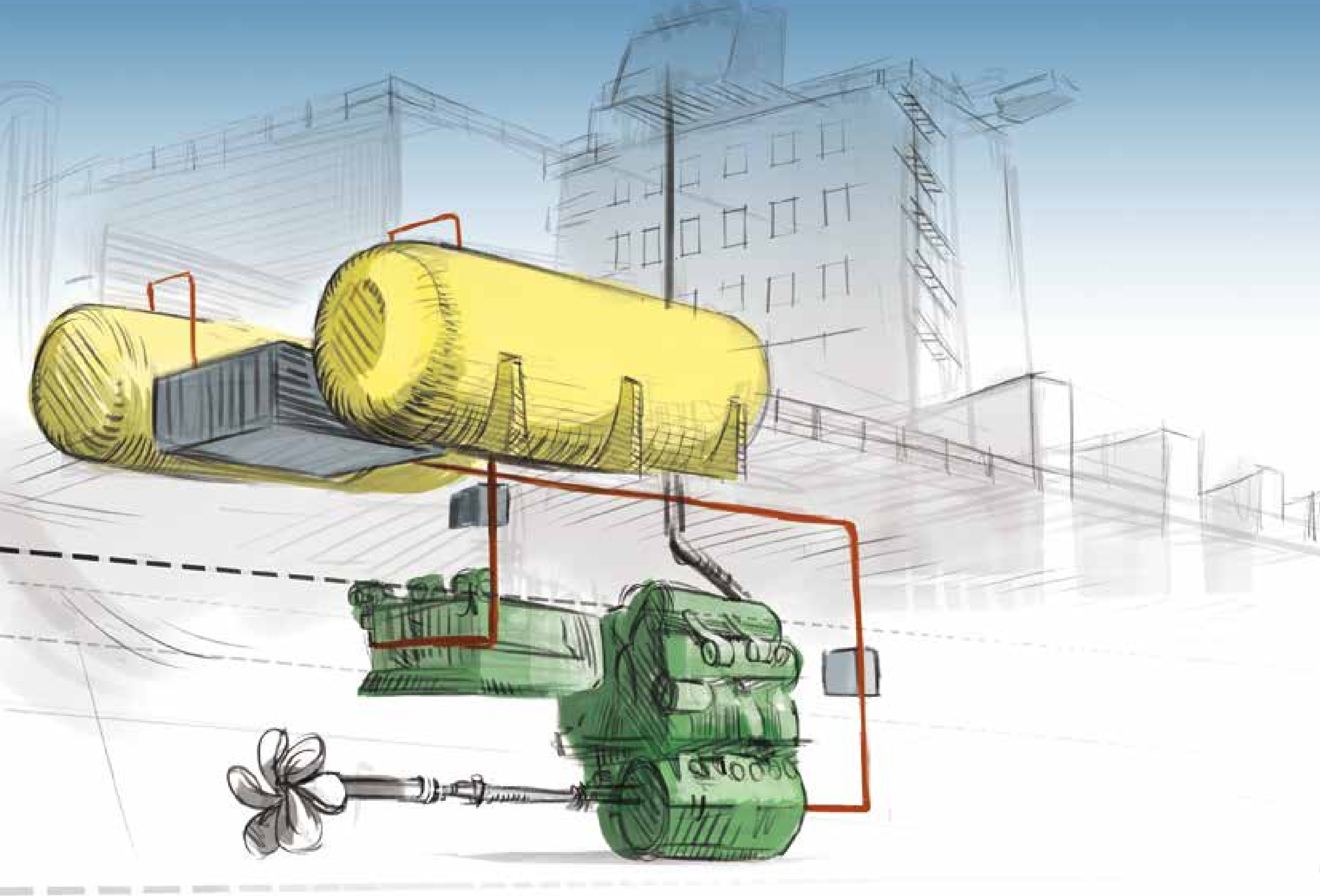

LVOC Combusting ME-GIE Engine

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MAN Diesel & Turbo

Contents

Introduction

The Mitsui-MAN B&W 7G50ME-C9.5-GIE engine originally designed for combustion of ethane gas also runs on 100% liquefied natural gas (LNG) but equally important it also combusts a mixture of LNG and volatile organic compounds (VOC) with limited change in gas mode efficiency. It has been established that the mixture can contain as much as 50% VOC by mass. Although the ignition properties of LNG and VOC are highly varying, the diesel-type combustion of the ME-GIE and the use of pilot diesel injection for ignition gives the engine the ability to run on almost any fuel gas quality with no or very limited efficiency penalties. The ME-GIE engine is therefore not vulnerable to the gas quality or low methane number, and knocking does not pose a risk. These engine characteristics are vital when burning VOC, because the composition of the VOC will vary depending on the origin of the crude oil cargo and maturing.

