulator or cabinet heater failure**	Electrical failure of heating element of regulator, trace heated line or panel heater, resulting in sampling issues #5 and/or #6	See sampling issues #5 and #6	Check cause of failure (component failure or issue with appropriateness and stability of power supply, for example), replace faulty heating element or resolve source of power failure	Selection of power supply and heating component suitable for min/max/normal electrical load required to serve heater in the specific application

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Table 3 *(continued)*

#	Sampling issue	Description of issue	Symptom	Remedy	Preventative action
4	**Safety Relief Valve Issue**	Release of pressure below threshold value or failure to reseat after relief	Insufficient pressure reaching analyser or rapid 'bouncing' of pressure as relief valve 'chatters' open and closed	Review process conditions and safety relief valve rating, replace safety relief valve	Correct sizing for the process conditions and regular service per manufacturer's instructions
5	**Joule Thomson (JT) Cooling Effect Issues**	Gas pressure reduction causes instantaneous / concurrent cooling, which if of sufficient magnitude can cause retrograde condensation of some components of the gas mixture, thereby distorting the sample's identity (chemical fingerprint)	Frosting / condensation forming on the outside of the pressure regulator (or other flow restriction / pressure reduction point) of the sampling system. Note: JT issues can occur on a molecular level without being visible or evident in the analytical result	Maintaining the sample temperature significantly above the dew point of the gas. Note: Pre-heating of the gas prior to pressure reduction is the only way to guarantee no transitory / partial condensation (caused by JT effect) occurs	From sample system design and stream data, identify when the gas could potentially approach phase boundary (dew point) and ensure sufficient heating applied upstream of that point.
6	**Sorption issues**	Molecules within a gas sample can and interact with internal surfaces of a sampling system: adsorbing to the surfaces under some conditions and desorbing from the surfaces in different conditions – both of which cause imprecision in the analytical result	Lower than expected analyte concentration measurements, presence of analytes when zero gas passed through system during e.g. purging	Replacement of items of sampling equipment that have large internal volumes (and therefore surface area), unpolished surfaces, untreated (inert coated) surfaces; e.g. sample probe, large double block and bleed valve. Heating of sample system components achieves a net reduction of adsorption to surfaces	See 9.1

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Annex A
(informative)

Purposes of sampling, panel of compounds and information in the sampling report

A.1 Purposes of sampling

Sampling is required to deliver process gas to an analytical instrument in numerous applications within the Natural Gas industry. Some examples of sampling applications, along with the measurement goals include:

— Energy determination for billing applications, typically combining continuous sampling with an online instrument to determine the heating value (and therefore monetary value) of the gas in units such as MJ, BTU or KWh;

— Metering and allocation applications utilizing gas composition

  a) combined with pressure and temperature, calculation of properties such as gas density at operating and standard conditions,

  b) combined with flow rate, calculation of representative gas composition used in hydrocarbon allocation systems;

— Gas quality for gas network entry points, such as gas terminals and biomethane entry points, in conjunction with continuous moisture, sulfur compound and dewpoint analytical instruments;

— Gas quality for processing, typically combining continuous sampling with an online instrument to determine composition, other properties of interest or presence and levels of contaminants such as moisture, hydrogen sulfide, mercury, ammonia and others (subject to the processing application);

— Gas quality for initial or batch audit or assessment purposes, typically combining spot sampling with offline laboratory analysis for trace contaminant compounds or representative sample gas composition for source evaluation and facility design studies.

A.2 Components and ranges of composition

This document may be used to sample all the components that are listed in EN 16726[4] and EN 16723-1[5] and EN 16723-2[6].

A.3 Information in the sampling report

If a sampling report is needed, it should contain information on:

— Date and time of sampling

— Gas type/name

— Sampling location/position/place/point

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Annex B
(informative)

Procedures for sampling

B.1 Procedure for low pressure sampling into glass cylinders

B.1.1 Specific safety precautions

Check that the sample cylinder (see Figure B.1) has no cracks. It is recommended that a flexible sleeve be used around the sample cylinder. Normally, this is not necessary for a line pressure of 0,5 kPa to 10 kPa, but there is always a risk that the line pressure will be somewhat higher than 10 kPa.

Use safety goggles during sampling.

