ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/01.3001.0012.2793

THE IMPACT OF METHANE SLIP FROM VESSELS ON ENVIRONMENT

Jerzy Herdzik

Gdynia Maritime University
Marine Power Plant Department
Morska Street 81-87, 81-225 Gdynia, Poland
tel.: +48 58 5586430, fax: +48 58 5586399
e-mail: j.herdzik@wm.am.gdynia.pl

Abstract

It was presented the ways of methane leakages during transport by sea. Due to greenhouse (GH), effect of carbon dioxide on atmosphere it was mentioned the carbon cycle on the Earth. Carbon dioxide is the main GH gas and it was indicated the change of concentration during last sixty years. It was increased about 30%. The possible methane leakages from vessels may increase the total GH effect due to high Global Warming Potential (GWP) of methane and other hydrocarbons. The carbon dioxide emission from engines is about 30% lower that from liquid marine fuels (diesel oils and heavy fuels). The liquefied natural gas (LNG) or compressed natural gas (CNG) seems to be a good ecological marine fuel. Due to methane leakages estimated on the level of 1-10% from mining to burning in the engines and the GWP on the level about 72-84 the look on methane as ecological fuel may change. It was calculated the equivalent effect (additional effect) of using methane as a marine fuel. Methane leakage on the level of 1-2.5% is equivalent to the same warming effect to the atmosphere as using popular marine diesel oils. Therefore, the leakage of methane during all operations should be as small as possible. In many cases, it is a serious problem for calculating the real leakages so they may be only estimated.

Keywords: *natural gas, methane slip, methane leakages, environment, impact on environment*

1. Introduction

Shipping market tries to find ecological fuels due to limitations of emission to the atmosphere nitrogen oxides, sulphur oxides, particulate matters and other greenhouse gases like carbon dioxide or hydrocarbons from engines and boilers. Of course, the price of wanted fuels should be reasonable taking into account additional costs and problems with using low sulphur fuels, exhaust gases cleaning methods or exhaust gas recirculation systems. Using natural gas as marine fuel allows for many expectances for fulfilment the environment limits [1, 5, 9]. Due to lower content of carbon and bigger low heat value (LHV) the emission of carbon dioxide is about 30% lower than from diesel oils. The other emission parameters (mentioned above) are also better.

There are some difficulties with using natural gas (mainly as liquefied natural gas) due to storage methods, tank's insulation, bigger capacity of tanks, fuel feeding systems, safety devices etc. [4, 7, 8, 12, 29]. On LNG carriers, the natural gas as fuel has the excellent future because we could not find proper solutions what to do with boil-off gas from cargo tanks. Here there are fuel tanks inside the cargo tanks and it is possible to evaporate so much gas as it is required for all energetic purposes.

2. Remarks about the influence of atmosphere gases on the environment

2.1. Green-house effect of carbon dioxide

There are many substances having the greenhouse effect on the earth atmosphere. Carbon dioxide is the first one and most important for earth climate is of course [18, 26-28]. This is a gas having strong effect on medium temperature on planet and acted as a thermostat. The carbon cycle on the Earth is the most important for the carbon dioxide concentration in the atmosphere. It depends on:

- volcanoes (they put the carbon dioxide into the atmosphere at a fairly constant rate with exception on eruption of super volcano),
- weathering of rocks (the fastness depends on medium temperature on the Earth),
- ocean uptake (the soils go into the seas as a deposits on the seabed),
- the industry emission.

The system needs thousands or millions years to stabilize after great disturbances. In the iced eras, the carbon dioxide concentration has been on a level of 200 ppm [26], in 1958 was about 315 ppm and climbs exponentially, in 2015 reached 400 ppm (see Fig. 1). Probably in July 2016, the carbon dioxide concentration was 404.50 ppm and in July 2017 reached 407.25 ppm.

