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ATM CONTRACT

CALCULATION ROUNDING-OFFS AND METHODS FOR THE NET UNLOADED ENERGY OF AN LNG CARGO

Revision 3

Une société de GDF SUEZ

1 METHOD FOR DETERMINING TRANSFERRED ENERGY

A schematic representation of the LNG loading and unloading flaps of an LNG carrier allows the amount of energy unloaded to be visualized (see diagram below).

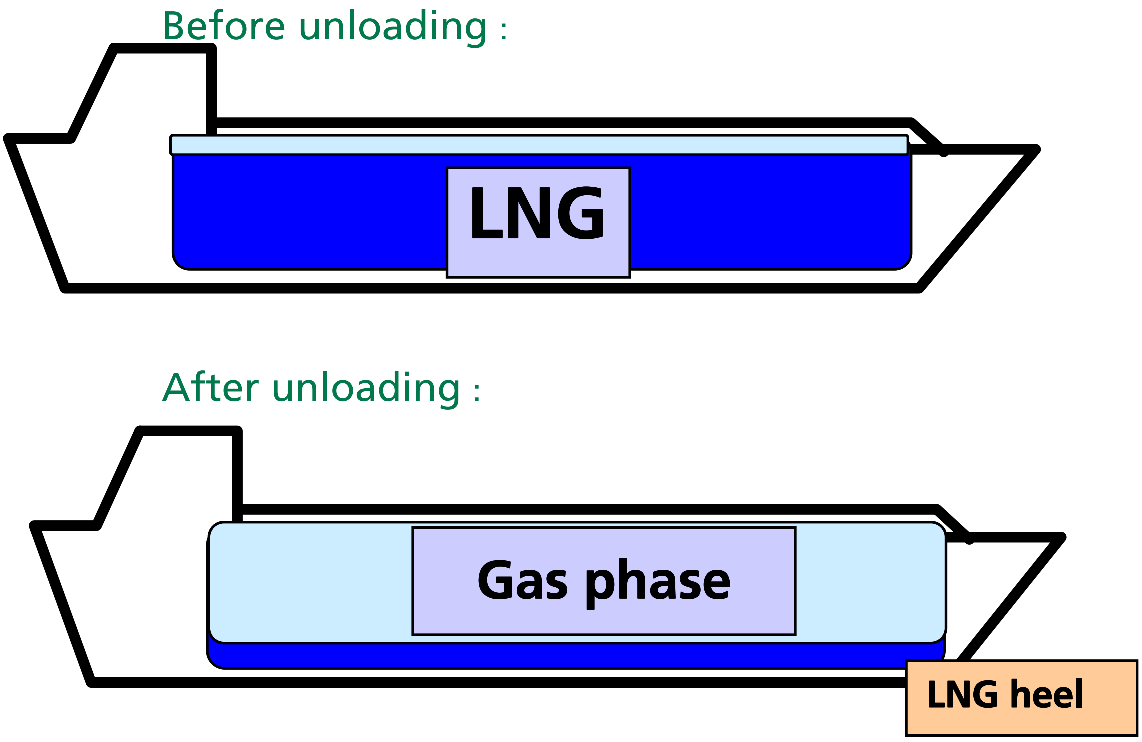

Diagram n°1: Before and after unloading phases of an LNG carrier

During these transfer operations, the volume of LNG unloaded is replaced by gas sent by the terminal. For the sake of convenience, this gas will be referred to as return gas in the rest of the text.

A heel of LNG remains in the carrier's tanks at the end of unloading (see diagram below).

The energy transferred, E, corresponds to the difference of the energies transferred in the form of LNG and in the form of gas [return gas (NG) + gas consumed by the carrier's machines if necessary (MG)]:

$$E = E_{LNG} - E_{NG} - E_{MG}$$

These energies are evaluated by determining volumes and/or the mass transferred and the calorific value by volume and/or mass for the duration of the transfer, or:

- For the LNG:

$$E_{LNG} = V_{LNG} \times \rho_{LNG} \times H_{LNG}$$

where: V_{LNG}: volume of LNG measured in the carrier's tanks;

ρ_{LNG}: density of the LNG calculated from the chromatographic analysis of the LNG (or D_{LNG});

H_{LNG}: calorific value on a mass basis of the LNG calculated from the chromatographic analysis of the LNG (or GCV_{LNG}).