Dimensions in millimetres

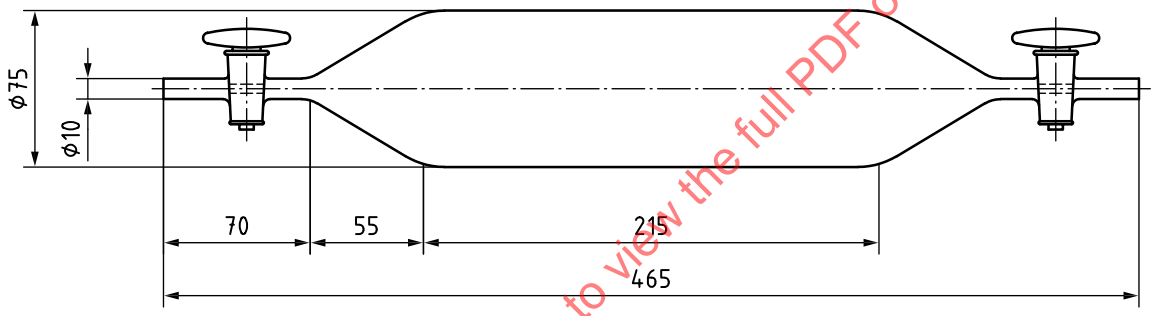

Figure B.1 — Glass sample container (1 l)

B.1.2 Preparation of the glass cylinder

Lubricate the stopcocks of the sample cylinder with silicone grease.

Clean the sample cylinder using a potassium hydroxide and soap solution.

Rinse afterwards with distilled water.

Dry the cylinder with hot air (water- and oil-free).

When hydrogen sulfide is to be analysed in the gas sample, rinse the sample cylinder with 0,01 mol/ H_2SO_4.

B.1.3 Sampling

For a typical sampling arrangement, see Figure B.2. (Figure B.3 shows a set-up for sampling from sub-atmospheric pipelines.)

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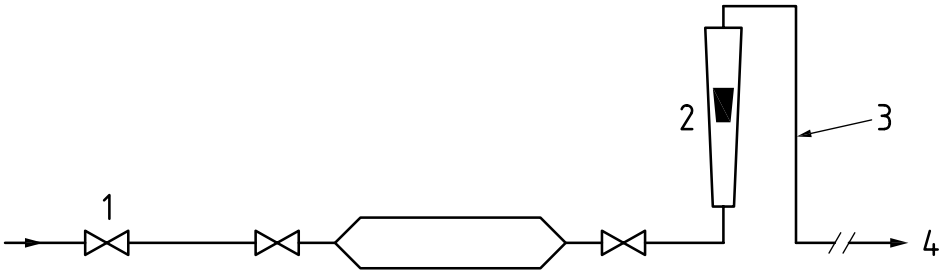
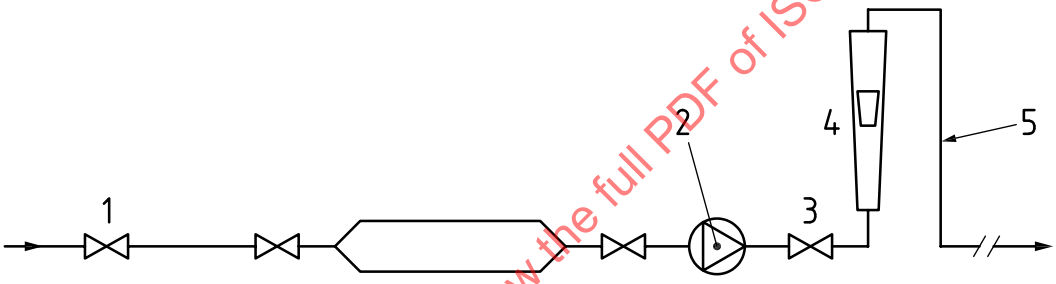


Key

1 sampling point
2 flowmeter
3 vent line
4 flare or vent

Figure B.2 — Sampling into glass cylinders



Key

1 sampling point
2 diaphragm pump (explosion-proof)
3 flowmeter valve
4 flowmeter
5 vent line

Figure B.3 — Sampling into glass cylinders from a sub-atmospheric pipeline

Measure the pressure at the sampling point. Make sure that the sample line overpressure does not exceed 0,2 MPa.

Connect the sample line to the sample cylinder.

Connect the inlet of the cylinder as close as possible to the sampling point using the sample line.

Connect the outlet of the sample cylinder to the inlet of the flowmeter.

Connect the outlet of the flowmeter to a vent or a flare pipe.

Open the two stopcocks of the sample cylinder in the order of the direction of the gas flow.

Adjust the flow through the sample cylinder by means of the flowmeter.

Vent gas.

Check the presence of liquid fall-out during venting.

Discard the sample in the event of considerable amounts of liquid occurring.

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Close the sample cylinder after 30 min of purging, closing the stopcocks in the order opposite to the direction of the gas flow so that the pressure builds up.

Disconnect the sample cylinder.

Secure the stopcocks with clamps against unintended opening and check for leaks.

