SIGTTO Society of International Gas Tanker & Terminal Operators Ltd

SIGTTO Briefing Note

IMO Data Collection System (DCS): Calculation of N_2 in LNG

First Edition

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Introduction and Scope

1. Introduction and Scope

1.1 Introduction

This briefing note discusses the application of the IMO Data Collection System (DCS) to LNG carriers. The paper provides guidance on the calculation of nitrogen to be deducted from total fuel consumption in accordance with MARPOL Annex VI and its associated Guidelines.

1.2 Scope

The intended audience for the document is charterers, owners and operators of LNG carriers, and terminals.

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DCS Regulation

2. DCS Regulation

2.1 MARPOL

MARPOL Annex VI Regulation 27 requires ships of 5,000 gross tonnage and above to collect consumption data for each type of fuel oil they use, as well as other, additional, specified data including proxies for transport work (Regulation 27.1 and Appendix IX). For the purpose of Annex VI *"fuel oil means any fuel delivered to and intended for use on board a ship"* (Regulation 2.1.14).

2.2 Guidelines

Unified Interpretations in circular MEPC.1/Circ.795/Rev.9 provides clarification concerning data collection for Boil-off Gas (BOG), in section 19:

> *"For Data relating to Boil-off Gas (BOG) consumed on board the ship for propulsion or operation (e.g. BOG used for propulsion, operational needs such as in a boiler, or burnt in a Gas Combustion Unit (GCU) for cargo tank pressure control or other operational purposes) is required to be collected and reported as fuel as part of the Ship Fuel Oil Consumption Data Collection System."*

The 2022 Guidelines for the Development of a Ship Energy Efficiency Management Plan (SEEMP) (Resolution MEPC.346(78)) Part II, paragraph 7, refers to the methods of collecting data on fuel oil consumption including LNG:

> *"7.1. …*
>
> *.4 method using LNG cargo tank monitoring on board:*
>
> *LNG ships use the Custody Transfer Monitoring System (CTMS) to monitor/record the cargo volumes inside the tanks. When calculating the consumption:*
>
> *.1 the LNG liquid volume consumed is converted to mass using the methane density of 422 kg/m^3. This is because LNG is transported at methane boiling point, while other heavier hydrocarbons have a higher boiling point and remain at liquid state; and*
>
> *.2 nitrogen mass content is subtracted for each laden voyage from LNG consumption as it does not contribute to CO_2 emissions;"*

3

LNG Cargo

3. LNG Cargo

3.1 Composition of LNG

Liquefied natural gas (LNG) consists predominantly of methane (CH_4) with some mixture of ethane, propane, butane, pentanes, and nitrogen. The exact composition of natural gas, and the LNG formed from it, varies according to its source and processing history. A typical composition will normally be found within the following indicative ranges:

Methane	85–95%
Ethane	3–8%
Propane	1–3%
Butanes	1–2%
Pentanes	0–2%
Nitrogen	0–2%

3.2 Boil-off Gas (BOG)

While the tanks on an LNG carrier (LNGC) are designed to stay cool, they cannot provide perfect insulation against warming. External heat ingress and vessel motions slowly heat the liquid inside the tanks, which causes the LNG inside to evaporate and produces BOG. To manage the pressure in the cargo tank, LNGCs typically use the BOG as fuel for propulsion.

As BOG develops, the more volatile components in LNG – nitrogen and methane – boil-off first. This changes the composition and quality of the LNG over time in a process known as ageing. The most dramatic effect of this ageing process is that the nitrogen content in the BOG is considerably higher than in the liquid cargo.

3.3 Nitrogen in BOG

Nitrogen as a component of natural gas is a benign component without energy value. The presence of nitrogen in liquefied natural gas is undesirable because of its innate properties.

The application of Raoult's law can show that the impact of the ethane, propane, butane and C_{5+} in the mixture that is LNG, is negligible since their vapour pressure at a typical LNG temperature of –160°C is less than 5 mb in a container where the vapour pressure is of the order of 1,100 mb absolute.

In assessing the composition of the BOG, this only leaves the methane and nitrogen content of the LNG as contributors. Typical nitrogen contents of LNG are of the order of 0.1 to 1.0% at the point of export, which can result in a nitrogen content in the vapour space in the range of approximately 6.5 to 25%.

