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Natural gas — Calibration of chilled mirror type instruments for hydrocarbon dewpoint (liquid formation)

*Gaz naturel — Étalonnage des instruments du type à miroir refroidi pour
points de rosée hydrocarbures (formation de liquide)*

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Foreword

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

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

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

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.

ISO/TR 12148 was prepared by Technical Committee ISO/TC 193, *Natural gas*, Subcommittee SC 1, *Analysis of natural gas*.

Introduction

Under certain conditions, higher hydrocarbons present in natural gas or similar gases can condense and the hydrocarbon liquids formed can cause difficulties in the operation of gas transport and distribution systems.

Hydrocarbon dew-point measurements, by condensation on a mirror, can give an indication of the conditions under which condensation starts. Theoretically, the hydrocarbon dew point is the temperature at which the first small droplets of liquid are formed at a fixed pressure. In practice, all dew-point-measurement methods are based on the observation of the formation of a film of hydrocarbon liquids on the surface of an illuminated, cooled mirror. The observation can be done visually (manual mirror) or by an electronic sensor (automatic chilled mirror). The cooling can be achieved in two ways: expansion of natural gas, compressed air or carbon dioxide or by applying a Peltier-cooling device. Either manual or automatic chilled mirrors can be applied to measure the hydrocarbon dew point of natural gas.

It is not possible to calibrate commercially available hydrocarbon dew point analysers in a traceable way, because no hydrocarbon dew-point reference material or reference instrument is available. Because of differences in working principles, analysers from different manufacturers can give different values for the hydrocarbon dew point for a given gas. In practice, the dew point of an automatic dew point monitor is often "tuned" to match the value measured by a manual chilled mirror, or "tuned" to the value calculated from a known gas composition using a thermodynamic model.

Modern automatic hydrocarbon-dew-point chilled-mirror instruments have the possibility of adjusting the value of the presented hydrocarbon dew point. Sometimes this adjustment is carried out by changing a physical setting in the instrument itself; in other cases the setting can be changed by entering a new value into the instrument's controller. The availability of such an adjustable parameter is a prerequisite for using the calibration procedure described in this Technical Report.

NOTE 1 Changing the setting of such a parameter can result in a major change in the presented hydrocarbon-dew-point value. For example, a study carried out under the auspices of the National Physical Laboratory^[2] shows from real measurements that the hydrocarbon dew point for a natural gas measured at the same pressure varies between $-6,28\text{ }^{\circ}\text{C}$ and $8,54\text{ }^{\circ}\text{C}$ [Gas B, with pressure equal to 3,5 MPa (35 bars), detector sensitivity varying between 110 mV and 275 mV].

In 2007, the results of a comprehensive study^[2] of the measurement of the hydrocarbon dew point of real and synthetic natural gases was published. In this study, six analytical methods were examined: one automatic chilled-mirror instrument, one manual chilled-mirror instrument, two laboratory gas chromatographs and two process gas chromatographs. In this study, it is concluded that the role of accurate synthetic gas mixtures in the calibration of chilled-mirror instruments is limited. Furthermore, it is stated that a standard composed of *n*-butane in nitrogen is indeed a straightforward and inexpensive way to calibrate a chilled-mirror instrument, yet forms an atypical, rapidly condensing hydrocarbon film. Therefore, such a calibration gas has limited use in calibrating a hydrocarbon-dew-point instrument.

NOTE 2 Several studies showed the importance of not only the component concentration in a calibration mixture but also knowledge of the nature of the components used. For example, a GERG study^[4] shows that adding aromatic and/or cyclic hydrocarbons has a significant influence on the hydrocarbon dew point.

Based on the working principle of chilled-mirror devices, there are five major sources that can be responsible for significant systematic errors in the measured hydrocarbon dew point and for which no adjustment can be made because no proper calibration method exists. These five sources are

- a) the often significant amount of liquid that it is necessary to form before the instrument is able to detect the dew point temperature;
- b) the cooling rate, which is often too fast to ensure that the temperature measured by a temperature sensor somewhere in the mirror equals the temperature of the mirror surface and the temperature of the gas in the measuring cell;

- c) the way the gas flow passes through the measurement cell during the actual measuring phase (continuous versus stop-flow principle);
- d) the measurement of the mirror temperature, which doesn't take place at the mirror surface itself but near the mirror surface;
- e) the hydrocarbon dew point that, when measured at a certain pressure setting, doesn't necessarily corresponds to the cricondentherm pressure valid for the actual gas composition.

In this Technical Report, a calibration procedure is presented which allows the adjustment and even the calibration of a hydrocarbon-dew-point chilled-mirror analyser against the indirect automatic weighing method according to ISO 6570. By using this procedure, the measured hydrocarbon dew point corresponds unambiguously to a given value for the potential hydrocarbon liquid content (PHLC) at this measured dew-point temperature. In this way, a traceable and much more objective measurement of the hydrocarbon dew point is possible. By doing an on-site comparison/calibration against the indirect automatic weighing method, it is even possible to correct for the gas-dependent performance of the hydrocarbon-dew-point analyser, which exists to some extent for different natural gases.

Measurements carried out according to ISO 6570 consist of cooling down a well defined gas flow to a specified and accurately measured temperature. The gas has enough time to form liquid and to establish a gas-liquid equilibrium at a certain pressure and temperature. This process is similar to the process that occurs in practice, when in a pipeline the pressure and/or temperature are reduced, the complete gas flow is cooled down and depending on the gas quality in the worst case can result in hydrocarbon liquid drop out. By calibrating a dew point analyser against ISO 6570, it is made sure that a dew point is obtained, which is related to the process which actually occurs in the pipeline upon pressure reduction, although the measurement technique is quite different to the process in the pipeline.

According to ISO 6570, the detection limit of the automatic weighing method is 5 mg/Nm^3 . Theoretically it can be argued that the temperature corresponding to a potential hydrocarbon liquid content of 5 mg/m^3 is not a correct estimate for the hydrocarbon-dew-point temperature. However, taking into account the measuring capabilities of the existing hydrocarbon-dew-point measurement devices, this effect can be neglected.

Based on the geometry of the measurement cell of a chilled mirror instrument, it is estimated by Cowper^[3] that it is necessary to condense approximately 70 mg/Nm^3 onto a mirror surface to register a hydrocarbon-dew-point temperature. Depending on the gas composition, this effect results in a bias of up to $-1,5 \text{ }^\circ\text{C}$ in the measured hydrocarbon dew point value.

NOTE 3 EASEE-gas (European Association for the Streamlining of Energy Exchange) recently agreed upon harmonized values of the hydrocarbon dew point throughout Europe (Common Business Practice 2005-001/01)^[1]. The required harmonized measuring method, which it is still necessary to identify, can clearly benefit from the proposed traceable calibration procedure presented in this Technical Report.

Natural gas — Calibration of chilled mirror type instruments for hydrocarbon dewpoint (liquid formation)

WARNING — The use of this Technical Report can involve hazardous materials, operations and equipment. This Technical Report does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this Technical Report to establish appropriate safety and health practices and to determine the applicability or regulatory limitations prior to use.

1 Scope

This Technical Report describes the principles of, and general requirements for, the traceable calibration of automatic hydrocarbon-dew-point chilled-mirror instruments using the indirect automatic weighing method (method B) described in ISO 6570:2001 to determine the potential hydrocarbon liquid content of natural gas, or similar gas. The calibration procedure is intended for use by chilled-mirror instruments in downstream applications transferring processed natural gas.

If the gas composition is constant, the manual weighing method (method A) described in ISO 6570:2001 is also applicable.

NOTE 1 Whether or not a gas composition is constant is difficult to establish. A process gas chromatograph (GC) measuring calorific values within 0,1 % is absolutely no guarantee for a constant hydrocarbon liquid drop-out content. Information up to C₁₂ is required to verify that the gas composition is constant.

NOTE 2 The application of this calibration procedure in the upstream area is not excluded *a priori*, however, currently there is no experience using this procedure in an upstream environment.

The usability of data on the potential hydrocarbon liquid content of natural gas for verification, adjustment or calibration of hydrocarbon-dew-point chilled-mirror instruments is based on the condensation behaviour of natural gases. Information on the condensation behaviour of natural gases and the various measuring techniques to determine properties, like hydrocarbon dew point and potential hydrocarbon liquid content, related to the condensation behaviour of natural gases are given in Annex A.

NOTE 3 Unless otherwise specified, gas volumes are in cubic metres at 273,15 K and 101,325 kPa.

2 Normative references

The following referenced documents are indispensable for the application 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 6570:2001, *Natural gas — Determination of potential hydrocarbon liquid content — Gravimetric methods*

3 Terms and definitions

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

3.1

potential hydrocarbon liquid content

PHLC

property of natural gas defined as the amount of the condensable liquid (in milligrams) at the pressure, p , and temperature, T , of the measurement per unit volume of gas at normal conditions, that is, at a temperature of 0 °C and a pressure of 101,325 kPa, by passing a representative sample of the gas through an apparatus where it is first brought to the pressure, p , and then cooled to the temperature, T

NOTE It is necessary to take care that only gas, not a two-phase mixture, has been withdrawn from the pipeline.

3.2

hydrocarbon dew point

HCDP

property of natural gas defined as the temperature, T_{HCDP} , at which an automatic chilled-mirror instrument detects the first presence of hydrocarbon liquid drop out at the pressure, p

NOTE In chemical thermodynamics, the “true” hydrocarbon dew point is the temperature (at a stated pressure) at which the enthalpy of the gas and liquid phases is identical. Since measurement of the dew point involves reduction of the system temperature, this equates to the temperature at which the first appearance of the liquid phase occurs. At this point, the quantity of liquid phase is infinitesimally small. Since no instrument is able to detect this infinitesimally small amount, the aforementioned definition of the hydrocarbon dew point is adopted in this Technical Report. However, depending on the gas composition and the sensitivity of the detection system of the hydrocarbon-dew-point chilled-mirror device, the measured hydrocarbon dew point can be considerably lower than the “true” hydrocarbon dew point.

3.3

PHLC reference value

parameter in the calibration procedure chosen by the user

NOTE At the PHLC reference value, the hydrocarbon dew point temperature and the temperature of the ISO 6570 measurement are equal.