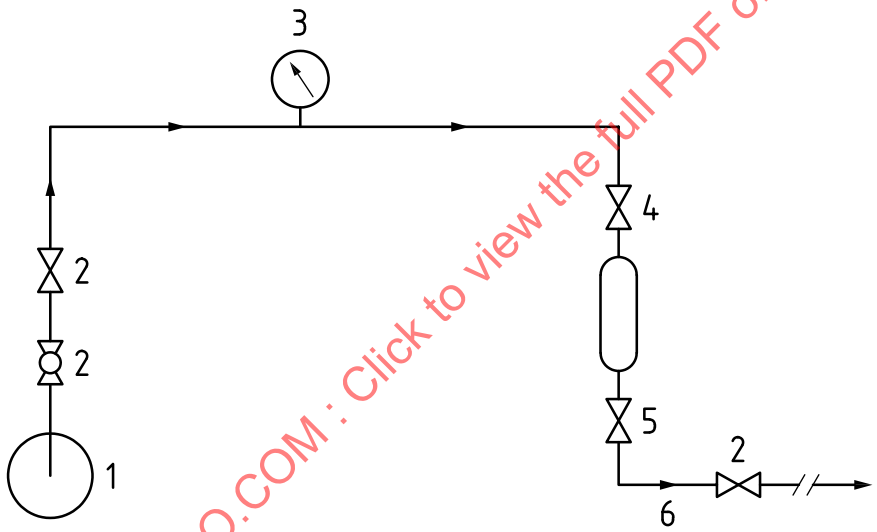
B.1.4 Preparation for transport

Use a suitable box f or transporting the sample cylinder.

Check whether grease, hydrocarbon condensate, dust or rust and/or water drops have been entrained in the gas flow.

B.2 Procedure for sampling by the fill-and-empty method

The equipment is arranged as shown in Figure B.4. The extension tube has a length of 0,6 m to 1,2 m. All materials, including the tubing, are of stainless steel. The extension tube can be coiled to allow the sampling apparatus to be more compact. This extension tube is needed to prevent heavy-hydrocarbon condensation in the sample container outlet valve.



Key

1 probe
2 valve
3 pressure gauge
4 inlet valve
5 outlet valve
6 extension tube

Figure B.4 — Fill-and-empty method

The procedure for sampling by this method is as follows:

Install the sample probe.

Connect up the sample line.

Open the valve at the sampling point and thoroughly blow out any accumulated material. Connect one end of the sample container through the sampling system to the gas source. Purge the line and container slowly with gas to displace the air.

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Close the extension line valve and allow the pressure to build up rapidly to the selected container pressure.

Close the inlet valve and slowly vent the container through the extension tube valve until it reaches atmospheric pressure.

Open the inlet valve.

Repeat the last two steps for a number of cycles (see Table B.1) to effectively purge the container of the original gas in the container.

Observe for traces of liquid at the discharge tube end.

After the last cycle, first close the extension tube valve and, after the pressure has built up to the selected container pressure, also close the sampling valve.

Record the container pressure

Record the source temperature.

Close the container inlet and outlet valves. Depressurize the sample line.

Remove the sample container.

Check for leaks by immersion of the valves in water, if possible, or use leak detector soap solution.

Plug the valves.

Table B.1 — Number of purge cycles

Final pressure in cylinder MPa	Number of purge cycles
0,1 to 0,2	13
0,2 to 0,4	08
0,4 to 0,6	06
0,6 to 1	05
1 to 3,5	04
≥3,5	03

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B.3 Procedure for sampling by the controlled-rate method

The following precautions are to be observed when sampling by this method:

a) The source pressure shall be sufficient to produce stable flow conditions in the flow tube. The pressure in the extension tube has to be 0,1 MPa or higher when venting to atmosphere.

b) The valves and piping in the sampling apparatus are sized large enough to allow sufficient flow upstream of the flow tube.

The sampling arrangement is shown in Figure B.5

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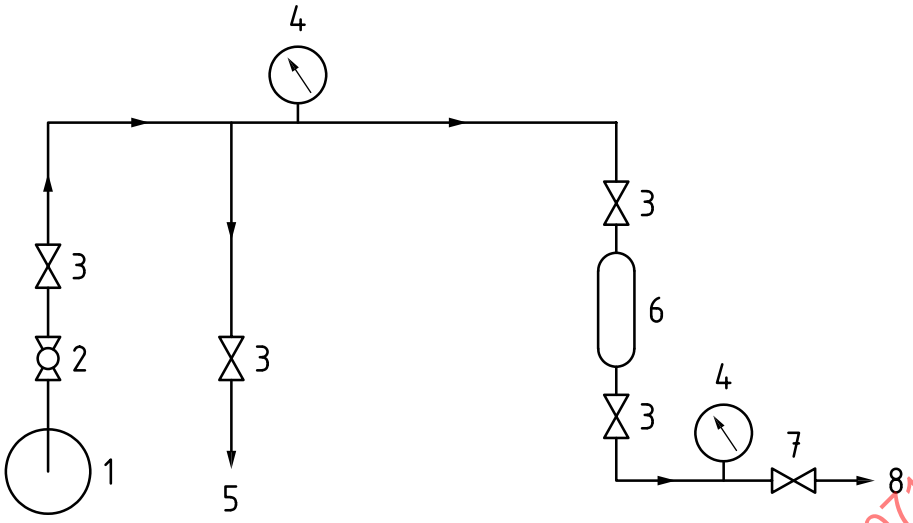

Key

1 probe
2 ball valve
3 valve
4 pressure gauge
5 vent
6 sample container
7 end valve
8 flow tube

Figure B.5 — Controlled-rate method

The procedure for sampling by this method is as follows:

Install a sampling probe and purge the probe with the natural gas.