The nitrogen content in the BOG is relatively higher during the first stages of a laden voyage than the latter part of the voyage, however, it remains a major component in the BOG throughout the voyage. The calorific value of the BOG reduces dramatically with increasing content of N_2.

3.4 Calorific Value of BOG

The nitrogen component in the BOG has no energy value and its impact on the net calorific value of the BOG is therefore considerable.

By way of example a typical BOG composition may be approximately 94% CH_4 and 6% N_2, which would represent a net calorific value reduction from 50.03 MJ/kg in pure methane to 45.02 MJ/kg in the actual BOG, which is a reduction of 10%.

The effect of reduced calorific value is that the engine management system increases the gas flow to the combustion unit to maintain the power production at the level requested, e.g. to maintain constant speed. A decreased net calorific value will therefore result in an increased reported consumption although CO_2 emissions remain the same.

It is for this reason the *"nitrogen mass content is subtracted for each laden voyage from LNG consumption as it does not contribute to CO_2 emissions"* (Resolution MEPC.346(78)) Part II, 7.1.4.2).

4

Reporting of LNG Consumption

4. Reporting of LNG Consumption

Reporting of LNG consumption to IMO DCS is normally based on accumulated data from the vessel's daily noon reports or CTMS readings at the start and end of a voyage. In both cases the reported consumption is the sum of all components existing in LNG.

As discussed above, the nitrogen content in LNG neither contributes to the calorific value of the BOG, nor to the CO_2 emissions. The N_2 content should therefore be deducted from the total LNG consumed prior reporting to IMO DCS. It is therefore suggested to introduce a correction factor, k_{N2}, that accounts for the content of N_2 in the LNG consumed:

$$m_{LNG\_Net} = m_{LNG\_Gross} \cdot k_{N2} \tag{1}$$

where,

m_{LNG_Net} = mass of LNG consumed, excluding N_2-content

m_{LNG_Gross} = mass of LNG consumed, including N_2-content

k_{N2} = correction factor for N_2-content.

k_{N2} should be calculated and documented for each voyage, and used to calculate the consumption to be reported to IMO DCS, m_{LNG_Net}.

4.1 Correction Factor

As described above, the most volatile components in the BOG, nitrogen and methane, evaporate first. The minor fractions of ethane, propane and butane may be considered as negligible.

The correction factor for nitrogen content in the BOG, k_{N2}, may be calculated in different ways, as described below.

4.2 Molar Mass

The molar mass of BOG may be expressed as the sum of the molar masses of CH_4 and N_2:

$$m_{BOG} = a \cdot m_{CH4} + b \cdot m_{N2} \tag{2}$$

where a and b express the fraction of the respective volume flow components in the BOG. The correction factor, k_{N2}, represents the fraction of CH_4 in the mass flow, i.e. the fraction that represents the energy flow, expressed as a function of the molar mass:

$$k_{N2} = \frac{a \cdot m_{CH4}}{m_{BOG}} = \frac{a \cdot m_{CH4}}{a \cdot m_{CH4} + b \cdot m_{N2}} \tag{3}$$

By introducing the molar masses of CH_4 and N_2, 16 and 28, respectively, the correction factor may be simplified as follows:

$$k_{N2} = \frac{16a}{16a + 28b} \tag{4}$$

Figure 1 below shows the correction factor as a function of the nitrogen fraction in the BOG. Where, for example, a volume flow of BOG consisting of 96% CH_4 and 4% N_2 has an estimated correction factor k_{N2} = 0.932.