4 Symbols

p pressure at which PHLC and hydrocarbon dew point measurement are carried out

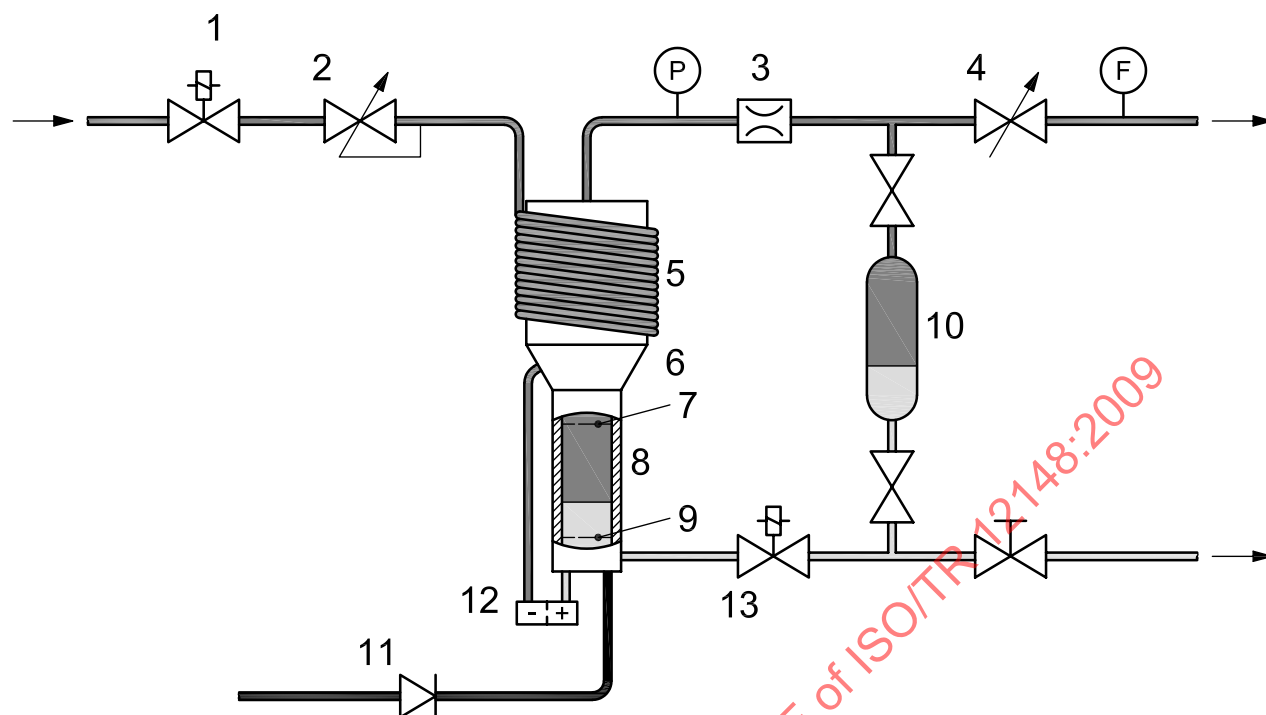
T temperature at which the PHLC measurement is carried out

5 Performance characteristics of automatic weighing method in accordance with ISO 6570:2001

WARNING — The instrumentation used for this method shall comply with local legal and safety regulations, especially with the local regulations for application of the instrumentation in hazardous areas.

5.1 Working principle

The principle of the indirect automatic weighing method (method B) is described in ISO 6570:2001. An example of an implementation of this method is shown in Figure 1. ISO 6570 states that the quantity of hydrocarbon liquids that can be formed at a certain pressure and temperature is determined by passing a representative sample of the gas through the apparatus where it is first brought to the required pressure and then cooled to the required temperature. The liquids formed during cooling are separated from the gas flow and collected by means of a cyclone separator into a measuring tube. The measuring tube is automatically drained when it is totally filled up with liquid. The liquid from the measuring tube is collected in a hydrocarbon-liquids drum. In the indirect automatic weighing method, the determination of the amount of hydrocarbon liquids formed is derived from the differential pressure measured along the measuring tube.



- Natural gas
- Condensate
- Calibration liquid

Key

- 1 relieve valve
- 2 pressure controller
- 3 restriction
- 4 flow controller
- 5 heat exchanger
- 6 gas/liquid separator
- 7 maximum level
- 8 measuring tube
- 9 minimum level
- 10 condensate drum
- 11 injection point for calibration liquid
- 12 differential pressure sensor
- 13 drain valve

Figure 1 — Implementation of indirect automatic weighing method according to ISO 6570 (GACOM[®] of N.V. Nederlandse Gasunie)¹⁾

1) GACOM is an example of a suitable product available commercially. This information is given for the convenience of users of ISO 12148 and does not constitute an endorsement by ISO of this product.

5.2 Functional requirements

5.2.1 General

To ensure the correct functioning of the indirect automatic weighing method, it is necessary to fulfil the requirements given in 5.2.2 to 5.2.8.

5.2.2 Gas sampling

The sampling point at the pipeline should be situated as described in ISO 10715 [6]. The sampling system should be such that a continuous gas withdrawal at a pressure and temperature considerably above the cricondentherm is possible. No liquids or aerosols should be withdrawn together with the gas sample. The sample line should be heat traced up to at least 35 °C. The sampling system should be clean to prevent or at least to minimize the adsorption of higher hydrocarbons.

NOTE (Excessive) adsorption of higher hydrocarbons in the sampling system results in a systematic error in the measured hydrocarbon dew point value.

5.2.3 Calibration of the differential pressure sensor

The indirect automatic weighing method requires calibration of the differential pressure sensor. The differential pressure transmitter is calibrated by introducing known amounts of a calibration liquid, such as *n*-decane, into the measuring tube at the temperature and pressure at which the PHLC measurement will be performed. Such calibration shall be carried out at least at the start of a new measurement or calibration series and after (large) adjustments of the measuring pressure, *p*, or measuring temperature, *T*.

NOTE Frequent calibration of the differential pressure sensor is required to exclude the possible interference of the static pressure and/or temperature on the raw output of the sensor. The measured differential pressures are small and, therefore, any small interferences can considerably disturb the measurement results.

5.2.4 Pressure controller

In ISO 6570, the pressure controller is allowed to introduce a maximum variation of 10 kPa in the gas/liquid cyclone separator. For this particular application, it is advised to use a pressure regulator that introduces variations in the pressure of less than 10 kPa. Either the pressure controller should be electrically heated or the sample line and controller should be heat traced up to at least 40 °C.

NOTE Commercially available, high-quality pressure controllers introduce variations in the pressure of less than 10 kPa only for gas flows of approximately 1 Nm³/hr.

5.2.5 Temperature control

In accordance with ISO 6570, the cooling bath shall be capable of maintaining the temperature of the cooling liquid at any point of the bath with a variation of less than 0,25 K.

NOTE For temperatures below –15 °C, the specification in this subclause is difficult to maintain without taking special precautions. Especially with high environmental temperatures, such as occur during summertime, regular thermostats are not able to meet the specified criterion.

5.2.6 Measurement of pressure and temperature

The pressure and temperature sensors shall be calibrated at least once a year.

5.2.7 Flow measurement

The device for measuring the gas flow through the instrument, which is normally operated with a gas flow of 1 Nm³/hr, shall be checked at regular intervals against a calibrated gas meter. Such verification shall be carried out at least at the start of a new measurement or calibration series.

The automatic measuring device is operating with a gas flow of $1\text{ Nm}^3/\text{hr}$ at a fixed pressure, most often between 2,7 MPa and 3,0 MPa [(27 and 30 bar) (at the cricondentherm)], and a temperature (e.g. $-3\text{ }^\circ\text{C}$) at which the hydrocarbon liquid content (often 5 mg/Nm^3) is specified in some contracts.

5.2.8 PHLC measurement period

Due to the nature of the PHLC measurement, measurement values become available at a certain time interval. Since a short cycle period results in PHLC measurements with a high uncertainty, it is advised to use a cycle time of at least 30 min.

NOTE For a proper calibration of a hydrocarbon-dew-point chilled-mirror instrument, it is advisable to compare data for a period of at least 24 hours or more.

5.3 Measurement uncertainty

The uncertainty in the PHLC value depends on the pressure and temperature set points and the condensation behaviour of the gas being measured. PHLC-values above 5 mg/m^3 shall be detected unambiguously. At low PHLC values (less than 30 mg/Nm^3), the uncertainty shall be equal or less than 5 mg/Nm^3 .

As an example, the results of two individual, indirect automatic weighing instruments are presented in Figure 2. Both devices measure the potential hydrocarbon liquid content of the same gas and are operating at the same pressure and temperature. These results give an indication of the achievable reproducibility, which is within $\pm 5\text{ mg/Nm}^3$. During other experiments with a stable, type H-gas (high calorific value), an even smaller random error (2σ) of $\pm 2\text{ mg/Nm}^3$ was found.