Choose the most suitable sampling unit. This depends on the sampling pressure. In most cases, a set suited for 0,8 MPa to 3 MPa, or a set suited for 3 MPa to 7 MPa can be applied.

Now install the sample container.

Open the sample valve and purge the sample container. Close all the valves.

Open the ball valve and sample valve slowly.

Slowly open the vent valve a little.

Close the sampling valve and wait until the pressure in the sampling line is near atmospheric. Repeat this purging procedure three times.

Close the vent valve.

Open the inlet valve slowly and then bring the sampling container up to the prevailing pressure.

Open the container outlet valve. Open the end valve.

Purge for at least 1 min.

Record, during purging, the temperature of the natural gas and the inlet and outlet pressure of the gas stream through the container.

Close the end valve. Close the outlet valve. Close the inlet valve. Close the sample valve.

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Record the container pressure and the service temperature.

Open the vent valve and wait till the pressure falls to atmospheric.

Remove the sampling unit and probe and check the sample container for leaks by immersion of the valves in water, if possible, or by using leak detector solutions.

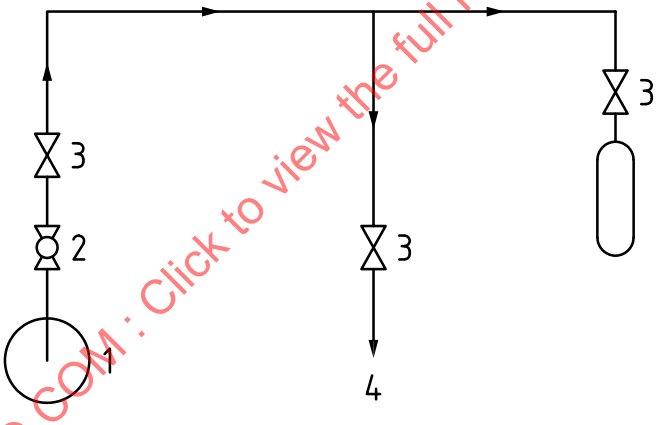
Plug the valves.

B.4 Procedure for sampling by the evacuated-cylinder method

The equipment arrangement is shown in Figure B.6 As an alternative to cylinder evacuation, the cylinder may be filled to a positive pressure with a gas which will not interfere with the analytical technique to be used

If the final pressure is below atmospheric pressure, the sample pressure is immediately increased to about 0,03 MPa gauge by pressurizing with a gas which will not interfere with the analysis. The pressures existing immediately before and after pressurization are recorded.

Suitable gases are hydrogen or helium, considering that they are not components of interest for the analyzer. The air content of the container is reduced to a low value either by purging with the pressurizing gas or by evacuating and filling with the pressurizing gas. The presence of the pressurizing gas will require some modification to the analytical method.



Key

1 probe
2 ball valve
3 valve
4 vent

Figure B.6 — Evacuated-cylinder method

The procedure for sampling by the evacuated-container method is as follows:

a) Cylinder preparation

Evacuate the sample container to a pressure of 100 Pa or less. (Use a cylinder that has been previously evacuated and tested to hold this vacuum.)

Check, before using the vacuum, with a vacuum gauge to be certain the valve has not leaked.

b) Sampling

Install the sampling probe.

Purge the probe with the pipeline gas.

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Install the sample container as shown in Figure B.6.

Slowly purge the sample line with gas to displace the air by partially opening the vent valve and the sample valve until gas is flowing slowly out of the vent valve.

Close the sample valve and allow the sample line to vent until atmospheric pressure is reached. Close the vent valve.

Open the sample valve fully.

Slowly open the container inlet valve, allowing the container pressure to increase to the source pressure

In some cases, condensation may be eliminated by sampling at a pressure less than the source pressure ("reduced pressure" method).

Close the container inlet valve and the sample valve.

c) Preparation for transport

Open the vent valve to release the pressure in the sample line. Remove the sample container.

Check for leaks by immersion of the cylinder inlet valve in water or, preferably, by using a leak detector.

Plug the valve.

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Annex C
(informative)

Gas sorption effect: adsorption/desorption

The processes of adsorption and desorption are of significant importance to the analysis of a number of constituents of interest that are found in natural gas. It is therefore of vital importance that these processes are well understood by persons constructing sampling systems. Adsorption is defined as the process whereby a substance (typically a gas or liquid) adheres to the surface of a solid (or less commonly a liquid). Broadly speaking, it encompasses the increase in concentration in a region where two phases are in mutual contact (i.e. the phase boundary) relative to the bulk phase.

