

Specification for

Calculation procedures for static measurement of refrigerated light hydrocarbon fluids

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Petroleum Standards Policy Committee (PTC/-) to Technical Committee PTC/12, upon which the following bodies were represented:

- Department of Energy (Gas and Oil Measurement Branch)
- Department of Trade and Industry (National Engineering Laboratory)
- Department of Transport (Marine Directorate)
- Institute of Petroleum
- Royal Institution of Naval Architects
- Salvage Association

The following body was also represented in the drafting of the standard, through subcommittees and panels:

Society of International Gas Tanker and Terminal Operators Ltd.

This British Standard, having been prepared under the direction of the Petroleum Standards Policy Committee, was published under the authority of the Standards Board and comes into effect on 15 May 1992

© BSI 11-1999

The following BSI references relate to the work on this standard:
Committee reference PTC/12
Draft for comment 82/52392 DC

ISBN 0 580 20871 0

Amendments issued since publication

Amd. No.	Date	Comments

Contents

	Page
Committees responsible	Inside front cover
National foreword	ii
Introduction	1
1 Scope	2
2 Normative references	2
3 Definitions and symbols	3
4 Volume of LPG at standard temperature	5
5 Mass	5
6 Energy content (calorific content)	8
7 Inter-conversion of liquid mass and vapour volume at standard conditions	9
8 Calculation of liquid density from composition	11
9 Calculation of calorific value from composition	13
Annex A (normative) Constants for density calculations	15
Annex B (normative) Orthobaric molar volumes of individual components of LNG	15
Annex C (normative) Correction factors for volume reduction of LNG mixtures	16
Annex D (normative) Gross calorific values for individual components	17
Annex E (normative) Relative molecular masses and compressibility factors of individual components	18
Annex F (normative) Chemical names corresponding to the chemical formulae used in this International Standard	19
Annex G (normative) Alternative equation for calculating the molar volume and saturated density of LPG mixtures	19
Annex H (normative) Critical temperature, acentric factor and characteristic volume of individual components used in equations	23
Table 1	2
Table 2	10
Table 3	12
Table 4	12
Table 5	13
Table 6	13
Table 7	14
Table A.1	15
Table B.1	15
Table C.1 — Correction factor k_1	16
Table C.2 — Correction factor k_2	16
Table D.1	17
Table E.1	18
Table F.1	19
Table G.1	21
Table H.1	23
List of references	Inside back cover

National foreword

This British Standard has been prepared under the direction of the Petroleum Standards Policy Committee. It is identical with ISO 6578:1991 *Refrigerated hydrocarbon liquids — Static measurement — Calculation procedure*, published by the International Organization for Standardization (ISO). ISO 6578 was prepared by Sub-committee 5, Measurement of light hydrocarbon fluids, of Technical Committee 28, Petroleum products and lubricants, in which the United Kingdom participated.

Cross-references

International Standard	Corresponding British Standard
ISO 91-1:1982	BS 6441:1983 <i>Schedule for petroleum measurement tables</i> (Identical)
ISO 3993:1984	BS 6665:1985 <i>Method for determination of density or relative density of liquefied petroleum gases and other light hydrocarbons by pressure hydrometer method</i> (Identical)

The Technical Committee has reviewed the provisions of ISO 91-2:1991 and ISO 5024:1976, to which normative reference is made in the text, and has decided that they are acceptable for use in conjunction with this standard.

A British Standard related to ISO 5024:1976 is BS 5579:1978 *Specification for standard reference conditions for measurement of petroleum liquids and gases*.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 24, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Introduction

Storage and transport of large quantities of refrigerated hydrocarbon liquids [e.g. liquefied natural gases (LNG) and liquefied petroleum gases (LPG)] is now common practice. Existing standards for the measurement of petroleum products are either not applicable to, or in some cases inadequate for, these products at low temperatures and, for these products, such standards shall be replaced or modified by the procedures in this International Standard.

Accurate measurement is essential in the sale, purchase and handling of refrigerated hydrocarbon liquids. Custody transfer agreements call for the standardization of static measurement procedures, and it is recommended that quantities be expressed in mass or energy units. It is recognized that other units are currently used for LPG transfers, but these are not covered in this International Standard.