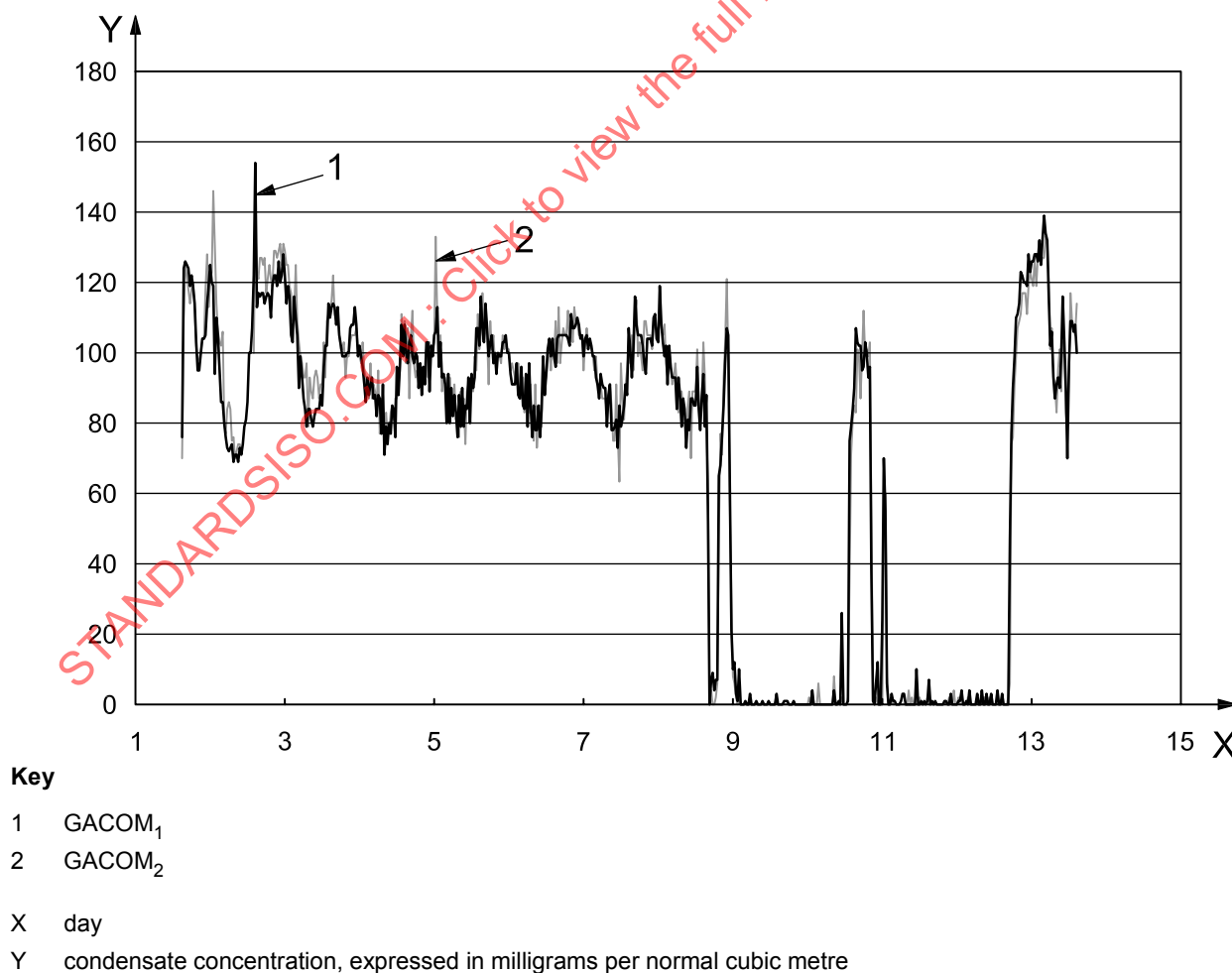


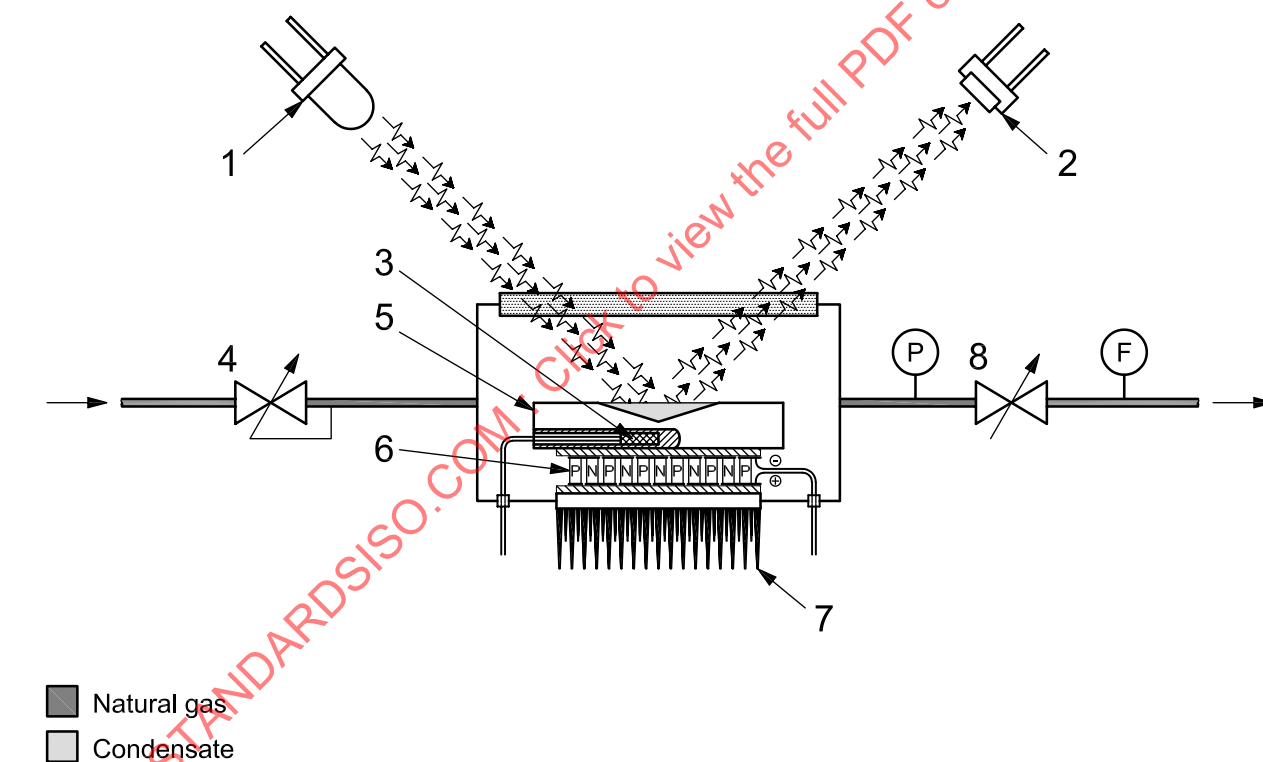
Figure 2 — PHLC measurements using 2 GACOM[®] units for an L-type gas at 2 700 kPa and $-3\text{ }^\circ\text{C}$

6 Performance requirements for a chilled-mirror-type instrument for hydrocarbon-dew-point determination

WARNING — The instrumentation used for this method shall comply with local legal and safety regulations, especially with the local regulations for application of the instrumentation in hazardous areas.

6.1 Working principle

Although there are some significant differences in the implementation, the measuring principle of a hydrocarbon-dew-point chilled-mirror instrument is identical for all instruments. After pressure reduction, the gas is passed through a measuring cell. During normal operation, the measuring pressure is chosen to be close to the value at which the dew-point temperature is at its maximum (the cricondetherm). The measuring cell has an observation window at one side and a mirror surface at the other side. This mirror is mounted on a cooling body and the cooling down can be accomplished in a controlled way. The cooling body itself is cooled either electrically (Peltier element) or by the expansion of carbon dioxide or another gas. The temperature of the mirror is measured continuously. The sample gas may be flowed through the cell continuously, or, having flowed sufficiently to purge the cell, mirror and pipe work, blocked in without flow while the cooling cycle of the mirror starts. The mirror surface is observed by reflected light, either visually by an operator in the manual version or by photocell in the automated instrument. An example of an implementation of an automatic dew-point chilled-mirror instrument is shown in Figure 3.



Key

- | | | | |
|---|---------------------|---|-----------------|
| 1 | light source | 5 | mirror |
| 2 | light detector | 6 | Peltier element |
| 3 | temperature sensor | 7 | heat sink |
| 4 | pressure controller | 8 | flow controller |

Figure 3 — Implementation of an automatic chilled-mirror device for hydrocarbon-dew-point determination

A dew point analyser does not determine the theoretical dew point temperature of a natural gas, but it measures the temperature at which a certain amount of liquid is condensed on the mirror so that a significant and reproducible change in light scattering is observed, either by a skilled person or by a light-detecting sensor. From calculations, it can be shown that the hydrocarbon liquid drop out that is required to get a reproducible dew-point observation often corresponds with 20 mg/Nm³ to 70 mg/Nm³ hydrocarbon liquid drop out. In fact, the dew-point meter can be considered as a potential hydrocarbon-liquid-content meter, and the measured dew point temperature is the equilibrium temperature, for example at 30 mg/Nm³ hydrocarbon liquid drop out.

Therefore, it is necessary to realize beforehand what an automatic dew point monitor is actually determining: certainly not the true thermodynamic dew point, but a temperature corresponding to a predetermined threshold value of the detector signal. This threshold value is determined by doing a "calibration" against a manual mirror or a dew-point calculation, often by using a multi-component gas mixture.

As stated before, existing dew-point analysers measure the "dew point" temperature at hydrocarbon liquid drop out values varying between 20 mg/Nm³ to 70 mg/Nm³. A reduction of this amount results in measured values closer to the "true" hydrocarbon dew point. Ideally, the dew-point analyser should determine a dew-point temperature corresponding to approximately 5 mg/Nm³ hydrocarbon liquid drop out, this being the value that can be determined accurately by ISO 6570 equipment. Then, the pipeline operator or end user can be certain that no significant amounts of liquid are formed upon pressure reduction. Depending on the gas composition, the difference in temperature corresponding to, respectively, 30 mg/Nm³ and < 5 mg/Nm³ can be less than 0,5 °C; however, it also can be more than 3 °C. Therefore, it is better to adjust the threshold level against traceable hydrocarbon liquid drop out measurements than by the methods used nowadays.

The cooling rate of the mirror of a dew-point analyser appears as another important parameter to verify for a proper dew-point measurement. Measurement of the dew point occurs in a small cell with the bottom surface containing the mirror assembly. Only this mirror assembly is cooled, resulting in temperature gradients in the measurement cell and in the gas inside the cell. Theoretically, the cooling rate of the mirror surface should be sufficiently slow that the gas temperature is always in equilibrium with the mirror temperature and that there is enough time for the hydrocarbon liquids to drop out on the mirror surface. In practice, the cooling rate is often much more rapid. A high cooling rate results in a lag in the decrease in gas temperature and the hydrocarbon liquids drop-out onto the mirror. Also, the temperature sensor, which is mounted somewhere inside the mirror, records a temperature lower than the actual surface temperature of the mirror. Both effects result in temperature readings lower than the real dew-point temperature.

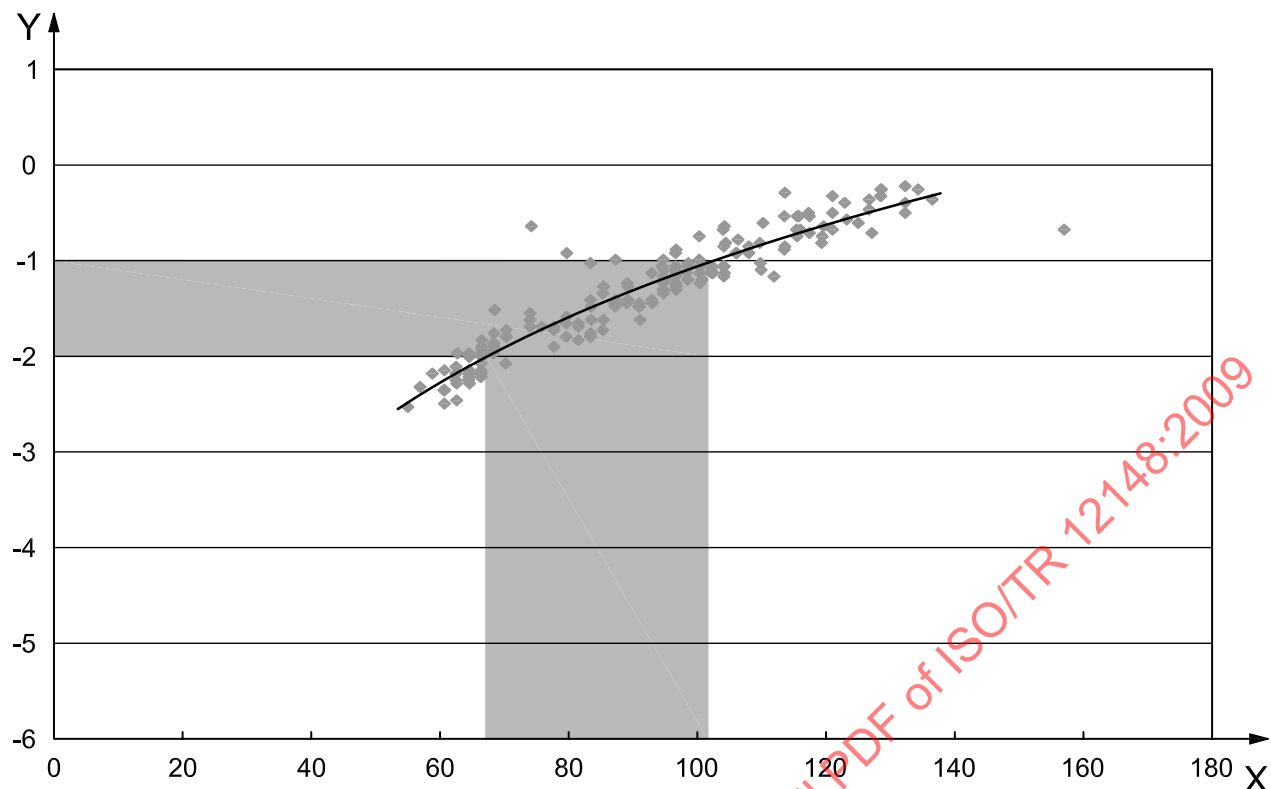
For those analysers that operate with a continuous gas flow during the complete measurement cycle, the flow through the measurement cell is an important parameter. The continuous flow of warm gas through the measurement cell influences the temperature of the gas in the vicinity of the mirror and, therefore, influences the measured dew point. In general, the dew point decreases when the gas is allowed to flow through the measurement cell during the cooling down of the mirror.