- For the return gas (NG) or $E_{\text{gas displaced}}$:

$$E_{NG} = V_{NG} \times H_{NG}$$

where: **V_{NG}**: volume of gas having taken the place of the unloaded LNG. This volume, brought under normal conditions (273.15 K and 1013.25 mbar), is calculated from the volume of transferred LNG and the pressure and temperature conditions of the gaseous phase in the tanks at the end of unloading (Volume of gas displaced);

H_{NG}: calorific value on a volumetric basis of the gas calculated from the chromatographic analysis of the return gas (or **GCV_{NG}**).

The diagram below clearly shows the energy transferred between the unloaded LNG and the return gas.

N.B.: the natural evaporations of the cargo during discharging are not counted; the missing quantity of LNG is compensated for by the lesser quantity of gas returned to the carrier's tanks.

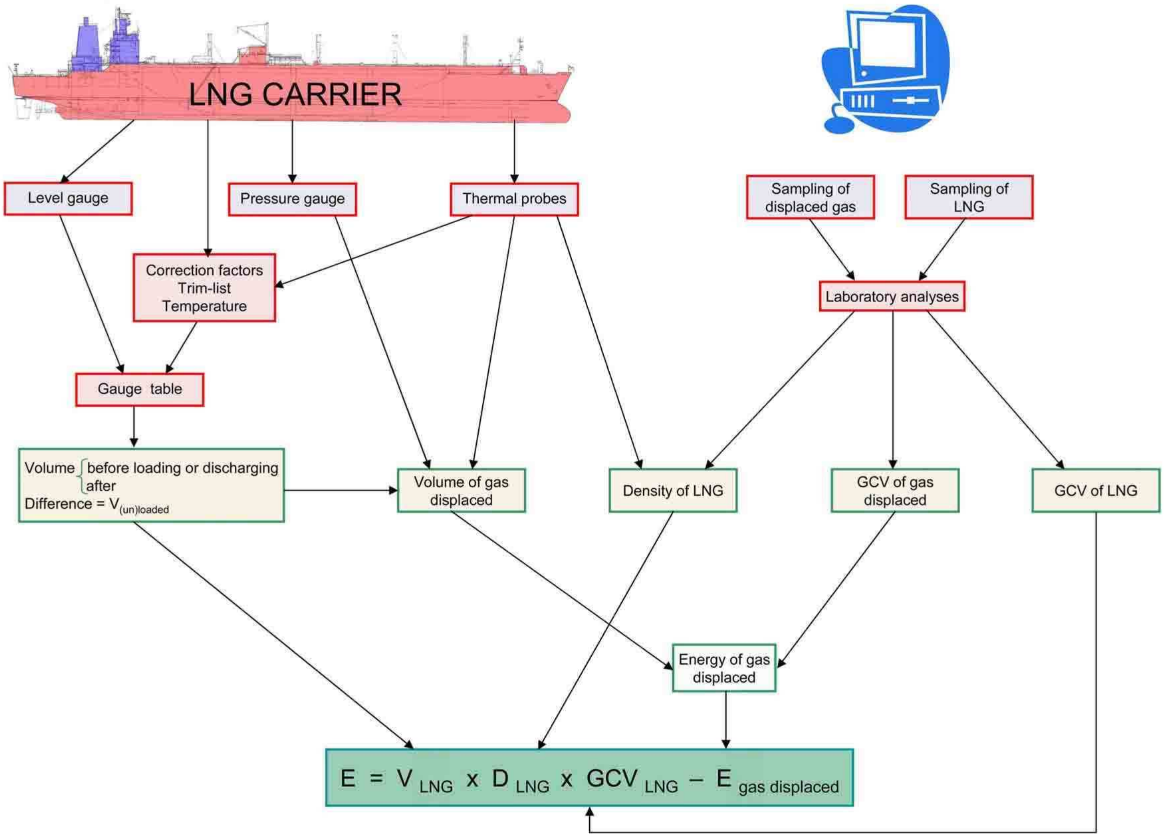

Diagram n°2: Principle of cargo reconnaissance

2 METHOD FOR CALCULATING THE TRANSFERRED ENERGY

2.1 Calculating the gross unloaded energy

The calculation of the gross unloaded energy is a function of:

- V_{LNG}: volume of unloaded LNG,
- ρ_{LNG}: density of unloaded LNG,
- H_{LNG}: calorific value on a mass basis of the unloaded LNG.

$$E_{LNG} = V_{LNG} \times \rho_{LNG} \times H_{LNG}$$

2.1.1 Calculating the volume of the unloaded LNG V_{LNG}

Calculation method

The volume of LNG unloaded is calculated by the difference between the volumes of LNG contained in the tanks before and after unloading.