There are two principal types of adsorption:

a) physisorption, which is defined as adsorption where the predominant forces involved are weak, intermolecular attractions that do not alter the chemical identity of the molecules themselves and

b) chemisorption, which is defined as adsorption entailing strong chemical attraction that does alter the chemical identity of the molecules.

This annex provides only the basic information on what should be considered so that significant errors or uncertainties in analytical results are not introduced from the construction of inappropriate sampling systems.

Further there is also a misconception for sampling systems that it is satisfactory to "condition" a surface by exposing it to a particular concentration of the adsorbate for a period of time. While this concept can work perfectly well for calibration or similar gases where the concentration of the adsorbate is intended to be "constant" it is not satisfactory for sampling systems where the whole purpose is looking for small changes in concentrations. One of the factors that determine the state of dynamic equilibrium between an adsorbent and an adsorbate is the concentration of the adsorbate in the gas mixture in contact with the adsorbent. Therefore if there is a change in the concentration of the adsorbate in the gas mixture then there is a time delay before a new equilibrium is reached through the process of either adsorption or desorption of the adsorbate. Consequently until the new dynamic equilibrium is reached there is the possibility of measuring a false concentration of the analyte.

The following text relates to the process of sorption as it relates to the surfaces of solids such as stainless steel and the reactive components as noted above.

While there is little quantitative data available about the strength of and amount of adsorption that occurs it is known that a dynamic equilibrium is reached. The dynamic equilibrium state is necessary throughout an entire sampling system and containment regime so that false measurements of the analyte are avoided. A dynamic equilibrium state is dependent upon the following:

— the material of the solid;

— the surface area of the solid in contact with the adsorbate;

— the temperature of the surface in contact with the adsorbate;

— the condition of the surface in contact with the adsorbate;

— the concentration of the adsorbate in the gas mixture;

— the pressure of the gas mixture.

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Annex D
(informative)

Cleaning of steel sampling cylinders

An example of a very thorough cleaning procedure is given below.

Vent off any residual sample gas. Evacuate or purge with nitrogen.

Fill the cylinder with a cleaning product. Shake the cylinder on a shaking machine for 2 h. Transfer the cleaning product to a suitable receptacle.

Fill again with fresh cleaning product and replace the cylinder on the shaking machine for 2 h.

Remove the cleaning product, drying with nitrogen ·or dry air.

Dry the cylinder further in a hot-air oven at 90 °C making sure that the valves, seats, seals temperature rating are compatible. If the cylinder is equipped with only one valve, evacuate the cylinder during the drying operation. If it is equipped with two valves, purge it with nitrogen during the drying. The drying operation takes approximately 12 h.

After cooling, fill the cylinder with nitrogen and empty it three times.

Afterwards, fill the cylinder with nitrogen to a pressure of 1 MPa.

Wait for 2 h and check by chromatography for the presence of cleaning product and other impurities.

Keep the corresponding chromatogram with the cylinder documents.

The amount of chromatographic checking may be reduced by using a statistical approach.

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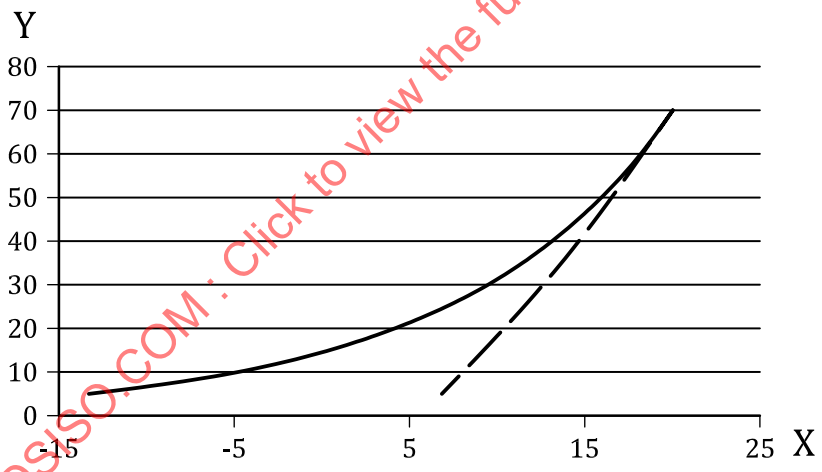
Annex E
(informative)

Joule-Thomson cooling and phase behaviour

The sampling of natural gas very frequently involves pressure reduction, from pipeline or plant pressure which can be up to 7 Mpa (70 bar) for transmission lines, or higher for process plant, to the pressure required for an analyser, which is commonly close to atmospheric pressure. When any gas expands, it cools due to a reduction in enthalpy. If the gas is a mixture containing condensable components, the drop in temperature can cause some of these components to form a separate liquid phase, thereby altering the composition of the gas phase and possibly blocking filters etc. A properly designed sampling system avoids such problems.