This opens for new applications of the engine in for example VLCCs and shuttle tankers and for power generation in remote power plants or in off-shore applications, such as floating production storage and offloading vessels (FPSOs), where VOC is abundant and poses a potential environmental hazard. Today, handling of crude oil on board crude oil carriers and in ports gives rise to economic losses and environmental hazard. To control the cargo tank pressure, VOC is discharged to the atmosphere, where the non-methane part may react with nitrogen oxide in the presence of light and create ozone and smog [1].

Hydrocarbon gases or VOC evaporate from crude oil, in particular in connection with loading, laden voyages and tank cleaning after discharge. The degree of evaporation depends on the vessel's tank design, ambient conditions and sailing schedule.

In a typical shuttle tanker, evaporation from crude oil results in approximately 200-300 m^3 liquid volatile organic compounds (LVOC) with a maximum of approximately 500 m^3 per trip.

Please note that the ME-C-LGIP engine type can also combust LVOC. In this case it is not possible to mix the LVOC with LNG, but instead LPG can be added. The engine will burn any mixture of LVOC and LPG. The LGIP engine will be described in a another paper.

Facts about Volatile Organic Compounds

An economic and environmentally attractive solution to discharging VOC to the atmosphere is to recover the VOC from the crude oil and separate it into liquid volatile organic compounds (LVOC) and semi-volatile organic compounds (SVOC), see Fig. 1. The VOC in the crude oil cargo tanks may contain all components of the crude oil including the heavier hydrocarbons.

The longer the crude oil tank contains the VOC gas, the larger the fraction of the heavier hydrocarbons that will be present in the VOC. In general, the molecular composition of the VOC depends on the tank retention time, temperature, pressure and how often the crude oil tank is vented. The crude oil cargo tank is pressurised with nitrogen during loading and discharge of cargo.

The heavier hydrocarbons, namely propane, i- and n-butane, i- and n-pentane, hexane and yet heavier hydrocarbons (C7 – C10+, see Table 1) constitute LVOC, which is collected in the separate VOC tank. The lighter fractions, mainly methane, ethane and nitrogen, which cannot be condensed, can also be collected in a pressure tank, a so-called compressed natural gas (CNG) tank.

To indicate the knocking tendency of a gas fuel, it is assigned a methane number which depends on the different constituents of the gas. Methane with a low knocking tendency is given the methane number 100 and hydrogen with a high knocking tendency is given the value zero. VOCs with a high content of propane and, in particular, higher hydrocarbons like butane, pentane, hexane, and heavier have very low methane numbers and a high knocking tendency. Due to its low methane number, the VOC cannot be used in Otto-cycle engines, so using it in the ME-GIE is the only right solution.

When combusting LVOC on the ME-GIE the LVOC must be mixed with CNG to lower the energy density by volume of the injected fuel. The mixing is determined by the injection pressure and the energy density of the fuel. If the energy density is high, the pressure has to be higher as well to secure sufficient air entrainment into the flame.