The calculation of the volume of LNG contained in a tank, at a given moment, is determined by reading from a measurement table according to the corrected level of LNG.

This corrected level of LNG is obtained from the level measured in a tank (by means of level gauges), to which are applied, if necessary, the corrections (trim, list, density, ….).

The volume of the carrier at a given moment is the sum of the volumes contained in the carrier’s various tanks.

Units and rounding-offs

The volume is expressed in m³

The volume of LNG, before and after cargo reconnaissance, is determined with three decimal places; the net volume is calculated by difference and is taken with three decimal places for calculating the energy.

2.1.2 Calculating the density of the unloaded LNG ρ_{LNG}

The density is calculated from various models based on state equations, corresponding state equations, etc., with as starting data:

- the composition of the LNG taken from the chromatographic analysis after sampling and vaporization of the latter; **the molar composition values are taken with 5 decimal places;**
- and the temperature of the LNG measured in the LNG carrier’s tanks; **the temperature of the LNG is taken in °C with 1 decimal place.**

In the LNG terminals of Fos sur Mer and Montoir-de-Bretagne, Elengy, a company of the GDF SUEZ group, uses the revised Klosek MacKinley (KMK) method[1] to determine the density of the LNG.

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[1] Klosek MacKinley method: Four mathematical models for the prediction of LNG densities - NBS Technical Note 1030 - December 1980

Areas of application of the calculation method

The limits of the Klosek MacKinley method on the composition of LNG and temperature are:

Methane (CH_4)	> 60 % mol.
Iso and normal butanes ($iC_4 + nC_4$)	< 4 % mol.
Iso and normal pentanes ($iC_5 + nC_5$)	< 2 % mol.
Nitrogen (N_2)	< 4 % mol.
Temperature (T)	< 115 K < - 158.15 °C

Formula for the Klosek MacKinley method

The method for calculating the density of LNG is based on an empirical evaluation of the molar volumes of the mixture in the thermodynamic state in question. Density is calculated as follows:

$$\rho_{GNL} = \frac{M_{mix}}{V_{mix}}$$

where:

ρ_{GNL} : density of LNG in kg/m³

M_{mix} : molecular weight of the mixture in g.mol^{-1}

M_{mix} : $$M_{mix} = \sum M_i . X_i$$

where : M_i is the molecular weight of the constituent *i* according to table 1 of ISO 6976 - 1995 (annexes 2);

: X_i is the molar fraction of the constituent *i*.

V_{mix} : molar volume of the mixture expressed in l.mol^{-1}

V_{mix} : $$\boldsymbol{V_{mix} = \sum X_i . V_i - \left[K_1 + (K_2 - K_1) \times \left(\frac{X_{N_2}}{0.0425} \right) \right] \times X_{CH_4}}$$

where : X_i is the molar fraction of the constituent i;

: V_i is the molar volume of the constituent *i* at the temperature of the LNG;

: K_1, K_2 which are correction factors.

The values of K_1 and K_2, expressed in l/mol, are determined by tables according to the molar mass of the LNG and the temperature of this LNG between 105 K and 135 K. Tables indicating the molar volumes in l/mol for the hydrocarbons C_1 to C_5, as a function of temperatures varying from

106 K to 118 K, are used by the method (see values in annex 1). **No rounding-off is performed during these calculations of K_1, K_2 and V_i.**

Calculation rounding-offs and units

The density calculations will be performed without any rounding-off using the KMK calculation codes (note NBS 1030 December 1980); the density is expressed in kg/m³.

2.1.3 Calculating the calorific value on a mass basis of the unloaded LNG H_{LNG}

Calculation method

The calorific value on a mass basis of the LNG is calculated from the molar composition, the molar mass and the molar calorific value of the various constituents. These values are taken from standard ISO 6976 - 1995 “Natural gas - Calculation of calorific values, density, relative density and Wobbe index from composition”.