Some general requirements for dew point analysers are

- digital outputs of date/time, dew-point temperature and pressure;
- the possibility of changing the detection point criteria;
- storage of the changes in the measurement method, so that after a power shut-down, the proper method is still available.

6.2 Precision

In order to obtain a proper calibration of the dew-point analyser by applying hydrocarbon liquid drop out measurements, the repeatability of the hydrocarbon analyser should be within 1 °C (2 σ value). The reproducibility can be determined at a constant gas composition, or during a period of time when hydrocarbon liquid drop out measurements give nearly constant values. If the gas quality is constantly changing, a plot of hydrocarbon liquid drop out versus dew point also gives a good indication of the reproducibility of the dew-point analyser; see Figure 4 [5].

**Key**

- X condensate concentration, expressed in milligrams per normal cubic metre
 Y dew point, expressed in degrees Celsius

Figure 4 — Relation between hydrocarbon dew point and hydrocarbon liquid drop out, showing the variation in dew point at fixed PHLC values: $2\sigma_{\text{HCDP}} \approx 0,3 \text{ }^{\circ}\text{C}$

7 Requirements/Points of interest to carry out a calibration

7.1 Process gas

For the purpose of this Technical Report, process gas is free of condensable substances, like glycol, water, compressor oil.

NOTE It is necessary to prevent the occurrence of mist flow in the sampling system.

During the calibration, there should be no very large variation in gas quality (e.g. from Wobbe Index 45 MJ/Nm^3 to Wobbe Index 55 MJ/Nm^3). Normal variations in gas quality are no problem and even calibrations at gathering pipelines from offshore fields should give no problems. Normally occurring dew-point variations of $10 \text{ }^{\circ}\text{C}$ to $15 \text{ }^{\circ}\text{C}$ should also give no problems during calibration.

7.2 Sampling system

The sample system should be designed as described in ISO 10715 (see also 5.2.2). The following points shall be considered.

- Changes in the gas composition caused by the sampling system shall be avoided. Therefore, the gas sampling system shall be designed with a minimum number of components and the analyser shall be positioned near the sampling point.

- If the presence of traces of liquid in the natural gas cannot be excluded completely, a sampling probe with a sintered stainless steel particulate filter is advised.
- If liquid is present in the natural gas, appropriate filtering at the sampling probe itself or immediately downstream of the probe (e.g. with a membrane filter) is advised to prevent any intrusion of traces of liquids and to maintain the integrity of the sampling system and the analyser. A check shall be made that the filter does not cause changes in gas composition that result in deviations in the measured hydrocarbon dew point.

NOTE Entrained liquids in the form of mist or small droplets present in the gas stream are sometimes encountered directly downstream of a gas-conditioning plant. Under these circumstances, it can be necessary to use a sampling probe with a membrane filter to safeguard the sampling system from being flooded with liquids. However, it is essential to check the sampling system for undesired changes in the gas composition, as this can occur using a membrane filter.

By applying a by-pass flow (fast loop), changes in the gas composition due to interaction with the filter material shall be minimized.

- The sampling line from probe to the analyser cabinet shall be heat traced to prevent any condensation in the sampling line.

The body of the pressure regulator shall be heated up to prevent condensation of liquids from the natural gas upon pressure reduction. A temperature of approximately 60 °C generally fulfils this requirement. Variation in pressure shall be within $\pm 0,01$ MPa (0,1 bar).

- The temperature of the analyser cabinet should be maintained at a level such that no condensation occurs in the sampling lines in the cabinet. A temperature of 30 °C generally fulfils this requirement.

It is advised to mount a sun screen above the analyser in case it is expected that exposure to direct sunshine can cause excessively high temperatures in the analyser cabinet.

7.3 Selection of the PHLC reference value

The PHLC reference value is an important parameter on which it is necessary to agree before the actual calibration of an automatic hydrocarbon-dew-point chilled-mirror instrument can be carried out. As stated in the introduction of this Technical Report, the detection limit of the automatic weighing method stated in ISO 6570 is 5 mg/Nm³, whereas the amount of liquid which it is necessary to condense onto a mirror surface to register a hydrocarbon dew point is approximately 5 mg/Nm³ to 70 mg/Nm³.

Depending on the sensitivity of the chilled-mirror detector system, it is possible to carry out a calibration at an arbitrary level starting at 5 mg/Nm³ and upwards. Since the setting of the PHLC reference value determines the measuring behaviour of the hydrocarbon-dew-point chilled-mirror instrument, it is important to specify the PHLC reference value for use during the calibration procedure and to clearly report the PHLC reference value on the calibration report.

Although it is possible to choose an arbitrary level for the PHLC reference value, it is advised to limit the choice for the PHLC reference value to the following three levels:

- 5 mg/Nm³, being the most sensitive value, corresponding to the highest value for the hydrocarbon dew point; using this PHLC reference value, the measured values of the calibrated chilled-mirror instrument fit perfectly to the regular contract specifications based on potential hydrocarbon liquid content.
- 70 mg/Nm³, being the least sensitive value, corresponding to the lowest value for the hydrocarbon dew point; using this PHLC reference value, the measured values of the calibrated chilled-mirror instrument correspond to the measuring behaviour of a manual chilled mirror.
- 30 mg/Nm³, being a value intermediate between the aforementioned minimum and maximum values; in general, it has been shown that automatic chilled-mirror instruments are capable of operating reliably and with low measurement uncertainty at a level of 30 mg/Nm³ to 40 mg/Nm³.

7.4 Compositional range of gases covered by the calibration procedure

The thermal and mass transfer processes that take place during the cooling of the mirror surface are of a complex nature and not completely understood. Current experience with the proposed calibration procedure indicates that the results of a calibration are valid for a wider range of natural gas compositions insofar as the gases show similar condensation behaviour. In the study carried out under the auspices of the National Physical Laboratory [2], synthetic mixtures of natural gas are categorized into three classes:

- “mid” condensation rate: selected to be representative of the gases found in most UK gas fields; for these gases, a decrease in temperature of 1 °C results in an increase in the hydrocarbon liquids formation ranging from approximately 100 mg/Nm³ to 300 mg/Nm³;
- “high” condensation rate for these gases, a decrease in temperature of 1 °C results in an increase in the hydrocarbon liquids formation ranging from 300 mg/Nm³ and onwards. In the aforementioned study, an example of a gas is presented in which a decrease of only 0,25 °C results in an increase in the hydrocarbon liquid drop out of 250 mg/Nm³;
- “low” condensation rate; for these gases, a decrease in temperature of 1 °C results in an increase in the hydrocarbon liquids formation of only less than 100 mg/Nm³. In the aforementioned study, an example of a gas is presented in which a decrease of 5 °C results in an increase in the hydrocarbon liquid drop out of only 25 mg/Nm³;

There are indications that the aforementioned classification can be appropriate to classify the natural gases with respect to calibration of hydrocarbon-dew-point chilled-mirror instruments. However, it is necessary to gain more experience to confirm this assumption.

CAUTION — No general advice can be given on the validity of the calibration for a given compositional range of gases. Therefore, it is necessary initially to carry out multiple calibrations with varying gas compositions to assess the validity of a calibration.

7.5 Calibration interval

It is difficult to make a general remark on the validity of a calibration in time. The validity depends heavily on various circumstances, such as the following:

- stability of the mechanical and electrical boards in the chilled mirror instrument itself;
- presence of impurities, like solids, glycol etc, in the gas to be sampled and the effectiveness of the sampling system to cope with such impurities;
- significant changes in the gas composition resulting in a shift in the condensation behaviour of the gas sampled as can occur in gathering pipeline systems in which gas wells are taken out or in production.

Existing experience show that for a relatively clean gas with a stable gas composition, a calibration can be valid for a period of at least a year.

CAUTION — No general advice can be given on the calibration interval. Therefore, it is necessary initially to carry out calibrations at regular intervals to assess the validity of a calibration in time.

8 Execution of calibration procedure

8.1 General

During the calibration of a dew-point analyser in accordance with ISO 6570, it is preferable that both measurement systems be connected to the same sampling probe.

It is preferable that the calibration be performed with the natural gas that is monitored later on by the hydrocarbon-dew-point analyser.

The complete sampling and conditioning system of the dew-point analyser shall be used during the calibration.

At start-up, the time-stamps of both analyser systems should be checked and, when necessary, synchronized.

Calibrating a hydrocarbon-dew-point analyser requires that the following steps be carried out subsequently.

- a) Monitor the hydrocarbon dew point for 3 days to 5 days with the factory settings.
- b) Monitor the minimum and maximum dew-point temperatures during this period of time.
- c) The hydrocarbon liquid drop out measurements in accordance with ISO 6570 shall be done at a cooling bath temperature, which is at least 2 °C above the lowest dew-point temperature recorded and when the difference between the minimum and maximum temperature is quite large, the cooling bath temperature shall be about 3 °C to 4 °C lower than the maximum dew point previously recorded, in order to prevent the formation of excessive amounts of hydrocarbon liquids.
- d) Record the hydrocarbon dew point and the hydrocarbon liquid drop out simultaneously for 3 days to 5 days.
- e) Observe whether hydrocarbon liquid drop out values in the range between 0 mg/Nm³ and 100 mg/Nm³ are obtained.