Although the principles of calculating the quantity of a static refrigerated hydrocarbon liquid are basically similar to those for petroleum liquids at ambient temperatures, there are differences caused by the low temperature and the physical properties of refrigerated hydrocarbons. These include the following:

- a) The liquid product is at or near a temperature at which bubbles of vapour are first formed within the liquid (bubble point). In a tank containing refrigerated liquid there will always be a small inward flow of heat through the insulation, which will cause a continuous vaporization of the product. The vapour will contain a higher concentration of more volatile constituents than the liquid. To avoid over-pressure, this vapour is vented from the tank and can be compressed, cooled and re-liquefied for re-introduction into the tank.
- b) When a liquid product is transferred from one tank to another, additional heat inflow will occur in the pipeline and also from work done by the pump, causing additional evaporation in the receiving tank.
- c) For custody transfers from a supply to a receiving tank, it is normal practice to provide a vapour return line linking the tanks to avoid displacement of vapour to the atmosphere. Build-up of pressure in the interlinked system is avoided by re-liquefaction.
- d) After a partial filling, stratification into different temperature and density layers may occur in the liquid contents of a tank. Therefore, a number of temperature measuring points and a special sampling system may be necessary. If the filling operation is such as to ensure mixing, these needs may be reduced.
- e) There is considerable evidence that large temperature gradients exist in the vapour space of any tank containing a refrigerated hydrocarbon liquid. These gradients may not be linear. Suitable compensation (physical or by calculation) must be made if the reading of the level-measuring device is affected by differential contraction of the level-sensor suspension.
- f) Refrigerated hydrocarbon liquids have large temperature coefficients of volumetric expansion and approximate values are given below:

— propane	0,20 %/°C
— methane	0,35 %/°C.

It is very strongly emphasised that errors in temperature measurement can account for the major part of the error in quantitative measurement and the greatest care is therefore needed in the selection and use of temperature measuring equipment.

This International Standard is applicable to the measurement of refrigerated liquids contained in land storage tanks and in ships' tanks when the liquids are fully refrigerated at a vapour pressure near to atmospheric pressure.

However, it is not intended that this International Standard be applied retroactively to existing business contracts, nor should it be applied if it is in conflict with government regulations.

No recommendations are given for the measurement of small parcels of refrigerated liquids, which are directly weighed.

Calculation procedures for refrigerated hydrocarbon liquids consisting predominantly of ethane or ethylene, or for partially refrigerated hydrocarbon liquids at pressures substantially above atmospheric, are not included. Consideration should be given to their inclusion in a subsequent revision, as and when more reliable data become available.

In order to implement the detailed recommendations given in this International Standard, it is essential that personnel responsible for the measurement procedures have the necessary experience and skill. At all times, scrupulous attention must be given to detail.

- NOTE Use of units:
- a) Temperature — Celsius temperature is used in connection with the measurement and transport of refrigerated gases and has been used in general in this International Standard; however, in some calculations the thermodynamic, i.e. kelvin, temperature scale must be used. For accurate conversion, $273,15\text{ K} \equiv 0\text{ }^{\circ}\text{C}$ should be used, but in the examples given here $273\text{ K} \equiv 0\text{ }^{\circ}\text{C}$ is sufficiently accurate.
 - b) Pressure — The pascal (Pa) is used as the unit of pressure in this standard, but the bar is given as an alternative unit. The bar may be substituted in calculations; the conversion $1\text{ bar} = 100\text{ kPa}$ should be used.

1 Scope

1.1 This International Standard specifies the calculations to be made to adjust the volume of a refrigerated hydrocarbon liquid, such as LPG or LNG, from the conditions at measurement to the equivalent volume of liquid or vapour at a standard temperature and pressure, or to the equivalent mass or energy (calorific content). It applies to quantities of refrigerated hydrocarbon liquids stored in or transferred to or from tanks and measured under static storage conditions by tank gauges.

1.2 Using these procedures, the final quantity shall be expressed in terms of the following:

- a) mass (see the note);
- b) energy (calorific content);
- c) equivalent volume of vapour under standard conditions.

NOTE The current practice for measurement of LPG is by apparent mass in air. The factors in Table 1 may be used to convert mass into apparent mass in air.

Table 1

Density at 15 °C kg/m³	Factor
500,0 to 519,1	0,997 75
519,2 to 542,1	0,997 85
542,2 to 567,3	0,997 95
567,4 to 595,0	0,998 05
595,1 to 625,5	0,998 15
625,6 to 659,3	0,998 25

1.3 If it is required to express the volume of liquid at a standard temperature, the procedures and correlations to determine such quantities are given in clause 4. The standard reference temperature for petroleum products is 15 °C (see ISO 5024), but references are made to calculations involving other widely used reference temperatures, i.e. 20 °C.