The relation used is produced thus:

$$\boldsymbol{H_{GNL} = \sum_{i=1}^{N}\left[\left(x_i \times \frac{M_i}{M}\right) \times \hat{H}_i^{\circ}(t_1)\right]}$$

where:

H_{GNL} : calorific value on a mass basis of the mixture

x_i : molar fraction of the constituent i

M_i : molar mass of the constituent *i*

$$M = \sum_{i=1}^{N} x_i \times M_i$$

$\hat{H}_i^{o}(t_1)$: calorific value on a mass basis of the constituent i of the mixture calculated **without rounding off** from table 3 calorific value on a molar basis (kJ/mol) and table 1 molar mass of constituents (kg/kmol) of standard ISO 6976-1995 according to the relation:

$$\hat{H}_i^{o}(t_1) = \frac{\overline{H_i^{o}(t_1)}}{M_i} \quad \text{(see tables in annex 2)}$$

Units and rounding-offs

The calorific value on a mass basis is expressed in MJ/kg or in other units kWh/kg in the reference combustion conditions at 0 °C at atmospheric pressure of 1.01325 bar. The physical constants of calorific value on a mass basis and the molar masses of the various components are taken from standard ISO 6976 - 1995. **No rounding off of H_{LNG} is made to calculate the gross unloaded energy.**

2.2 Calculating the energy of the gas returned to the LNG carrier

The calculation of the energy returned to the LNG carrier E_{NG} is based on the following terms:

- the volume of gas V_{NG},
- and the calorific value on a volumetric basis of the return gas H_{NG}.

2.2.1 Calculating the volume of the return gas V_{NG}

The volume of NG transferred is calculated by difference from the volume of unloaded LNG, corrected according to:

- the temperature of the gaseous phase,
- and the pressure in this same gaseous phase.

Between two cargo reconnaissances, the natural evaporations are taken into account on the volume of LNG transferred, since the reduction in the corresponding LNG level is measured.

Outside of cargo reconnaissances (before and after), these evaporations are not taken into account, although reincorporated by the Terminal.

Calculation method

The volume of gas returned to the carrier between two cargo reconnaissances, corresponding to the geometric volume of the unloaded LNG, must be brought back to the pressure and temperature conditions of 1.01325 bar and 0 °C respectively; it must be corrected according to the return temperature and pressure conditions of the gas phase of the LNG carrier. The correction of the compressibility factor of the return gas, which is not taken into account in this calculation because of its negligible impact on the measurement of the volume of the return gas, is to be noted.

$$V_{GN} \approx V_{GNL} \times \frac{273{,}15}{273{,}15 + t} \times \frac{P}{1{,}01325}$$

where: V_{GN} : volume of gas brought back to normal conditions of pressure and temperature; **no rounding off is performed for the return gas calculation;**

P : absolute pressure expressed in bar or mbar, prevailing in the tanks of the LNG carrier; **the measurement is taken to the nearest mbar for the calculations;**

t : temperature of the gas phase expressed in degrees Celsius. The value of this temperature is equal to the mean of the values indicated by the temperature sensors not immersed in the LNG left in the carrier's tanks; **the temperature is taken to the nearest 0.1 °C for the calculations.**

Units and rounding-offs

The volume of the return gas V_{GN} is expressed in m³ in normal conditions of pressure and temperature (1.01325 bar; 0 °C), **without rounding off when calculating the energy of the return gas.**

2.2.2 The calorific value of the return gas H_{NG}

The real-gas calorific value on a volumetric basis of the LNG is calculated from the molar composition and the molar calorific value of the various constituents. These values are taken from standard ISO 6976 - 1995 “Natural gas - Calculation of calorific values, density, relative density and Wobbe index from composition”.

In all cases, the terminal operator must taken into account, for discharging purposes, the higher calorific value of the return gas and use this when calculating the transferred energy; this will help improve the accuracy of the annual energy balance of the LNG terminal.

Calculation method

The ideal-gas calorific value on a volumetric basis for a combustion temperature t_1 of a constituent i measured at a temperature t_2 and under pressure p_2 is calculated using the following equation:

$$\tilde{H}_i^\circ[t_1, V(t_2, p_2)] = \overline{H_i^\circ}(t_1) \times \frac{p_2}{R \times T_2}$$

where:

$\tilde{H}_i^\circ[t_1, V(t_2, p_2)]$	is the ideal-gas calorific value on a volumetric basis of the constituent i;
$\overline{H_i^\circ}(t_1)$	is the calorific value on a molar basis
R	is the molar constant of the gases being equal to 8.314 510 J.mol^{-1}.K^{-1}
$T_2 = (t_2 + 273.15)$	is the absolute temperature in K