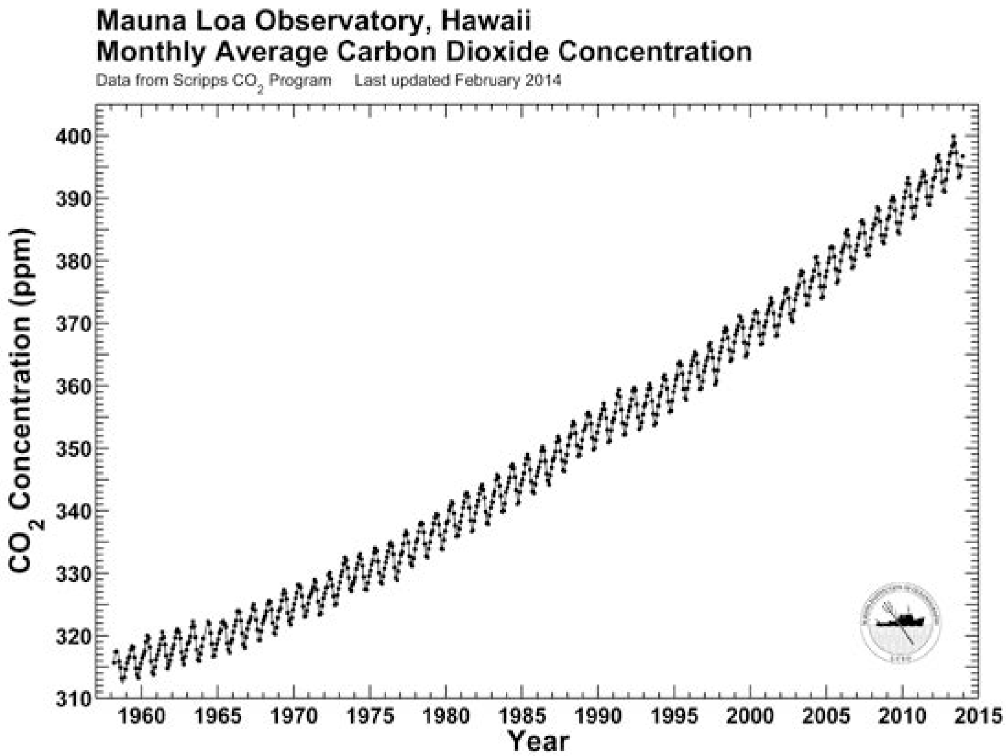

Fig. 1. The carbon dioxide concentration from 1958 to 2015 in the atmosphere [26]

The industry emission of carbon dioxide is the main reason of such situation. About a half of mentioned emission was accumulated into the oceans, but the other half increases the atmosphere concentration. From fossil fuels, the world emission increases every year as follows [27]:

- in 1900 was $0.6 \cdot 10^9$ tons,
- in 1960 was $2.6 \cdot 10^9$ tons,
- in 1980 was $5.4 \cdot 10^9$ tons,
- in 2000 was $6.6 \cdot 10^9$ tons,
- in 2014 reached $9.8 \cdot 10^9$ tons (9800 Mtpa).

2.2. Green-house effect of methane

There are many indicators of gases warming effects. The global warming potential (GWP) is the most popular one. The GWP indicator depends on the type of gas and time taking into account in comparison to carbon dioxide effect [6, 13, 14]. For methane the GWP coefficient (depending on time, accordingly 100 and 20 years) is from 25 to 72 (in other sources from 28 to 84) [6, 13, 26]. It means that 1 unit of methane in 20 years period has the same warming effect like 72 units of carbon dioxide.

2.3. Others effects of using methane as fuel

Natural gas (NG) is one of the fossil fuels. The main component is methane (CH_4). For low purity, methane there is about 91% of CH_4 for high purity about 97%. It contents other gases like nitrogen, ethane and below 1% of higher hydrocarbons [2, 11, 15, 16, 19, 25].