If the values are between 0 mg/Nm³ and 10 mg/Nm³, then the cooling bath temperature should be set 2 °C to 3 °C lower. If the values are, for example, between 40 mg/Nm³ and 160 mg/Nm³, the cooling bath temperature should be set 2 °C to 3 °C higher. Subsequently, it is necessary to repeat step d).

- f) Make a graph of liquid drop-out (X-axis) versus dew point. Say the cooling bath temperature is T °C. The graph shows that liquid drop-out values of 5 mg/Nm³ to 10 mg/Nm³ correspond with dew point temperatures in the vicinity of T °C.
- g) Often, the dew points corresponding with 5 mg/Nm³ to 10 mg/Nm³ liquid drop out are 1 °C to 4 °C lower than the cooling bath temperature, T , using the factory settings for the dew-point analyser. There are two methods to improve the agreement between dew point and liquid drop-out: method A (see 8.2) and method B (see 8.3).
- h) Modify the dew-point reading of the hydrocarbon-dew-point analyser using method A or method B and then carry out measurements for another 3 days to 5 days to check whether the relationship between the dew point and the liquid drop-out has improved.

8.2 Method A — Change in trip point value

Method A is carried out as follows (see example in Clause C.3).

- a) Determine the shift in dew point, so that the new dew point corresponds with a liquid dropout of 5 mg/Nm³ to 10 mg/Nm³ at a cooling bath temperature that equals the new dew point value.
- b) Use a cooling curve (graph of detector signal versus mirror temperature) to determine the required detector signal for the improved dew-point detection (the new trip point value).
- c) Store this new threshold value in the dew-point analyser and check whether the analyser gives higher dew point readings.
- d) Record dew point and PHLC values for some days and examine the improved relationship.

8.3 Method B — Direct change of dew point value

Method B is carried out as follows (see example in Clause C.4).

- a) Determine the shift in dew point, ΔT_{dp} , so that the new dew point corresponds to a liquid dropout of 5 mg/Nm³ to 10 mg/Nm³ at a cooling bath temperature that equals the new dew-point value.
- b) Recalculate the hydrocarbon dew point: $T_{newHCDP} = T_{oldHCDP} + \Delta T_{dp}$.
- c) Record dew point and PHLC-values for some days and examine the improved relationship.

8.4 Which method should be used?

Method A should, in general, be applied. It is the correct method from a physical point of view. The application of a lower threshold value means that less liquid is formed on the mirror.

If a shift in hydrocarbon dew point of more than 3 °C is required with respect to the factory settings, method B is advised. A large shift in dew-point results requires quite a low threshold value. In Annex C, it is shown that, for lower threshold levels, the variation in dew point increases rapidly up to several degrees Celsius, making method A less suitable.

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Annex A (informative)

Condensation behaviour of natural gas

A.1 Phase envelope of natural gas

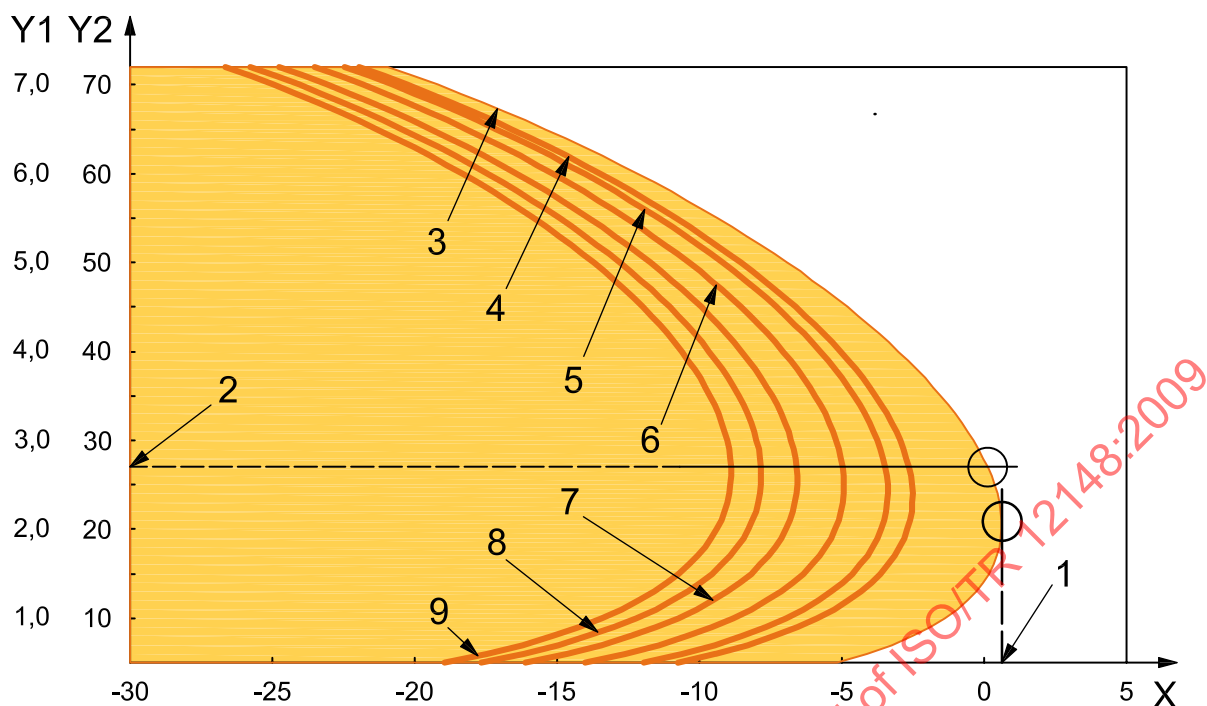
During storage, transportation and processing, natural gas can form small amounts of liquid when the pressure decreases. This phenomenon is called retrograde condensation and can sometimes lead to problems in the operating facilities. The temperature and pressure at which the condensation occurs follows a curve that forms a so-called phase envelope (the outermost right curve or dew point curve in Figure A.1). Within the phase envelope, hydrocarbon liquids are formed to the left of the dew point curve. The further left in the phase envelope, the more hydrocarbon liquids are formed. The maximum temperature for any pressure at which hydrocarbon liquids can be formed is called the cricondentherm.

Gas transport companies want to prevent formation of hydrocarbon liquids in their gas grid. Particularly at points where the pressure falls below 4 MPa (40 bar), for example, as a result of a pressure drop during transportation or at control stations and city gate stations at which pressure reduction takes place, there is a potential risk for liquid formation. Also, end-users receiving high-pressure gas for their gas turbines are concerned about hydrocarbon liquid drop out during pressure reduction, because severe damage to hot-gas-path components can occur if hydrocarbon liquids enter a gas turbine. Measuring techniques that are able to detect the ability of the gas to form liquid at excessively high temperatures are either based on the detection of an amount of liquid at a specified temperature and pressure (gravimetric methods) or are based on the detection of the first droplets of liquid on a mirror at a certain temperature (hydrocarbon-dew-point meters).

A.2 Measurement techniques

Theoretically, the hydrocarbon dew point is the temperature at which the first small droplets of liquid are formed at a fixed pressure. In practice, all dew-point-measurement methods are based on the observation of the formation of a film of hydrocarbon liquids on the surface of an illuminated, cooled mirror. The observation can be done visually (manual mirror) or by an electronic sensor (automatic chilled mirror). The cooling can be achieved in two ways: expansion of natural gas, compressed air or carbon dioxide or by applying a Peltier cooling device. Either manual or automatic chilled mirrors can be applied to measure the hydrocarbon dew point of natural gas. An alternative method for the determination of the hydrocarbon dew point is the calculation from a detailed gas composition. This method is based on several assumptions (highest hydrocarbon number required, grouping of hydrocarbon isomers, optimal equation of state) and often the outcome is adjusted against a manual or automatic chilled mirror. The advantages and disadvantages of the applied methods are summarized in Table A.1. It is not possible to calibrate commercially available hydrocarbon-dew-point analysers in a traceable way, because no hydrocarbon-dew-point reference material or reference instrument is available. Because of differences in working principles, analysers from different manufacturers can give different values for the hydrocarbon dew point for a given gas. In practice, the dew point of an automatic dew-point monitor is often "tuned" to match the value measured by a manual chilled mirror, or "tuned" to the value calculated from the known gas composition using a thermodynamic model. Moreover, as a result of the working principle of the instruments, there are two major sources that can be responsible for significant systematic errors in the measured hydrocarbon dew point, and for which it is not possible to adjust because no proper calibration method exists. These two sources are

- a) the often significant amount of liquid that it is necessary to form before the instrument is able to detect the dew point temperature;
- b) the cooling rate, which is often too fast to ensure that the temperature measured by a temperature sensor somewhere in the mirror equals the temperature of the mirror surface and the temperature of the gas in the measuring cell.



Key

X temperature, expressed in degrees Celsius

Y1 pressure, expressed in megapascals

Y2 pressure, expressed in bars

1 cricondentherm

2 pressure measurement

3 curve for gas containing 0 mg/Nm³

4 curve for gas containing 5 mg/Nm³

5 curve for gas containing 10 mg/Nm³

6 curve for gas containing 25 mg/Nm³

7 curve for gas containing 50 mg/Nm³

8 curve for gas containing 75 mg/Nm³

9 curve for gas containing 100 mg/Nm³

Figure A.1 — Example of phase envelopes for natural gas at various concentrations of hydrocarbon liquids

Table A.1 — Advantages and disadvantages of the different measuring methods

Method	Advantages	Drawbacks
Manual weighing method (method A) in accordance with ISO 6570:2001	Traceable method Accurate results	Time consuming Requires stable gas composition PHLC value only at a single combination of pressure and temperature, not necessarily the conditions at the cricondentherm
Indirect automatic weighing method (method B) in accordance with ISO 6570:2001	On-line method Calibration possible Traceable method	Expensive measurement PHLC value only at a single combination of pressure and temperature, not necessarily the conditions at the cricondentherm
Manual chilled mirror	Ease of operation Low capital costs Portability	Requires a skilled operator Off-line method Difficult to achieve the necessary low cooling rate to obtain a correct measurement value Dew point only at a single pressure not necessarily the pressure at the cricondentherm No traceable calibration possible and, therefore, the possibility of introducing systematic errors
Automatic chilled mirror	On-line method Commonly encountered in daily field operations	Dew point only at a single pressure not necessarily the pressure at the cricondentherm No traceable calibration possible and, therefore, the possibility of introducing systematic errors
Calculation from a detailed gas analysis and an equation of state	Dew-point calculations over the full range of pressures Calculation of the PHLC values over the full range of pressures and temperatures	Frequent calibration of the gas chromatographic equipment Skilled operators High capital costs Sensitive to minor contaminants in the gas Interoperability is difficult to achieve due to different types of GC columns, analysing methods, calibration gases applied, different choices in equations of state, the method used to assign thermodynamic properties to gas analysis data, etc.