For a mixture of known composition, the ideal-gas calorific value on a volumetric basis is expressed thus:

$$\tilde{H}_{mel}^\circ = \sum_{i=1}^{N} \left[x_i \times \tilde{H}_i^\circ[t_1, V(t_2, p_2)]\right]$$

where x_i is the molar fraction of the constituent i of the mixture

For a mixture of known composition, the real-gas calorific value on a volumetric basis is expressed thus:

$$H_{GN} = \frac{\tilde{H}^{\circ}_{mél}}{Z_{mél}} = \frac{\sum_{i=1}^{N}\left[x_i \times \tilde{H}^{\circ}_{i}\left[t_1, V\left(t_2, p_2\right)\right]\right]}{1-\left[\sum_{i=1}^{N}\left(x_i\sqrt{b_i}\right)\right]^2}$$

where: H_{GN} : real-gas calorific value on a volumetric basis of the return gas

$Z_{mél}$: compressibility factor of the return gas equal to $1-\left[\sum_{i=1}^{N}\left(x_i\sqrt{b_i}\right)\right]^2$

where: $\sqrt{b_i}$: so-called summation factor of the constituent *I* (annex 2)

Units and rounding-offs

The real-gas calorific value on a volumetric basis is expressed in MJ/m³ or in other units such as the kWh/m³ in reference combustion conditions at 0 °C at atmospheric pressure of 1.01325 bar and reference volume conditions at 0 °C at atmospheric pressure of 1.01325 bar. The physical constants of higher calorific value are on a molar basis and the molar masses of the various components are taken from standard ISO 6976 - 1995. **No rounding-off is performed when calculating the energy of the return gas.**

2.3 Calculating the net unloaded energy (formulae and rounding-offs for the calculation)

Calculation method

In summary, the net unloaded energy is expressed according to the formula:

$$E_{GNL} = V_{GNL}\left[\left(\rho_{GNL} \times H_{GNL}\right) - \left(\frac{273{,}15}{273{,}15 + t} \times \frac{P}{1{,}01325} \times H_{GN}\right)\right]$$

Units and rounding-offs

All calculations that lead to the net discharged energy are made without rounding off via the calculator and use as starting data those mentioned below, among others:

V_{LNG} : expressed in m^3 to 3 decimal places
ρ_{LNG} : expressed in kg/m^3 without rounding off for the calculation; no rounding off for the calculations of K1, K2 and Vmol; the molar composition of the LNG is given to 5 decimal places or if %molar three decimal places; the temperature of the LNG in °C is given to one decimal place
H_{LNG} : calorific value on a mass basis of the LNG expressed in MJ/kg or kWh/kg without rounding off for the calculation; the molar composition of the LNG is given to 5 decimal places or if %molar three decimal places;
t : temperature of the return gas expressed in °C is given to one decimal place
P : pressure of the return gas is expressed in bar to three decimal places or in mbar to the nearest mbar
H_{NG} : real-gas calorific value of the return gas expressed in $MJ/m^3(n)$ or $kWh/m^3(n)$ without rounding off for the calculation; the molar composition of the LNG is given to 5 decimal places or if %molar three decimal places.

E_{LNG} : net unloaded energy expressed in MJ or kWh **with no rounding off.**

Conversions

- MJ to kWh
  1 Wh (Treference combustion) = 3600 J (Treference combustion)

- MJ to MMBtu (ASTM E380-72)
  1 MMBtu (Treference combustion) = 1055.056 MJ (Treference combustion)

with Treference combustion = 0 °C or 15 °C or 20 °C or 25 °C or 60 °F

For different Treference combustions, the conversion coefficients are not the same.

3 CERTIFICATE OF UNLOADING AND CERTIFICATE OF QUANTITY

For the certificates of unloading and certificate of quantity, the characteristics of the cargo are given as follows:

V_{LNG} before unloading : in m^3 to (3) decimal places
V_{LNG} after unloading : in m^3 to (3) three decimal places
V_{LNG} unloaded : in m^3 to (1) one decimal place
Temperature of LNG before unloading : in °C to (1) one decimal place
Pressure of tanks after unloading : in mbar to the nearest (1) one mbar
Temperature of NG after unloading : in °C to (1) one decimal place
Composition of LNG : in % molar to (3) decimal places
Composition of the return gas : in % molar to (3) three decimal places
Wobbe index : in kWh per m^3 to (2) two decimal places
H on a mass basis or on a volumetric basis : in kWh/kg or per m^3 to (2) decimal places
Density of LNG : in kg/m^3 to (3) decimal places
Density of the gaseous LNG : in kg/m^3 to (3) decimal places
Relative density of gaseous LNG : without unit, to (3) decimal places
Quantity of NG energy returned to carrier : in kWh to nearest kWh (no decimal places)
Unloaded net energy quantity : in kWh to nearest kWh (no decimal places)