Taking into account the low heat value (LHV) for marine diesel oil (MDO) and methane as follows:

– LHV_{MDO} = 42700 kJ/kg,
– LHV_{CH4} = 48400 kJ/kg

and the carbon dioxide emission coefficient c_F:

– c_{FMDO} = 3.12 kg CO_2 per kg of fuel,
– c_{FCH4} = 2.75 kg CO_2 per kg of fuel

and to assume that the engine efficiency is the same when fuelled MDO or LNG the comparison indicator *CI* between methane and diesel oil will be:

$$CI = \left(\frac{c_{FCH4}}{c_{FMDO}}\right)\left(\frac{LHV_{MDO}}{LHV_{CH4}}\right), \tag{1}$$

we reach *CI* = 0.7776.

It means that that producing the same quantity of energy emission of CO_2 from LNG will be about 22.24% lower than from MDO. In [6] it was calculated the emissions intensity factors for 1 GJ energy as:

– for MDO 69.8 kg CO_2-e/GJ,
– for LNG 53.6 kg CO_2-e/GJ,

the comparison indicator *CI* will be:

$$CI = 53.6/69.8 = 0.7679.$$

It means that the received results of *CI* are very close.

The effect of MDO pollution on environment is crucial especially for inland waters, seas and oceans. In normal vessel operation, if happened any leakage, this is still liquid which may be gathered to container or tank and should not have a big impact on atmosphere, for this consideration the effect let be zero.

On other hand, the effect of LNG leakages may be essential for the atmosphere due to the GWP for methane. The problem is to estimate how many percentage the leakages make in total volume of used methane as a fuel. The estimation level changes from 3 up to 9% depending on the source of publication and the ways of calculations [13, 14].

Calculating the equivalent carbon dioxide emission from methane c_{FCH4}^{eq}:

$$c_{FCH4}^{eq} = c_{FCH4}\left(\frac{LHV_{MDO}}{LHV_{CH4}}\right), \tag{2}$$

it was received $c_{FCH4}^{eq} = 2.426$.

Taking into account equivalent emission of CO_2 by the additional warming effect from methane leakages and from methane burning in comparison to emission CO_2 from MDO we have equation (3):

$$m_F c_{FCH4}^{eq} + m_L GWP_{CH4} = m_F c_{FMDO}, \tag{3}$$

where:

m_F – burning fuel mass,

m_L – mass of methane leakage,
GWP_{CH4} – global warming potential for methane = 72.

Calculating the specific mass leakage of methane to the equivalent warming effect, received equation (4):

$$\frac{m_L}{m_F} = \frac{c_{FMDO} - c^{eq}_{FCH4}}{GWP_{CH4}} \tag{4}$$

and result $m_L/m_F = 0.009639$.

It means that only about 1% of methane leakage counteracts the ecological advantage of using methane as a fuel. If we put into equation (4) $GWP_{CH4} = 25$, the m_L/m_F will amount 0.02376.

Summing up the leakage of methane during all operations should be as small as possible. Methane leakage on the level of 1-2.5% is equivalent to the same warming effects to the atmosphere as using the popular MDO.

Carbon dioxide is not only the one gas, which goes to the atmosphere during burning the MDO or LNG.

2.4. Emission limitations of other gases to the atmosphere

After burning the MDO or LNG as fuels in diesel engines in exhaust gases, we have other gases dangerous as well: sulphur oxides SO_x, nitrogen oxides NO_x, particulate matters (PM), and hydrocarbons C_mH_n. There is about 5% of water steam but in spite of strong warming effect the time of staying in the atmosphere is only 3-5 days, so the proposition was that GWP for steam is zero.

The MARPOL Convention in annex 6 requires the existing and future limits of emission outside and inside the ECA areas. The NO_x and SO_x emission limits is shown in Fig. 2.