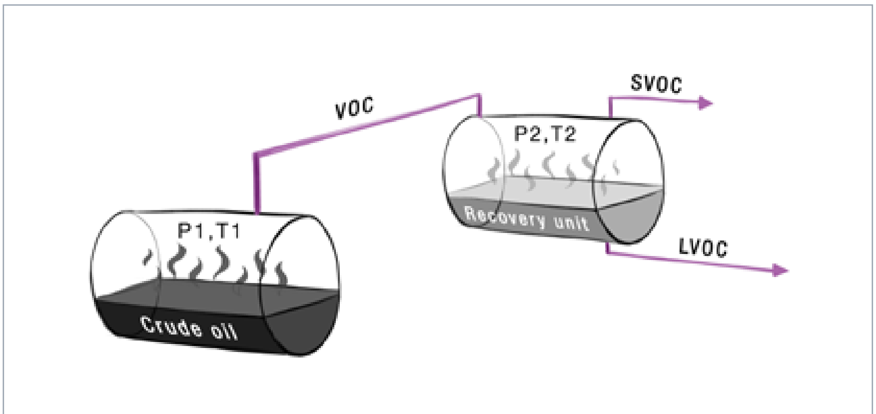

Fig. 1: Schematic showing VOC recovery

It is vital that the fuel remains on one phase in the fuel gas supply system (FGSS) and during injection in order to keep a constant amount of energy injected per engine cycle. Furthermore, the requirement to fuel being in a single phase minimises the risk of cavitation, and it ensures that the right energy content is injected. LNG and LVOC have been found to be fully miscible at pressures above 250 bar without any phase seperation.

Two parameters give rise to a limitation on the LVOC concentration in the LVOC and CNG fuel mixture. The first parameter is the amount of the heaviest hydrocarbons, C10+ in the LVOC. Too high a concentration of these (C10+ > 1 mol%) will cause the fuel gas to form liquid and gas phases in the FGSS and during injection. Knowing the C10+ concentration is important to avoid two phases when mixing with methane. To be on the safe side the molar content of C10+ should be below 0.1 mol%. In this case CNG can be mixed with any concentration of LVOC.

The second parameter is the amount of nitrogen in the LVOC – CNG fuel. The nitrogen concentration should be less than 30 mol%, which does not seem difficult to comply with. The SVOC will contain large amounts of N_2.

Component	Component	Weight%	Mol%	Molar mass g/mol	Density g/cm³
Nitrogen	N_2	0.02	0.04	28.01	0.808
Methane	C1	0.15	0.50	16.04	0.3
Ethane	C2	5.83	10.68	30.07	0.358
Propane	C3	28.66	35.81	44.1	0.508
i-Butane	iC4	9.43	8.95	58.12	0.563
n-Butane	nC4	22.11	20.97	58.12	0.585
i-Pentane	iC5	7.37	5.63	72.15	0.625
n-Pentane	nC5	7.83	5.98	72.15	0.631
Hexane	C6	7.19	4.71	84.2	0.6675
Heptane	C7	6.43	3.65	97	0.7378
Octane	C8	3.23	1.65	107.7	0.7654
Nonane	C9	0.68	0.32	117.9	0.781
Decane	C10 and nC10+	0.26	0.1	n.a	n.a
SUM		100,00	100,00		

Table 1: VOC composition and classification of hydrocarbons

ME-GIE and VOC

The layout of the FGSS depends on the type of ship. In the following, two different configurations of the FGSS will be briefly presented. The supply systems meet the ME-GIE requirements to supply pressure and temperature, which means 380 bar at 45°C.

In the first FGSS system shown in Fig. 2, LVOC and LNG is supplied from two separate strings that are mixed before the engine. The LVOC kept in the VOC tank at ambient temperature is, depending on the temperature, either cooled or heated in the heat exchanger to match the requirements to the fuel supply pressure and temperature of the ME-GIE engine.

The turnkey pump and vaporiser unit (PVU) recently developed by MAN Diesel & Turbo combines the cryogenic