Natural gases show very non-ideal phase behaviour, referred to as retrograde. To illustrate this, first consider the behaviour of an air/water mixture. When saturated at 20 °C and 7 MPa (70 bar), the mixture contains 0,047 % of water. The dewline of this mixture is shown by the solid line in Figure E.1. Any pressure/temperature conditions to the right of this line represent single phase gas. The dewline itself is the locus of points at which liquid water first appears, and conditions to the left of the line represent two-phase mixtures, with the amount of liquid water increasing as one moves further to the left of the line.



Key

X	temperature (°C)
Y	pressure (bar = 0,1 MPa)
———	dewline
— —	J-T cooling

Figure E.1 — Phase behaviour of air/water mixture

Figure E.1 also shows the Joule-Thomson (J-T) cooling curve as a broken line. This represents the temperature change as the mixture is expanded from 70 bar to 5 bar, and shows a drop from 20 °C to 7 °C. All points on this line are to the right of the dewline, and so no separation of liquid water occurs. This corresponds closely to ideal gas behaviour and the pressure change for this mixture is problem-free.

Hydrocarbon mixtures behave in a more complex manner, as illustrated in Figure E.2. This shows the behaviour of a methane/n-nonane mixture, which is also saturated at 20 °C and 70 bar, and contains 0,065 % nonane. Two differences from Figure E.1 are evident. The J-T effect produces a significantly

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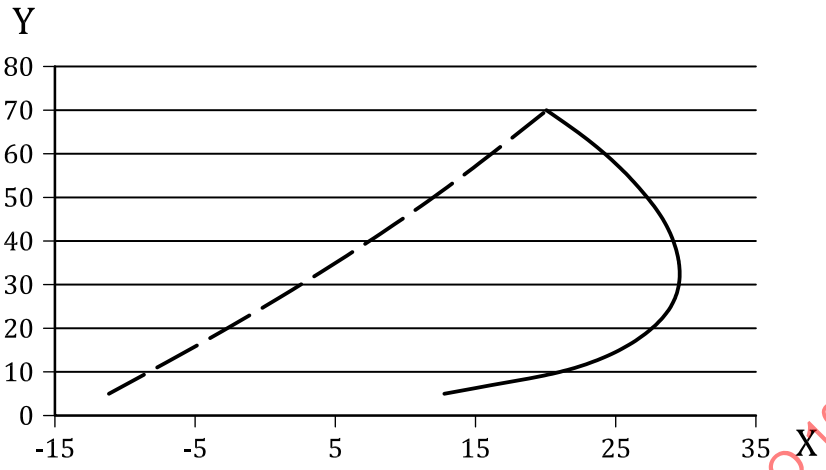
larger temperature drop, falling from 20 °C to –11 °C as opposed to 7 °C. This is due to the significantly higher compression factor, Z (in the equation PV = ZRT), for methane as opposed to air. At 20 °C and 70 bar, Z = 0,992 for air (close to ideal) but 0,882 for methane.



Key

X	temperature (°C)
Y	pressure (bar = 0,1 MPa))
———	dewline
— —	J-T cooling

Figure E.2 — Phase behaviour of methane/nonane mixture

The more spectacular difference is in the shape of the dewline. Instead of falling consistently as the pressure falls, the dewpoint temperature increases over the range 70 bar to 30 bar, and only starts to fall thereafter. This means that at all pressures below 70 bar a varying proportion of the nonane is present as liquid. This problem can be avoided by pre-heating the gas mixture before pressure reduction so that the J-T line stays to the right of the dewline in the single gas phase region. The alternative approach of heating the mixture after pressure reduction has the problem, particularly when sampling from a flowing system, that the phases may not recombine so as to represent the starting condition (Figure E.2).

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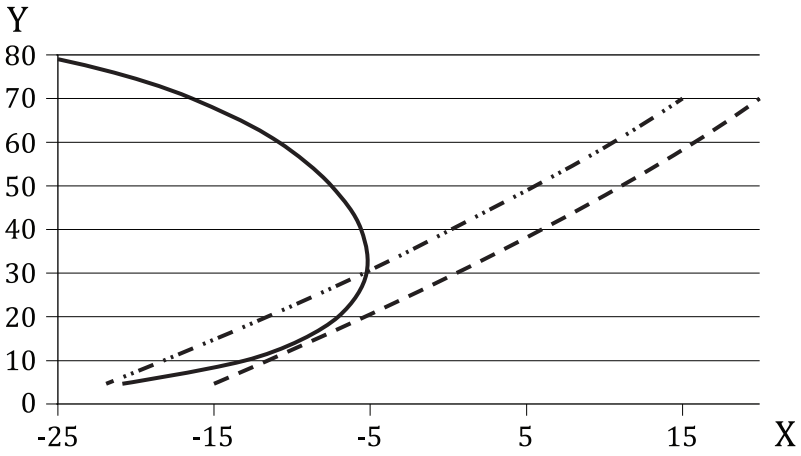