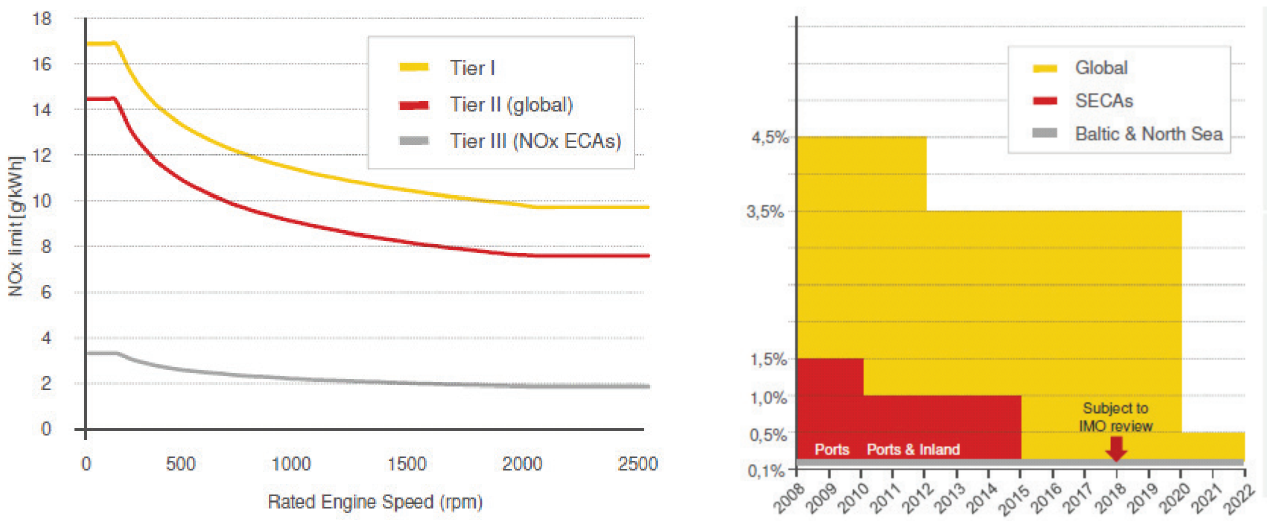

Fig. 2. Existing and possible future emission limits of NO_x and SO_x [16]

Preparing the diesel engines for smaller emission of NO_x and SO_x the ways and methods to fulfil the International Maritime Organization (IMO) requirements were developed. It was built the scrubber systems (cleaning the exhaust gases to required limits) or exhaust gas recirculation (EGR) systems. It was changed fuel burning processes, air turbochargers, air delivery systems etc. The engine modifications increase the specific fuel consumption (about 1-2%) with decreasing the engine nominal power, engine efficiency and due to bigger fuel, consumption increased the carbon dioxide emission to the atmosphere.

The remedy on it is using LNG as a fuel. The conversion on dual fuel (DF) engine example is mv. Bit Viking (presented in Fig. 3). The vessel operation experience shows that [28]:

– carbon dioxide emission reduced of more than 25% (additional a little bigger efficiency of engine working on LNG),