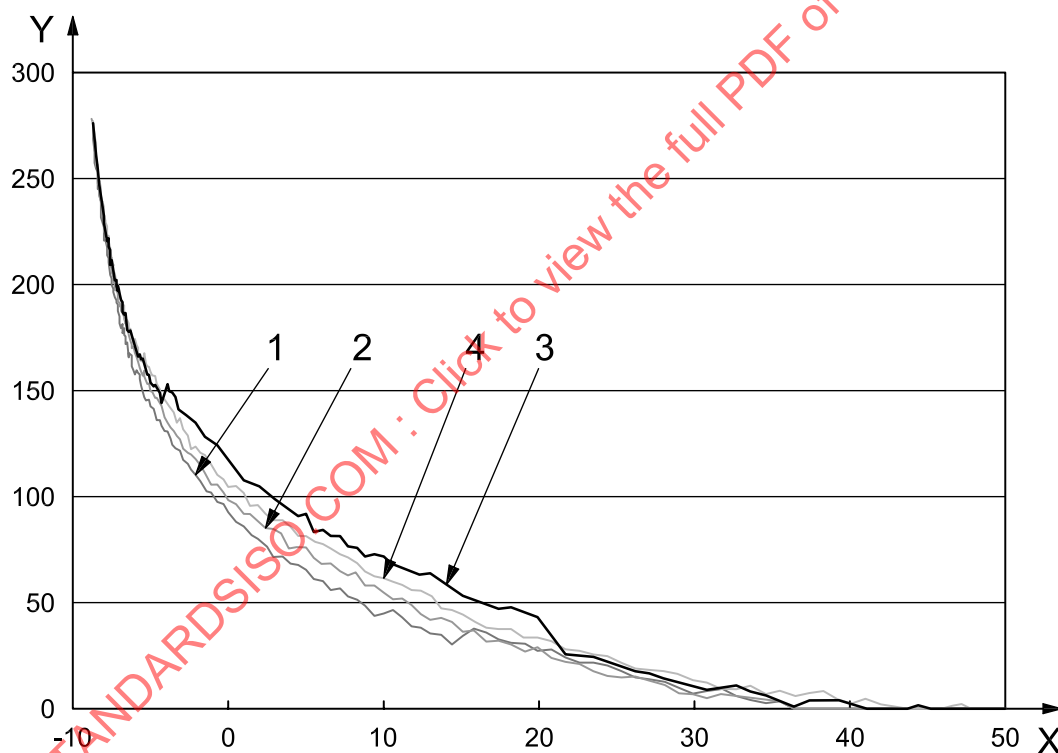
Annex B (informative)

Example of a hydrocarbon-dew-point analysis

B.1 Measurement principle

In Figure B.1 is shown the increase in detector signal that is due to an increase of condensation of higher hydrocarbons on the mirror surface, whilst the mirror is being cooled down. At the start of a measurement, the mirror temperature is 50 °C. At a specified detector signal (often called threshold value or trip-point value), the analyser outputs the corresponding mirror temperature as the hydrocarbon-dew-point temperature.

In Figure B.1 are shown four consecutive measurements. All four measurements give the same hydrocarbon dew point of –8,7 °C. Two features show up in Figure B.1. The first feature is that large variations in mirror temperature occur for a given detector signal below 150 mV. So, if the trip-point value is below 200 mV, the variation in dew point increases rapidly. The second feature is that above 175 mV, all curves run parallel.



Key

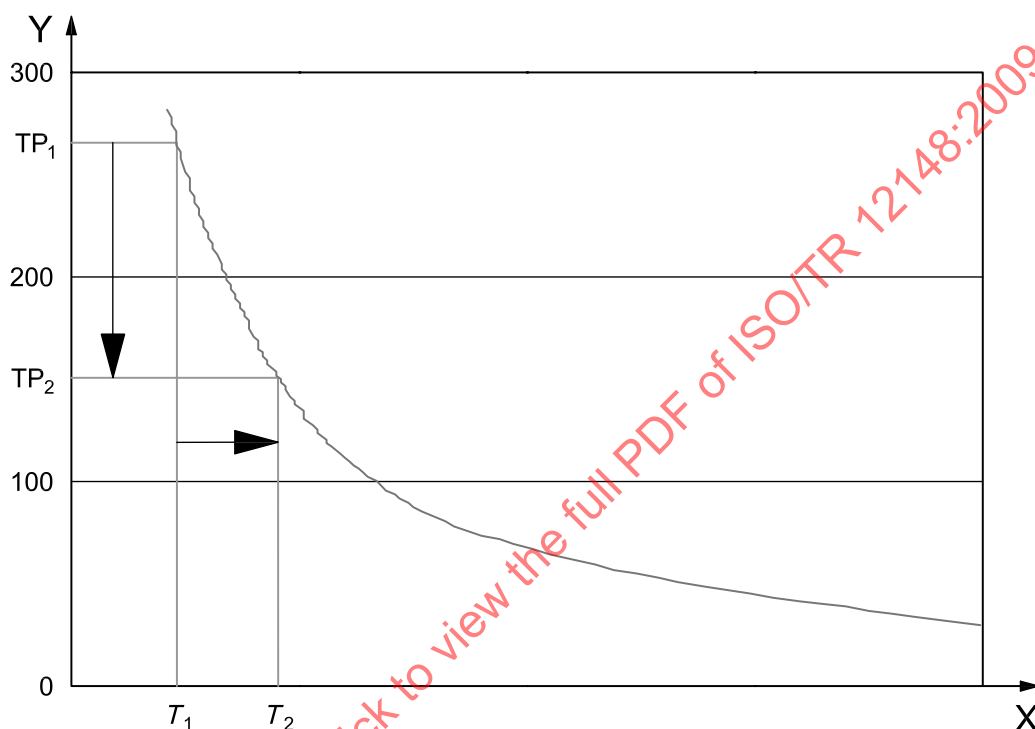
- 1 measurement cycle 1
- 2 measurement cycle 2
- 3 measurement cycle 3
- 4 measurement cycle 4

X mirror temperature, expressed in degrees Celsius
Y detector signal, expressed in millivolts

Figure B.1 — Increase in detector signal due to condensation on cooling the mirror

B.2 Dew point calibration in accordance with method A

Often the hydrocarbon dew point recorded by an automatic hydrocarbon-dew-point analyser is too low, because quite some liquid formation occurs at the factory trip-point setting. Higher dew points can be obtained by lowering the threshold value of the detector signal. This is shown graphically in Figure B.2. Upon lowering the trip point from TP_1 to TP_2 , the recorded hydrocarbon dew point temperature changes from T_1 up to T_2 . When the required increase in hydrocarbon dew point has been determined by using a plot of dew point versus PHLC-values, then the decrease in trip point can be obtained quite easily from a graph such as that presented in Figure B.2.



Key

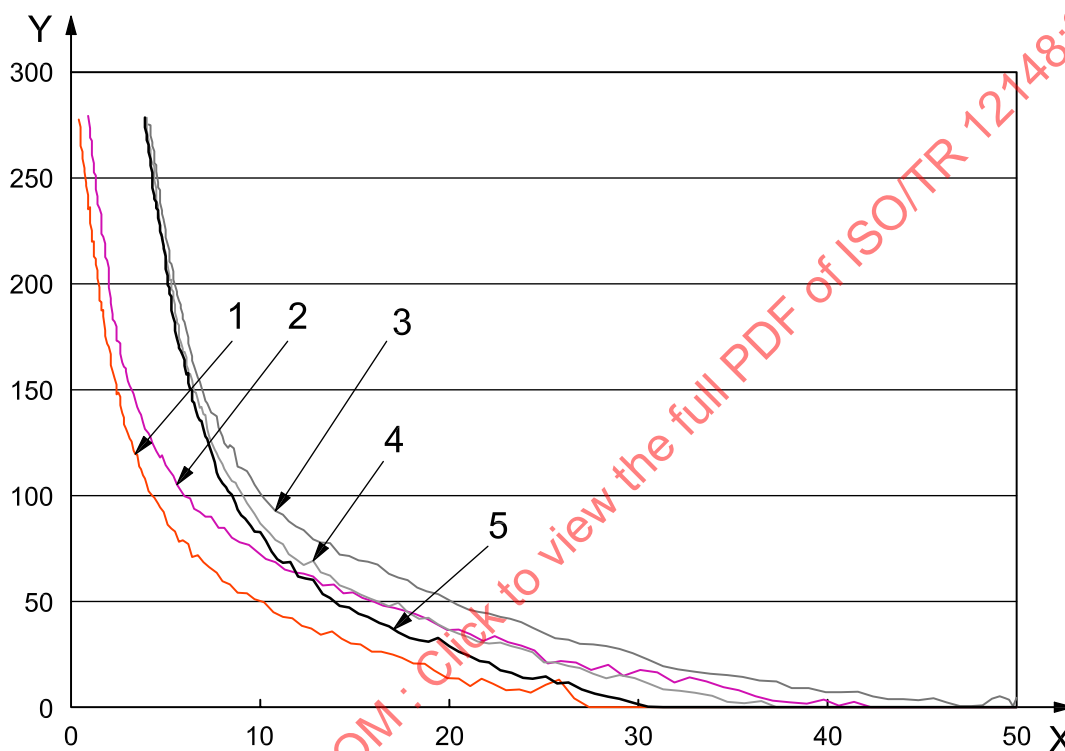
- X mirror temperature, expressed in degrees Celsius
- Y detector signal, expressed in millivolts

Figure B.2 — Graphical representation of how the dew point can be increased by lowering the trip point value.

B.3 Dew point calibration according to method B

It was already shown that the random error in dew point increases upon lowering the threshold value. For some gases, the dew-point temperature requires an increase of 3 °C to 4 °C in order to get a good relationship between the dew point and the hydrocarbon liquid drop out. For a gas having cooling curves such as those presented in Figure B.1, this means that it is necessary for the trip point to decrease to about 125 mV, a value at which quite large variations in dew point occur.

Figure B.3 shows that the cooling curves have approximately the same slope above a detector signal of 150 mV. An upward shift in the dew point of 3,5 °C appears to correspond with a cooling curve that shows a parallel shift to the right of 3,5 °C. This means that as long as the cooling curve maintains the same slope, it is allowed just to add 3,5 °C to the measured dew point in order to obtain the correct dew point.