ANNEX 1:

COMPONENT MOLAR VOLUMES

Component	**Molar volume*, l/mol**							**Molar mass****
	118 K	**116 K**	**114 K**	**112 K**	**110 K**	**108 K**	**106 K**	
CH_4	0.038817	0.038536	0.038262	0.037995	0.037735	0.037481	0.037234	16.043
C_2H_6	0.048356	0.048184	0.048014	0.047845	0.047678	0.047512	0.047348	30.070
C_3H_8	0.062939	0.062756	0.062574	0.062392	0.062212	0.062033	0.061855	44.097
iC_4H_{10}	0.078844	0.078640	0.078438	0.078236	0.078035	0.077836	0.077637	58.123
nC_4H_{10}	0.077344	0.077150	0.076957	0.076765	0.076574	0.076384	0.076194	58.123
iC_5H_{12}	0.092251	0.092032	0.091814	0.091596	0.091379	0.091163	0.090948	72.150
nC_5H_{12}	0.092095	0.091884	0.091673	0.091462	0.091252	0.091042	0.090833	72.150
N_2	0.050885	0.049179	0.047602	0.046231	0.045031	0.043963	0.043002	28.0135

*Source: N.B.S. - Technical note 1030 December 1980.
*Source: ISO 6976 - 1995 Table 1

VOLUME CORRECTION FACTOR - k_1 x 10^{-3}

Molecular weight of mixture g/mol	**Volume reduction, l/mol**						
	105 K	**110 K**	**115 K**	**120 K**	**125 K**	**130 K**	**135 K**
16	-0.007	-0.008	-0.009	-0.010	-0.013	-0.015	-0.017
17	0.165	0.180	0.220	0.250	0.295	0.345	0.400
18	0.340	0.375	0.440	0.500	0.590	0.700	0.825
19	0.475	0.535	0.610	0.695	0.795	0.920	1.060
20	0.635	0.725	0.810	0.920	1.035	1.200	1.390
21	0.735	0.835	0.945	1.055	1.210	1.370	1.590
22	0.840	0.950	1.065	1.205	1.385	1.555	1.800
23	0.920	1.055	1.180	1.330	1.525	1.715	1.950
24	1.045	1.155	1.280	1.450	1.640	1.860	2.105
25	1.120	1.245	1.380	1.550	1.750	1.990	2.272

Source: N.B.S. - Technical note 1030 December 1980.

VOLUME CORRECTION FACTOR - $k_2 \times 10^{-3}$

Molecular weight of mixture	Volume reduction, l/mol						
	105 K	**110 K**	**115 K**	**120 K**	**125 K**	**130 K**	**135 K**
16	-0.010	-0.015	-0.024	-0.032	-0.043	-0.058	-0.075
17	0.240	0.320	0.410	0.600	0.710	0.950	1.300
18	0.420	0.590	0.720	0.910	1.130	1.460	2.000
19	0.610	0.770	0.950	1.230	1.480	1.920	2.400
20	0.750	0.920	1.150	1.430	1.730	2.200	2.600
21	0.910	1.070	1.220	1.630	1.980	2.420	3.000
22	1.050	1.220	1.300	1.850	2.230	2.680	3.400
23	1.190	1.370	1.450	2.080	2.480	3.000	3.770
24	1.330	1.520	1.650	2.300	2.750	3.320	3.990
25	1.450	1.710	2.000	2.450	2.900	3.520	4.230

Source: N.B.S. - Technical note 1030 December 1980.

ANNEX 2:

Molar mass, superior ideal calorific value on a molar basis and summation factors (ISO 6976 – 1995: tables 1, 2 & 3)

Component	**Molar mass (kg/kmol)**	**Superior ideal calorific value on a molar basis (kJ/mol)**	**$\sqrt{b_i}$ at T 0 °C and P = 101.325 kPa**
Methane	16.043	892.97	0.0490
Ethane	30.070	1564.34	0.1000
Propane	44.097	2224.01	0.1453
n-Butane	58.123	2883.82	0.2069
2-Methyl propane	58.123	2874.20	0.2049
n-Pentane	72.150	3542.89	0.2864
2-Methyl butane	72.150	3535.98	0.2510
2,2-Dimethylpropane	72.150	3521.72	0.2387
Nitrogen	28.0135	0	0.0224