1.4 If, for quantity calculations, the product density or the calorific value is required, this shall be either determined directly or calculated from the product composition analysis. The procedures for these subsidiary calculations are given in clauses 8 and 9.

1.5 The mandatory basic data and source references used in the calculation procedures are given in Annex A to Annex F.

2 Normative references

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

- ISO 91-1:1982, *Petroleum measurement tables — Part 1: Tables based on reference temperatures of 15 °C and 60 °F*.
- ISO 91-2:1991, *Petroleum measurement tables — Part 2: Tables based on reference temperatures of 20 °C*.

ISO 3993:1984, *Liquefied petroleum gas and light hydrocarbons — Determination of density or relative density — Pressure hydrometer method.*

ISO 5024:1976, *Petroleum liquids and gases — Measurement — Standard reference conditions.*

3 Definitions and symbols

3.1 Definitions

For the purposes of this International Standard, the following definitions shall apply. Definitions are given for those terms which have particular relevance in calculation procedures used for refrigerated hydrocarbon liquids.¹⁾

3.1.1

refrigerated hydrocarbon liquids

liquids composed predominantly of hydrocarbons, which are stored in a fully refrigerated condition at pressures near atmospheric

3.1.2

liquefied natural gases (LNG)

liquids composed predominantly of methane

3.1.3

liquefied petroleum gases (LPG)

liquids composed predominantly of any of the following hydrocarbons or mixtures thereof: propane, propene, butanes and butene

3.1.4

gross calorific value (specific energy) on mass basis

the number of heat units generated when unit mass of a product in the vapour phase at standard temperature and pressure is burned completely in dry air. The gaseous products of combustion are brought to the same standard conditions of temperature and pressure but the water produced is condensed to liquid in equilibrium with water vapour

3.1.5

gross calorific value (specific energy) on volume basis

the number of heat units generated when unit volume of a product in the vapour phase at standard temperature and pressure is burned completely in dry air. The gaseous products of combustion are brought to the same standard conditions of temperature and pressure but the water produced is condensed to liquid in equilibrium with water vapour

3.1.6

orthobaric density

the mass of the liquid occupying unit volume at a given temperature, the liquid being in equilibrium with its vapour

3.1.7

densitometer

an instrument for measuring density

3.1.8

volume basis (ideal)

a volume calculated on the basis that the vapour behaves like an ideal gas

3.1.9

volume basis (real)

volume calculated on the basis that the vapour behaves like a super-compressible gas

¹⁾ An International Standard (ISO 4273) dealing with terms relating to petroleum measurement is to be published.

3.1.10

compressibility factor

the ratio of the real volume of a given mass of gas at a specified temperature and pressure to its volume under the same conditions calculated from the ideal gas law

3.2 Symbols

The following symbols are defined here for use in this International Standard, but additionally some symbols are given a more restricted meaning when used in some equations. The restricted meaning is then given after the equations.

$H_{s,m,i}$ is the gross (superior) calorific value on a mass basis, in megajoules per kilogram, of component i (see Annex D);

$H_{s,m}$ is the gross (superior) calorific value on a mass basis, in megajoules per kilogram, of the liquid;

$H_{s,V,i}$ is the gross (superior) calorific value on a volume basis (ideal), in megajoules per cubic metre, of component i (see Annex D);

$H_{s,vol}$ is the gross (superior) calorific value on a volume basis, in megajoules per cubic metre, of the vapour at the appropriate standard temperature and pressure;

m is the mass, in kilograms, of product transferred, i.e. liquid plus vapour;

m_{liq} is the mass, in kilograms, of liquid;

M_i is the molecular mass, in kilograms per kilomole, of component i (see Annex E and Annex G);

M_{mix} is the relative molecular mass, in kilograms per kilomole, of the vapour mixture;

P_s is the standard reference pressure, i.e. 101,325 kPa (1,013 25 bar);

P_{vap} is the pressure, in kilopascals (bars), of the vapour in the container;

Q is the net energy, in megajoules, transferred, based on gross calorific value;

Q_{liq} is the energy (calorific) content, in megajoules, of the liquid;

t is the temperature, in degrees Celsius, of the liquid;

T_s is the standard reference temperature, i.e. 288,15 K (15 °C);

T_{vap} is the temperature, in kelvins, of the vapour in the container;

V_i is the molar volume, in cubic metres per kilomole, of component i , as a liquid at temperature t °C;

V_{liq} is the volume, in cubic metres, of the liquid at temperature t ;