Key

X	temperature (°C)
Y	pressure (bar)
———	dewline
- - - -	J-T 20 deg
- ·· - ·· -	J-T 15 deg

Figure E.3 — Phase behaviour of real natural gas

Typical behaviour of a real natural gas is shown in Figure E.3. This is equilibrated at 80 bar and 26 °C. This degree of cooling is required to avoid subsequent retrograde condensation. The highest dewpoint temperature for this mixture is about −5 °C at 35 bar. The J-T curve showing the expansion cooling from 20 °C and 70 bar only just avoids intersecting with the dewline. If the gas is expanded from 15 °C and 70 bar, the J-T curve clearly intersects the two-phase region. Within the two-phase region, the amount of condensate increases as the J-T curve moves further to the left of the dewline, and the composition of the condensate varies with both temperature and pressure. Given the complexity and variability of the condensate, it is evident that subsequent heating of the two phases is very unlikely to produce a single phase which is representative of the initial composition.

The shape of the J-T curve does not vary much between different gas compositions. As a crude rule of thumb, it can be assumed that each pressure reduction of 2 bar causes a temperature drop of 1 °C. Both the shape and the position of the dewline vary significantly with composition, and are profoundly influenced by traces of higher molecular weight components. Detailed analytical measurement is necessary to allow the shape of the dewline to be calculated with sufficient confidence so that the amount of pre-heating that is necessary can be deduced.

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Annex F
(informative)

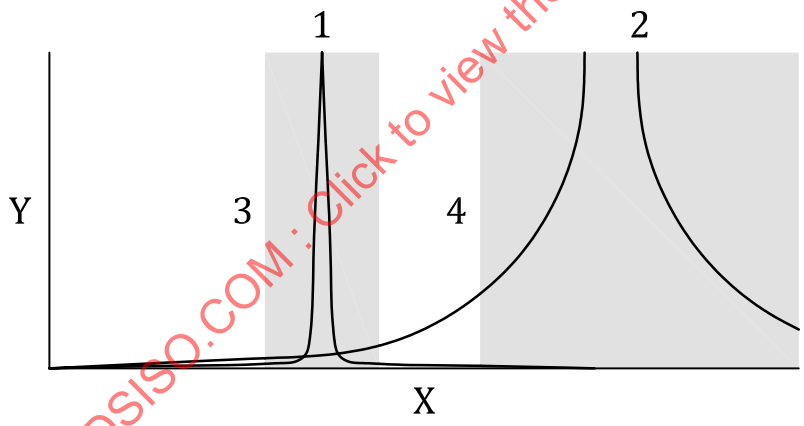
Vortex shedding and associated problems

ViV (Vortex Induced Vibration), occurs due to vortex formation and shedding when fluid passes a bluff body. The vortex shedding around a cylindrical body, such as a sample probe, occurs at the lateral surfaces of the probe shaft and around the tip (subject to tip profile).

— The vortex shedding is regular, meaning a net cyclic load is imparted onto the probe shaft which induces vibrations that correspond in direction to the net forces imparted by the vortex shedding (can be in-line with flow, lateral to flow and a combination of both "Figure F.1").

— The conditions that determine when and how severely the vortex shedding activates are: probe profile/geometry/length, process velocity/pressure/density/viscosity, as well as some macro conditions such as main pipe geometry, flow regime etc.

— ViV issues occur when induced vibrations reach certain critical ratios to the natural frequency of the sample probe, as you enter a resonant mode with associated spike in amplitude of vibration and associated forces imparted on the probe body. Research and testing have shown that the ratio of the induced vibration frequency and natural frequency of the probe can be as low as 0,4; much lower than ~1:1 ratio predicted in some previous standards.



Key

X fluid velocity
Y vibration amplitude
1 in-line resonance
2 transverse resonance
3 $f_s = 0{,}4\, f_n{}^c$ (where f_s is Strouhal" frequency and $f_n{}^c$ is natural frequency)
4 $f_s = 0{,}8\, f_n{}^c$

Figure F.1 — Vortex induced vibration (source ASME PTC 19.3TW:2016[7])

In accordance with the vortex shedding theory, the oscillating mechanisms and frequency can be described by a non-dimensional number, the Strouhal number (*St*), as follows (see Reference [8]);

$$f = StU/D \tag{F.1}$$

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where

D is the diameter of the cylinder, in meters;

U is the flow velocity approaching the cylinder, in meters per second;

f is the frequency of vortex shedding, in hertz.

Moreover, the vortex pattern varies over a range of major Reynolds number regimes across a smooth cylinder, as shown in Figure F.2. The vortex shedding is a function of Reynolds number (Re), which is:

$$Re = U\,D/\nu \tag{F.2}$$

Where ν is the kinematic viscosity of the fluid.