Key

- 1 Day A – Measurement cycle 1
 - 2 Day A – Measurement cycle 2
 - 3 Day B – Measurement cycle 1
 - 4 Day B – Measurement cycle 2
 - 5 Day B – Measurement cycle 3
- X mirror temperature, expressed in degrees Celsius
Y detector signal, expressed in millivolts

Figure B.3 — Cooling curves obtained at different days at the same sample point

Annex C (informative)

Examples of a calibration

C.1 Set-up

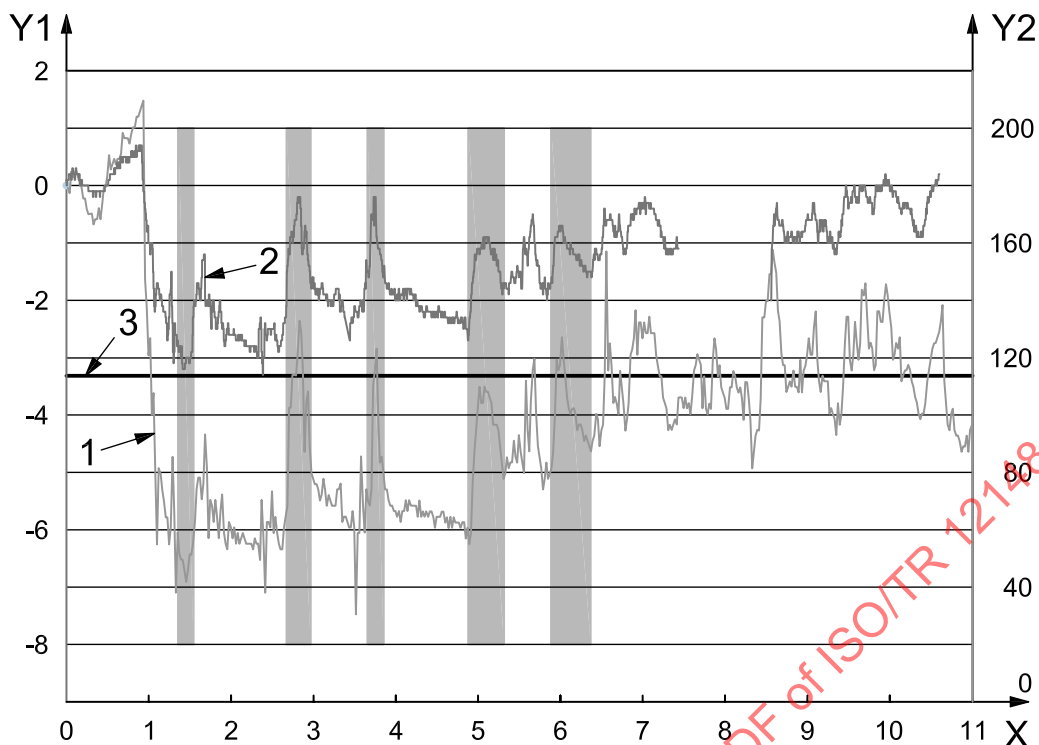
In the past, Gasunie Engineering & Technology carried out tests with different hydrocarbon dew-point analysers and compared the outcome with hydrocarbon liquid drop out measurements. The agreement between hydrocarbon dew point and hydrocarbon liquid drop out was still not satisfactory.

Michell Instrument Ltd. offered a possibility to test their newly developed Condumax II²⁾ hydrocarbon dew point analyser. The Condumax II was installed in a GACOM unit (a mobile unit for automatic measurements of PHLC values) of Gas Transport Services. The GACOM is continuously connected to a high-pressure gas-sampling probe, which takes sample gas from the middle of the pipeline, thus avoiding interference by liquids adsorbed or running along the pipe wall. Gas at line pressure 5 MPa to 7 MPa (50 bar to 70 bar) flows through a traced, stainless-steel, < 10 m tube to the GACOM unit. In the GACOM unit itself, the tubing is traced as well. Before the gas enters the Condumax II, it passes a coalescing filter and a traced pressure regulator, set at a fixed pressure between 2,7 MPa and 3 MPa (27 bar and 30 bar). The gas flow through the Condumax II is adjusted with a needle valve to approximately 30 l(normal)/hr.

C.2 Measurements with L-gas

The first results obtained with L-gas (low calorific value) are shown in Figure C.1.

2) Condumax II is an example of a suitable product available commercially. This information is given for the convenience of users of ISO 12148 and does not constitute an endorsement by ISO of this product.



Key

X day

Y1 dew point, expressed in degrees Celsius

Y2 condensate concentration, milligrams per normal cubic metre

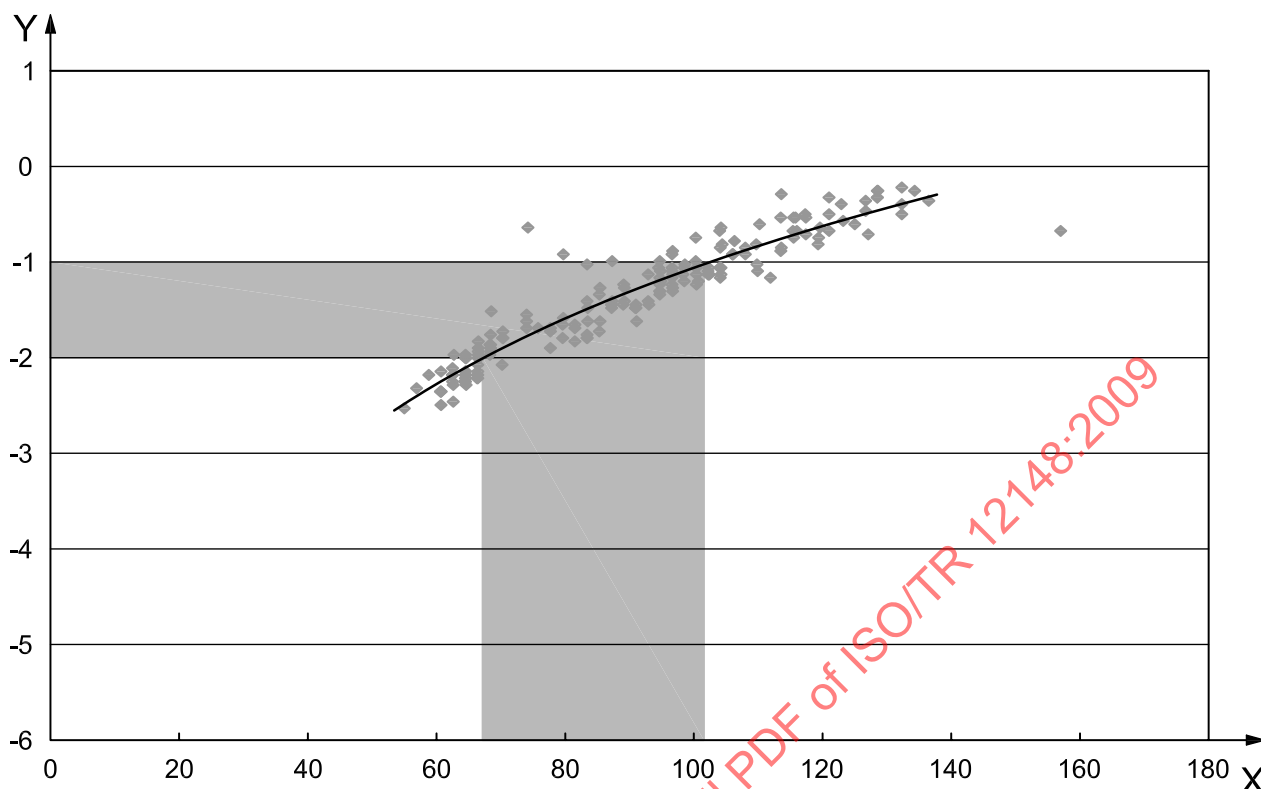
1 curve of the condensate concentration

2 curve of the dew point

3 temperature of PHLC measurement

Figure C.1 — Dew point and PHLC measurements for L-gas — Gacom at 2,7 MPa (27 bar) and -3°C and Condumax II at 2,7 MPa (27 bar)

The GACOM was operated at 2,7 MPa (27 bar) and a temperature of -3°C . The PHLC value, that is the amount of hydrocarbon liquids formed at these conditions, varied between 40 mg/Nm^3 and 200 mg/Nm^3 . The Condumax II was operated at exactly the same pressure and with the standard factory settings. The measured hydrocarbon dew point varied between -3°C and 0°C . There appears to be a good relationship between dew point and PHLC value, an increase in dew point coincides with an increase in PHLC value and vice versa. It is also evident that small changes in dew point correspond to relatively large changes in PHLC value. This is shown more clearly in Figure C.2.

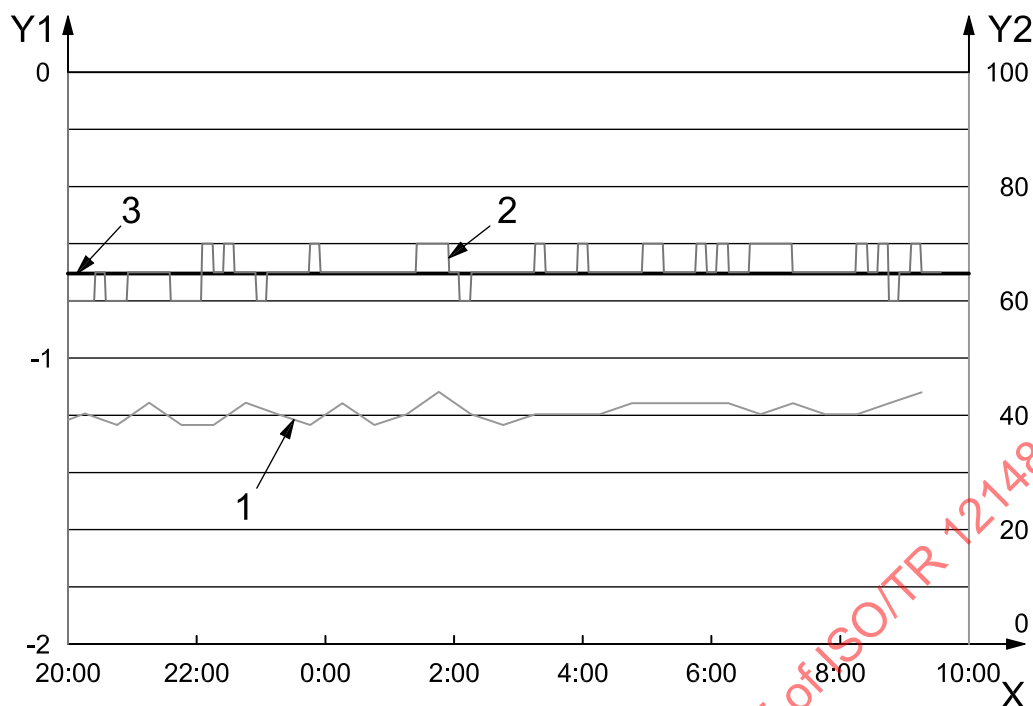
**Key**

- X condensate concentration, milligrams per normal cubic metre
 Y dew point, expressed in degrees Celsius

Figure C.2 — Relationship between PHLC value and hydrocarbon dew point for L-gas

It can be concluded from Figure C.2 that a dew point variation of $\pm 0,5\text{ }^{\circ}\text{C}$ corresponds with a variation in PHLC of $\pm 15\text{ mg/Nm}^3$. It can also be seen from Figure C.2 that a measured hydrocarbon dew point value of $-3\text{ }^{\circ}\text{C}$, which is the bath temperature of the GACOM, corresponds to a PHLC value somewhere around 40 mg/Nm^3 . This means that the Condumax II is certainly not measuring the “true” hydrocarbon dew point, but is presenting a “dew point” temperature at which a certain amount of hydrocarbon liquids have already formed.