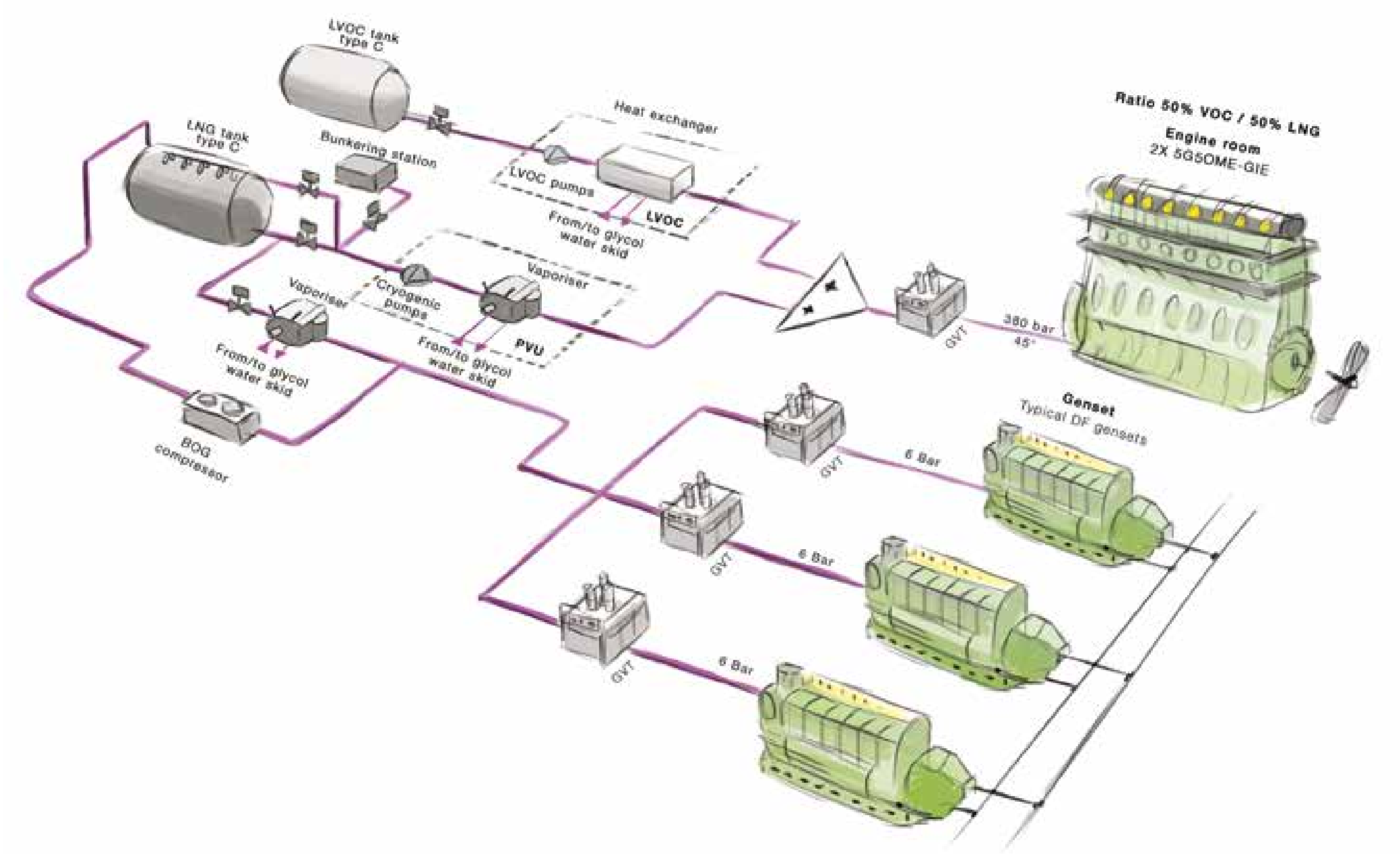

Fig. 2: FGSS for the LVOC burning ME-GIE two-stroke engine

pump and vaporiser in a compact unit offering a simplification of the entire FGSS. The PVU contains three cryogenic booster pumps, a compact vaporiser and LNG, glycol and natural gas (NG) filters.

In the second FGSS shown in Fig. 3, the VOC is separated into LVOC and SVOC. These are later mixed in a predetermined ratio, as mentioned earlier, before injection in the ME-GIE. Before delivery and gas trial it is required that the enigne is tested on the testbed on both LNG and a mixture of LNG and LPG. The LVOC does not need to be avilable at the testbed, a mixture of LNG and LPG is sufficient.