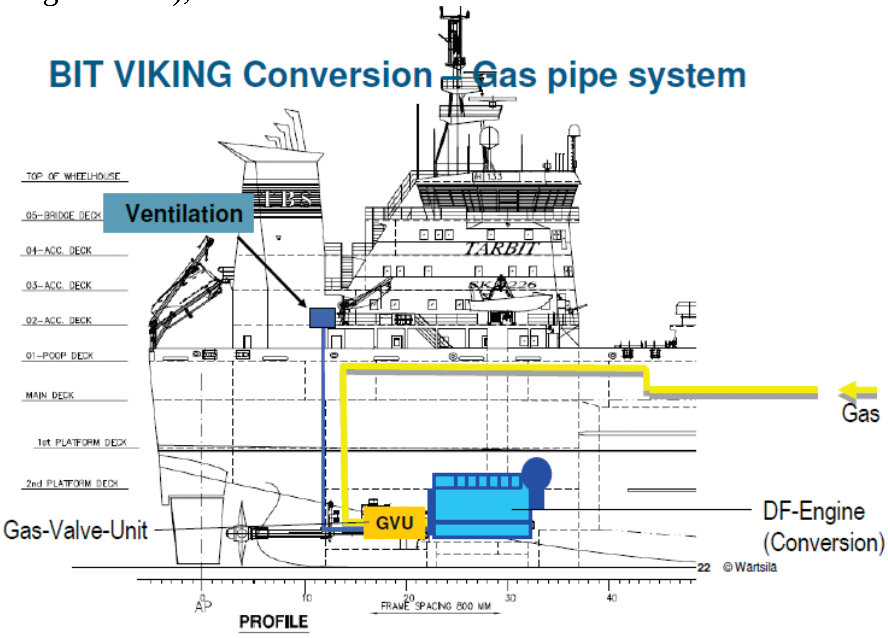

Fig. 3. Mv. Bit Viking conversion on possibility of using methane as fuel [28]

– emission of SO_x is approximately zero (LNG during cleaning and preparing for reliquefaction processes has no sulphur),
– NO_x emission reduced to 90% (fulfils the requirements of Tier 3 the Annex 6 of MARPOL Convention),
– no abrasive wear caused by heavy fuel oils (HFO) operation in DF-engines,
– no HFO residues in engine lubricating oil,
– no limitations on gas engine operation regarding operating time and shipping routes,
– ship-operating costs reduced of approx. 20%,
– and others [28].

3. The future of natural gas as a marine fuel

The age of hydrogen will come in next twenty-fifty years but now it is a necessary to undertake a decision what kind of fuel is the best for shipping. The use of methanol is feasible on some markets but due to a few disadvantages: smaller lower heat value (about a half than diesel oil), toxicity, and flammability it will be only one of possible ecological fuel.

The market of natural gas (mainly liquefied natural gas) seems to be more attractive [10, 17, 20-22]. Raw natural gas is processed to remove most of non-methane gases (nitrogen, carbon dioxide, compounds of sulphur) and contaminants before it is liquefied. The composition of LNG varies but contains more than 90% of methane (for high purity methane over 97%). The 100% methane (possible after purification process) will not be probably used on a big scale. The use of natural gas as a marine fuel has been promoted when compared to residual oil fuels. Using LNG produces less of the three main pollutants attributing to shipping (nitrogen oxides, sulphur oxides and particulate matters). The reduction emission of nitrogen oxides is on level of 80%, the sulphur oxides and particulate matters PM_{10} is near 100% and additionally the emission of carbon dioxide is reduced about 30%. However, emissions of carbon monoxide and total hydrocarbons were higher. Analysis of the exhaust gases showed that around 85% of hydrocarbons emissions from

LNG were methane. The unburnt methane makes about 7 g per 1 kg of LNG (0.7%) at higher engine loads, rising to 23-36 g at low loads [3, 15, 23, 24, 30].

The demand for LNG as a marine fuel in next twenty years depends on the environmental restrictions concerning to all types of fuel but the many analysis showed the growth in a mass and in a contribution.

4. Final remarks

LNG fuels allows for decreasing the local pollution emissions. Using of natural gas as a marine fuel fulfils the criteria of Annex VI MARPOL Convention. Wider conversion to natural gas needs establishing the LNG bunkering network [13]. It will be easier done for shorter transport routes (problems with worldwide bunkering and storage) due to necessary LNG supply and delivery to ships (infrastructure). Dual fuel engines give the possibility of switching on natural gas on the Environment Control Areas (ECA), roads and in ports.

It must be remembered that the impact of methane on the environment is strong and the methane slip should be restricted. It is a time for achieving fleet wide climate-neutral performance on LNG in shipping.