To verify the amount of hydrocarbon liquids formed on the mirror during stable gas conditions, the bath temperature of the GACOM was adjusted to the dew point measured by the Condumax II. The results are shown in Figure C.3. Again, these results confirm that the measured dew point corresponds with approximately 40 mg/Nm^3 at the same pressure and temperature. It can be concluded from Figure C.3 that over a period of more than 12 h the dew point remained at a value of $-0,7\text{ }^{\circ}\text{C}$ with a variation within $\pm 0,1\text{ }^{\circ}\text{C}$ and the PHLC value equal to $40\text{ mg/Nm}^3 \pm 2\text{ mg/Nm}^3$. These results confirm the stability and small random errors in the measured values of both instruments. The detector signal of the Condumax II increases with decreasing mirror temperature due to the formation of additional liquid on the mirror. Figures C.2 and C.3 show that the threshold value of the detector signal corresponds to 40 mg/Nm^3 hydrocarbon liquid drop out. A reduction of the threshold value results in measured dew points closer to the “true” hydrocarbon dew point of the gas. Although a value of 5 mg/Nm^3 is achievable with the automated ISO 6570 instrument, a level of 10 mg/Nm^3 was designated for the initial test.



Key

X time, expressed in hours

Y1 dew point, expressed in degrees Celsius

Y2 condensate concentration, milligrams per normal cubic metre

1 curve of the condensate concentration

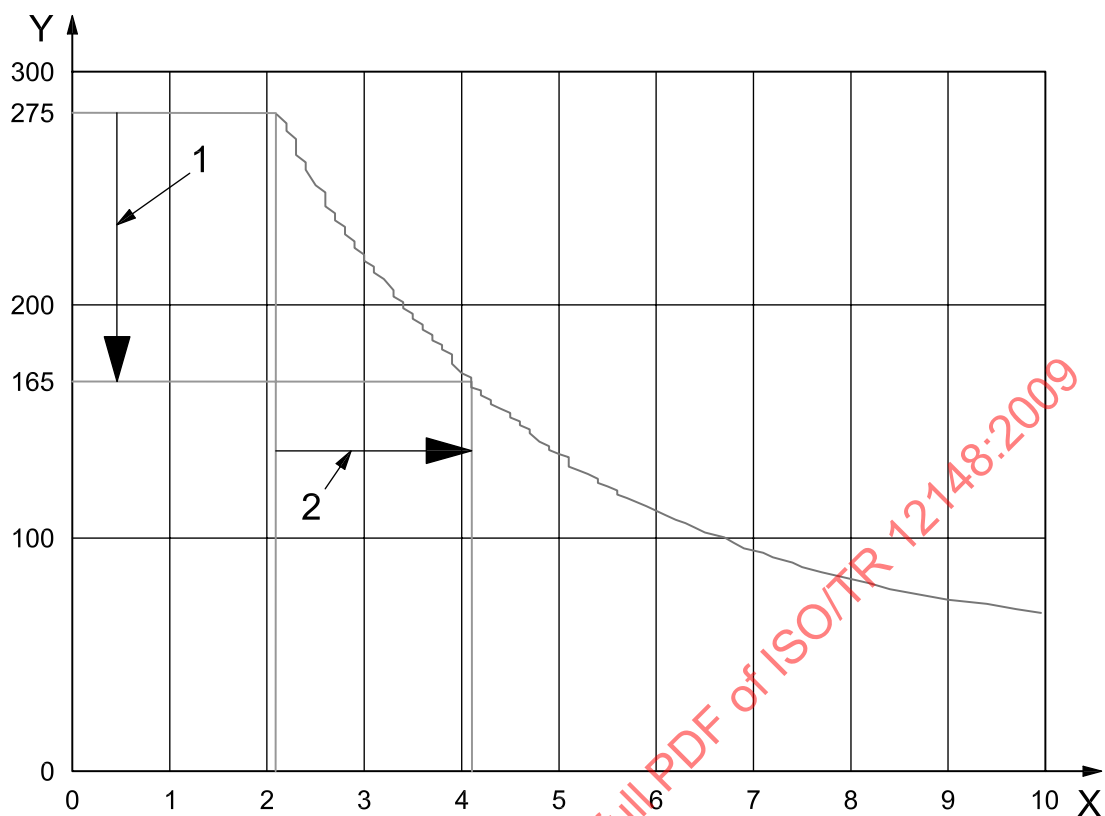
2 curve of the dew point

3 temperature of the PHLC measurement

**Figure C.3 — Dew point and PHLC-value for L-gas —
GACOM at 2,7 MPa (27 bar) and $-0,7\text{ }^{\circ}\text{C}$ and Condumax II at 2,7 MPa (27 bar)**

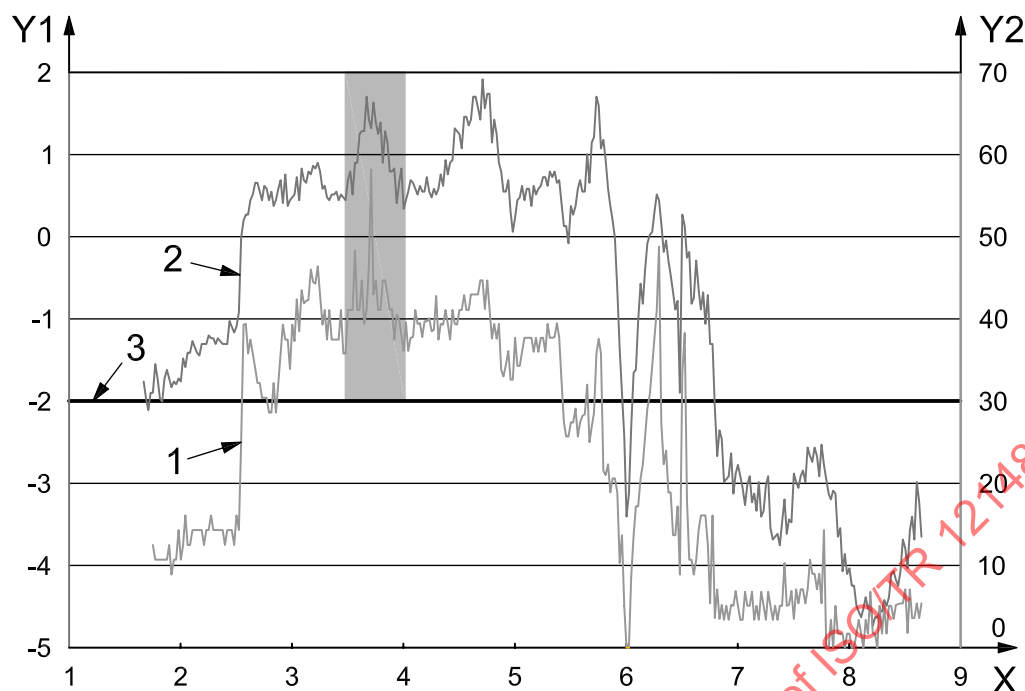
C.3 Calibration according to method A for a L-gas

From the data points in Figure C.2, it can be estimated that for a proper relationship between the “dew point” and the 10 mg/Nm^3 hydrocarbon liquid drop out, the value of the dew-point measured by the Condumax II should be increased by approximately $2\text{ }^{\circ}\text{C}$ for these L-gases. From Figure C.4, this corresponds to a reduction in trip-point value from 275 mV down to 165 mV. To verify this adjustment in practice, the threshold value was decreased accordingly and again measurements were carried out with L-gas. The results for the measured dew points and PHLC values measured at the same pressure and a cooling bath temperature of $-2\text{ }^{\circ}\text{C}$ are shown in Figure C.5.

**Key**

- X mirror temperature, expressed in degrees Celsius
- Y detector signal, expressed in millivolts
- 1 reduction in trip point
- 2 increase in mirror temperature

Figure C.4 — Determination of new trip point value for a known shift in hydrocarbon dew point



Key

- X day
- Y1 dew point, expressed in degrees Celsius
- Y2 condensate concentration, milligrams per normal cubic metre
- 1 curve of the condensate concentration
- 2 curve of the dew point
- 3 temperature of the PHLC measurement

Figure C.5 — PHLC-value measured at -2°C and 2,7 MPa (27 bar) and dew point measured at the same pressure for L-gas

Because the gas quality frequently changed during the measurements, both dew point and PHLC varied. Unfortunately, a dew point of -2°C was rarely recorded. However, it is possible to draw up a graph of the measured PHLC values versus the dew-point temperature. This graph is shown in Figure C.6. It can be concluded from Figures C.5 and C.6 that, by changing the threshold value of the detector signal, it is indeed possible to get an improved relationship between the measured hydrocarbon dew point and a low value (10 mg/Nm^3) for the potential hydrocarbon liquid content without deterioration of the instrument performance. It is even possible to get dew-point values corresponding to a 5 mg/Nm^3 hydrocarbon liquid drop out. It can be seen from Figure C.6 that a hydrocarbon liquid drop out of 5 mg/Nm^3 at -2°C corresponds to a dew-point temperature of approximately $-3,5^{\circ}\text{C}$. For the dew-point temperature to correspond properly to 5 mg/Nm^3 , it is necessary to increase the dew point from $-3,5^{\circ}\text{C}$ up to -2°C . According to Figure C.4, this can be accomplished by decreasing the trip-point value from 165 mV to 125 mV.

Figure C.6 clearly demonstrates that the relationship between dew point and PHLC is non-linear. The slope of the curve gradually decreases in going from a low to a high PHLC value, meaning that the rate of change in the dew point is larger when the PHLC ranges from 5 mg/Nm^3 to 10 mg/Nm^3 than when the PHLC ranges from 40 mg/Nm^3 to 45 mg/Nm^3 . This behaviour is in agreement with the constant hydrocarbon liquid drop out curves shown in Figure A.1.