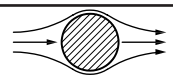
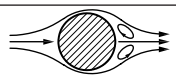
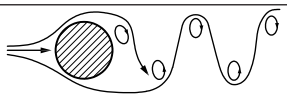
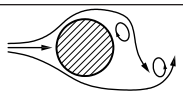
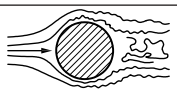
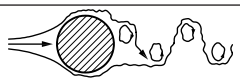
	$Re < 5$ Regime of unseparated flow
	5 to 15 < Re < 40 A fixed pair of Föppl vortices in wake
	40 ≤ Re < 90 and 90 ≤ Re < 150 Two regimes in which vortex street is laminar
	150 < Re < 300 Transition range to turbulence in vortex 300 < Re < 3x10^5 Vortex street is fully turbulent
	3 × 10^5 < Re < 3,5 × 10^6 Laminar boundary layer has undergone turbulent transition and wake is narrower and disorganized
	3,5 × 10^6 < Re Re-establishment of turbulent vortex street

Figure F.2 — Vortex patterns created from different Reynolds Number regimes[8]

Because there is a strong correlation between St and Re as shown in Figure F.3[8], the characteristic of the oscillatory wake can be predicted by inferring the oscillatory frequency from a series of wind tunnel tests.

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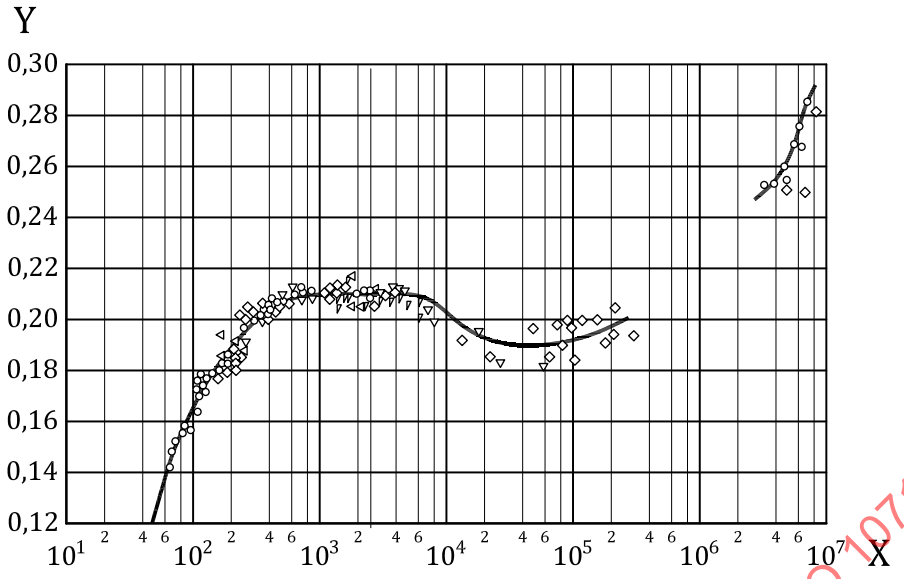

Key

X	Reynolds number
Y	Strouhal number
○	0,023 5 cm of diameter
◇	0,061 3 cm of diameter
▽	0,098 9 cm of diameter
◁	0,318 0 cm of diameter
▱	0,635 0 cm of diameter

Figure F.3 — Relationship between *St* and *Re* for cylinders with diameters between (2 to 25) cm

Despite an abundance of generic vortex shedding theory, a simple, comprehensive set of calculations applicable to sample probes is not readily available in an international standard. However, a number of references exist from international bodies such as EEMUA, IPA and IEC. A fairly comprehensive set of calculations for thermowells, of similar shape and form as sample probes, is found in ASME PTC 19.3 TW 2016. Computational fluid dynamics can be utilized to assess suitability of a design in given conditions.

Changing the geometry/length of the sample probe design can achieve the objective of staying outside of a potentially dangerous operating envelope with regards ViV. However, making a probe too short risks losing the representativeness of the sample. Making the probe shaft thicker *increases* the magnitude of the vortex shedding and associated loads, which can be translated to the main pipeline connection if the probe shaft itself is overly stiff.

Furthermore the probe needs to be designed to reduce vortex shedding and/or to be resistant to the vibrational effects of vortex shedding.

Care should be taken to consider ALL conditions a sample probe will be exposed to during its service life, including, but not limited to: full system blow down, cycling of conditions during start-up/commissioning/de-commissioning, production ramp-up and others. This is important as the design of sample probe should be resilient to vortex induced vibration-causing regimes in all operational modes.

Proprietary sample probe technology has been developed to disrupt the formation of vortices at the lateral surfaces of the probe shaft across a range of conditions, using helical strakes. However, users should request evidence from manufacturers of such equipment that the design has been scientifically proven to effectively counteract the vortex shedding effect and is suitable for the given process condition (range) expected.

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