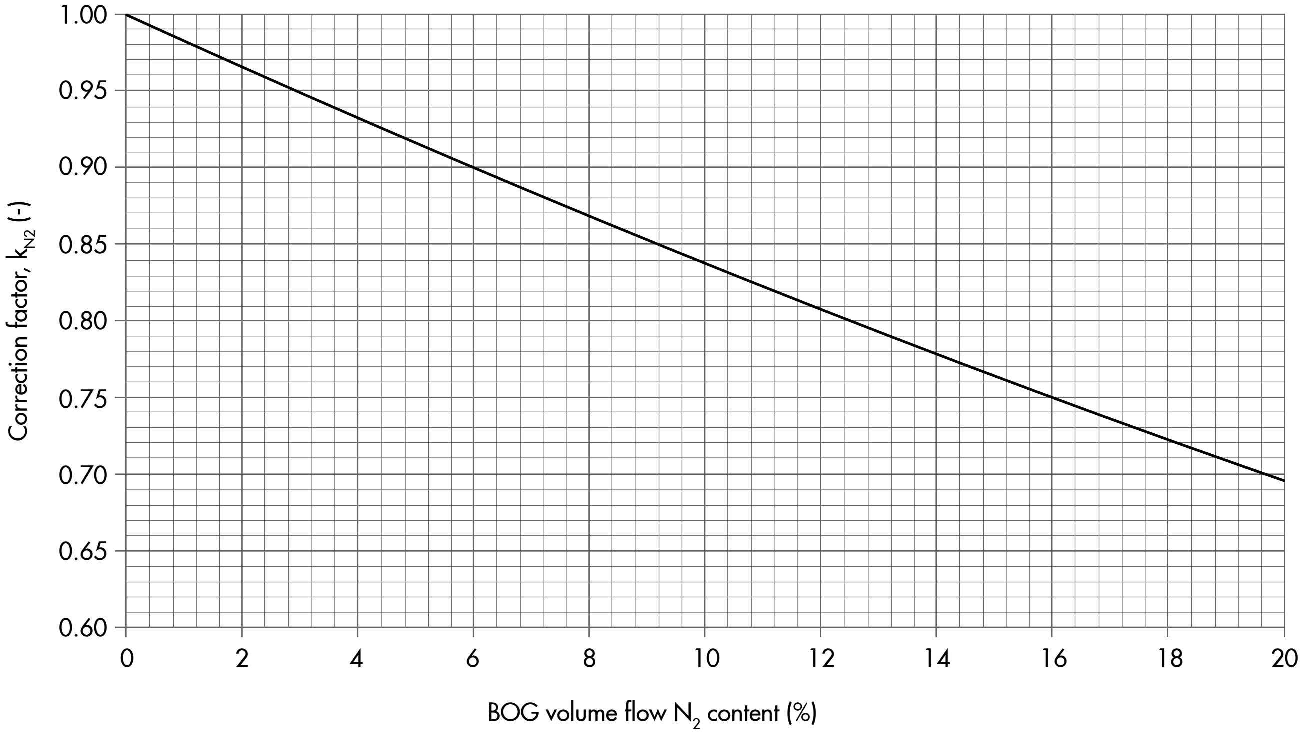

Figure 1: LNG consumption correction factor vs gas flow N_2 content

4.3 Net Calorific Value

A more simplified method for calculating K_{N2} is to use the calculated net calorific value at the documented volume flow fraction and divide by the net calorific value of pure methane.

$$k_{N2} = \frac{NCV_{BOG}}{NCV_{CH4}} \tag{5}$$

Example:

Referring to the example given in 3.4 above, with a BOG composition of 96% CH_4 and 4% N_2:

k_{N2} = 46.64/50.03 = 0.932

4.4 N_2 Consumption

This method is based on known LNG cargo composition at the start and end of a voyage, i.e. loading and discharge. For a known LNG cargo composition, one may easily calculate the total molar mass of N_2 in the loaded LNG as well as in the discharged LNG. The correction factor to be used in the formula (1) above may therefore be expressed as follows:

$$k_{N2} = \frac{m_{LNG\_Gross} - m_{N2}}{m_{LNG\_Gross}} \tag{6}$$

where,

m_{LNG_Gross} is the mass of LNG consumed, including N_2-content

m_{N2} is the calculated consumption of N_2 over the voyage based on known LNG compositions.

A calculation example is provided below utilizing typical data:

		LNG Received		LNG Discharged	
Component	**Mi Molecular Weight**	**Xi Molar Fraction**	**Xi*Mi Molecular Mass**	**Xi Molar Fraction**	**Xi*Mi Molecular Mass**
Methane – CH_4	16.042	97.22	15.596	97.435	15.631
Ethane – C_2H_6	30.069	1.77	0.532	1.864	0.561
Propane – C_3H_8	44.096	0.07	0.031	0.077	0.034
i-Butane – i-C_4H_{10}	58.122	0.01	0.006	0.007	0.004
N-Butane – n-C_4H_{10}	58.122	0.14	0.081	0.12	0.070
i-Pentane – i-C_5H_{12}	72.149	0.00	0.000	0.00	0.000
n-Pentane – n-C_5H_{12}	72.149	0.00	0.000	0.00	0.000
Hexane Plus – C_6H_{14}	86.175	0.00	0.000	0.00	0.000
Nitrogen – N_2	28.013	0.79	0.221	0.50	0.140
Oxygen – O_2	31.999	0.00	0.000	0.00	0.000
Carbon Dioxide – CO_2	44.010	0.00	0.000	0.00	0.000
Total		100.00	16.467	100.00	16.440
Density		0.4313 t/m³		0.4310 t/m³	
Cargo loaded/discharged		149,037.1		146,657.6	
LNG Mass (t)		64,279.7		63,209.4	
LNG Mass consumed (t)		1,070.3			
N_2 mass (t)		862.7		538.3	
N_2 consumed (t)		324.4			
Methane mass (t)		745.9			

Mass of nitrogen in the LNG may be calculated as follows:

$$m_{N2} = \frac{mol_{N2}}{mol_{total}} \cdot v_{cargo} \cdot \delta$$

where,

mol_{N2} is the molar mass fraction of N_2 in the respective LNG volumes

mol_{total} is the molar mass of the LNG composition

V_{cargo} is the cargo volume in m^3

δ is cargo density in t/m^3

If consumed LNG over the voyage is 1,070.3 tons, the correction factor to be applied will be:

$$k_{N2} = \frac{m_{LNG\_Gross} - m_{N2}}{m_{LNG\_Gross}} = \frac{1{,}070.3 - 324.4}{1{,}070.3} = 0.697$$

And LNG consumed reported as 745.9 t.

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Calculation Data

5. Calculation Data

The above calculations assume that the fractions of nitrogen and methane in the BOG is known. Documentary evidence of cargo composition is normally issued and signed in load port. Such papers document the composition of LNG, i.e. in liquid condition, normally around –160°C and atmospheric pressure.

The LNG boils-off (evaporates) during the voyage and the BOG is consumed and utilised for power generation and propulsion. The composition of the BOG differs considerably from the composition of LNG as the nitrogen content is more prominent, often in the range 10–20 times higher than in the LNG.

The nitrogen content can be determined in several ways, explained below: using gas chromatography, empiric calculations, or using certified LNG composition at discharge.

SIGTTO recommends using gas chromatography or using certified LNG composition at discharge. To facilitate accurate reporting, SIGTTO recommends terminals provide certified cargo composition at discharge.

5.1 Gas Chromatography

Gas chromatography (GC) is a common type of chromatography used in analytical chemistry for separating and analysing compounds that can be vaporized without decomposition. Typical uses of GC include testing the purity of a particular substance or separating the different components of a mixture.

Gas chromatography has been used for verification of BOG composition onboard LNG vessels for some years already. Their main purpose has been to document the calorific value of the BOG to prevent engine knocking. The industry is currently developing engine control systems that includes in-line gas chromatography for automatic engine control and knocking protection.

A gas chromatograph, correctly installed, calibrated, and maintained is the most reliable method for analysing and documenting the composition of BOG from LNG cargo tanks. Although it is not widely installed across the existing fleet of LNGCs.

5.2 Empirical Calculations

Various applications have been developed to estimate the composition of BOG based on the composition of LNG in the cargo tanks and the cargo temperature. These may be used either for laden voyages using the cargo quality papers, or ballast voyages by updating heel composition based on the composition of the LNG delivered to the receiving terminal.

5.3 Certified LNG Composition

The N_2 consumption method (4.4) assumes the composition of the LNG is known at both loading and discharge. The N_2 'consumed' in the consumption process may be easily calculated if the LNG composition is known for both the received cargo and the delivered cargo. To facilitate accurate reporting SIGTTO recommends terminals provide certified cargo composition at discharge.

5.4 Default Mass Value

It is recommended the actual cargo data is used. However, the SEEMP guidelines permit a default value of 0.422 t/m^3. In such cases the volume of gas consumed should be multiplied by the default value. In the example above the reported consumption would be:

$$(149{,}037.1 - 146{,}657.6) \times 0.422 = 1{,}004.1 \text{ t}$$

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