References

[1] Baekert, M., *LNG as fuel for shipping*, Norsk Gassforum, DNV-GL, Brussels 2016.
[2] *Cargo Operating Manual of Al Qattara*, 2008.
[3] Contessi, C., *Gas engine emissions. Wartsila dual engines*, Wartsila 2013.
[4] Corbett, J. J., et al., *Methane emissions from natural gas bunkering operations in the marine sector: A total fuel cycle approach*, prepared for: US Department of Transportation Maritime Administration, 2015.
[5] Friederich, G., *LNG as ship fuel*, Innovation Update, Germanischer Lloyd, 2013.
[6] *Gas tanker advanced course*, IMO, 2009.
[7] *QGII QFLEX operational manual*, Hamworthy Gas Systems AS, 2006.
[8] *Guide for LNG fuel ready vessels*, ABS, 2014.
[9] Herdzik, J., *LNG as a marine fuel. Possibilities and problems*, Journal of KONES Powertrain and Transport, Vol. 18, No. 2, pp. 169-176, 2011.
[10] Herdzik, J., *Aspects of using LNG as a marine fuel*, Journal of KONES Powertrain and Transport, Vol. 19, No. 2, pp. 201-210, Warsaw 2012.
[11] Herdzik, J., *Consequences of using LNG as a marine fuel*, Journal of KONES Powertrain and Transport, Vol. 20, No. 2, pp. 159-166, 2013.
[12] Herdzik, J., *The possibility of natural gas transport by ships in state of methane hydrates*, Scientific Journals of Gdynia Maritime University, No. 91, pp. 54-63, 2015.
[13] Herdzik, J., *Remarks about the European ports regulations of natural gas bunkering*, Scientific Journals of Gdynia Maritime University, No. 100, pp. 100-108, 2017.
[14] history.aip.org/climate/co2.htm, accessed 22 August 2017.
[15] *In focus – LNG as ship fuel. Latest development and projects in the LNG industry*, DNV GL, 2015.
[16] intertanko.com/Documents/ISTEC%20LNG%20WG%202015/Maran%20-%20TRI%20 FUEL%20ENGINES.pdf, accessed: 12 June 2017.
[17] Khameneh, N. A., et al., *Methane hydrates as potential energy resource*, Project Report – Natural Gas TPG 4140, NTNU, Trondheim 2012.
[18] *Liquefied Natural Gas (LNG) Bunkering study*, DNV-GL, report No. PP087423-4, rev. 3, 2014.
[19] *LNG carrier operation technology text*, Mitsui OSK Lines Ltd., 2007.
[20] *LNG custody transfer handbook*, G.I.I.G.N.L. DS TML/Z-CG-2001.
[21] McGuire and White, *Liquefied Gas Handling Principles on Ships and in Terminals*, SIGGTO, Witherby Publishers, 2008.

[22] *Marine Resources – Opportunities and Risks*, World Ocean Review 3/2014.
[23] *Methane emissions from LNG-powered ships higher than current marine fuel oils*, Science for Environment Policy, European Commission, 28 January 2016.
[24] *Natural gas as a transportation fuel energy*, Morgan Stanley Research 2013.
[25] *Natural gas for ship propulsion: Rules and regulations*, Holland Shipbuilding Association, 2011.
[26] Rehder, D., et al., *Methane hydrate pellet transport using the self-preservation effect: A techno--economic analysis*, Energies, Vol. 5, pp. 2499-2523, 2012.
[27] *Trends in global CO_2 emissions*, PBL Netherlands Environmental Assessment Agency, report 2016.
[28] Verbeek, R., et al., *Environmental and economic aspects of using LNG as a fuel for shipping in The Netherlands*, TNO-RPT-2011-00166, 2011.
[29] Vandebroek, L., Berghams, J., *Safety aspects of using LNG for marine propulsion*, Procedia Engineering, Vol. 45, pp. 21-26, 2012.
[30] Thomson, H., et al., *Natural gas as a marine fuel*, Energy Policy, Vol. 87, pp. 153-167, 2015.

Manuscript received 07 February 2018; approved for printing 01 June 2018