V_m is the ideal gaseous molar volume, in cubic metres per kilomole, at standard conditions of pressure and temperature:

i.e. 22,413 8 m³/kmol at P_s and 273,15 K (0 °C);

23,644 7 m³/kmol at P_s and T_s ;

V_{vap} is the vapour volume, in cubic metres, in the container;

x_i ; x_j are the mole fractions of the components i and j , respectively;

x_1 is the mole fraction of methane in the LNG;

x_2 is the mole fraction of nitrogen in the LNG;

Z_i is the compressibility factor for component i at the required pressure and temperature;

Z_{mix} is the compressibility factor for the vapour mixture under known conditions of temperature and pressure;

ρ_t is the density, in kilograms per cubic metre, of the liquid at temperature t .

Additional subscripts: F and I indicate, respectively, the final and initial measurements or product properties in either of the two containers used for a transfer.

NOTE Other units may be used for the calculations in this International Standard, provided that they are dimensionally consistent, but vapour temperature and pressure should be expressed in absolute units.

4 Volume of LPG at standard temperature

The procedure for converting the volume of refrigerated LPG to its equivalent volume at a standard temperature and corresponding equilibrium pressure includes the following aspects:

- a) Very large factors may have to be applied for the correction of observed density to density at standard temperature, e.g. a correction for the effect of a temperature difference of 60 °C may be necessary for refrigerated propane. Provided that the LPG does not contain more than 20 % of unsaturated hydrocarbons the correction tables referred to in ISO 91 shall be used for volume corrections. However, the tables for this density range are those retained from the 1952 edition of the API-ASTM-IP Petroleum Measurement Tables (see sub-clause 3.4 of ISO 91-1:1982). If the LPG contains 20 % or more of unsaturated hydrocarbons, the density shall be calculated using the method given in clause 8.
- b) The equivalent liquid content in the vapour space of a container holding refrigerated LPG is significantly less than if the tank and contents are at ambient temperature. Therefore, any error in accounting for the equivalent liquid content in the vapour space will be of lesser significance.

NOTE 1 The following examples illustrate the magnitude of errors that can be introduced by using the tables referred to in ISO 91.

- a) Pure butene or propene: the maximum error will be approximately 2 % for a correction from – 60 °C to + 20 °C;
- b) Mixtures containing approximately 20 % of unsaturated hydrocarbons: a typical error will be approximately 0,1 % for a temperature difference of 20 °C.

NOTE 2 A condition in which a liquid has a vapour pressure significantly higher than atmospheric pressure at a standard temperature of 15 °C (or 20 °C or 60 °F) can only be considered as a pseudo-condition, and the volume of the liquid in this condition may be used only when convenient in a procedure for obtaining the density at refrigerated temperatures by means of pressure hydrometer measurement at ambient conditions (see ISO 3993).

5 Mass

5.1 Mass of liquid phase

5.1.1 Calculate the mass of liquid (m_{liq}), in kilograms, using the equation

$$m_{\text{liq}} = V_{\text{liq}} \varrho \quad \dots (1)$$

where V_{liq} and ϱ are for the same value of the temperature t .

EXAMPLE

Measured volume of liquid LNG in a container = 45 550 m³ at a temperature of – 163,5 °C.

Calculated density at – 163,5 °C = 468,3 kg/m³

Mass of LNG (m_{liq}) = 45 550 × 468,3 kg = 21,33 × 10⁶ kg or 21,33 × 10³ t

5.1.2 The density at a specified temperature shall be measured using either a pressure hydrometer (LPG) or a suitable densitometer, or shall be calculated from a composition analysis (see clause 8)

5.1.3 If the actual temperature t_2 at which the density is measured does not differ by more than 5 °C from the temperature t_1 of the main bulk of liquid in the container, then the observed density may be corrected to the required bulk temperature by means of the equation

$$\varrho_{t,1} = \varrho_{t,2} + F(t_2 - t_1) \quad \dots (2)$$

where

$\varrho_{t,1}$ and $\varrho_{t,2}$ are the densities at temperatures t_1 and t_2 respectively;

F is the density correction factor applicable to the particular liquid. The units of F shall be compatible with the units of ϱ , e.g. when ϱ is expressed in kilograms per cubic metre, F is expressed in kg/(m³ °C).

Product	F kg/(m ³ °C)
LNG [> 80 % (m/m) methane]	1,4
Liquid propanes [> 60 % (m/m) propane]	1,2
Liquid butanes [> 60 % (m/m) butane]	1,1