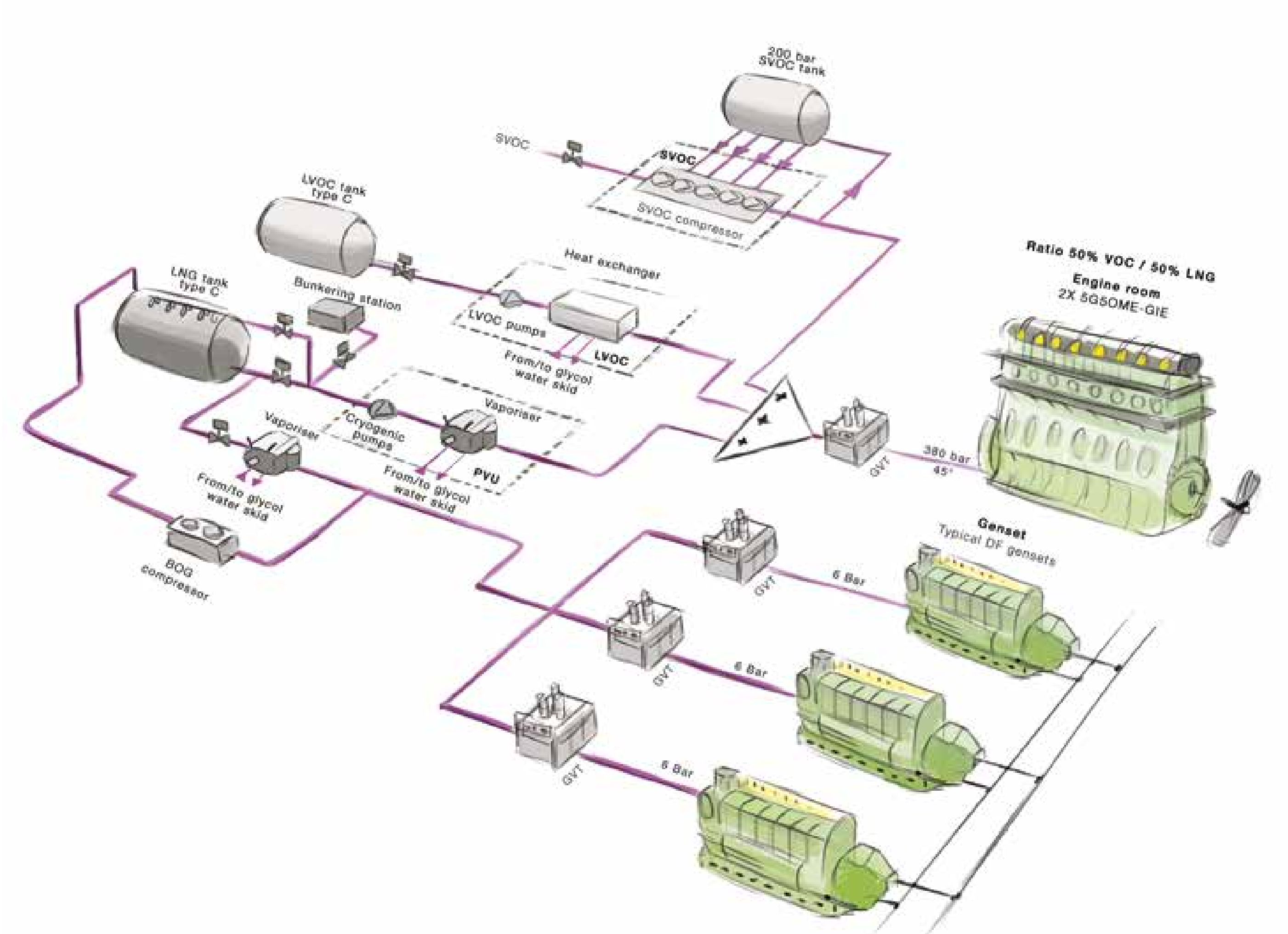

Fig. 3: FGSS where the recovery unit separates the VOC into LVOC and SVOC, which are mixed and burned in the ME-GIE in a predefined ratio

Summary

The capability of the multi-fuel Mitsui-MAN B&W 7G50ME-C9.5-GIE engine to combust ethane gas, 100% LNG or a mixture of LNG and VOC opens for new possible applications in for example VLCCs, shuttle tankers, for power generation in remote power plants or in off-shore applications, such as floating production storage and offloading vessels (FPSOs).

It has been established that the mixture can contain as much as 50% VOC, but the value is likely to increase even more. The ignition properties of VOC with a very low methane number imply that it cannot be utilised in an Otto-cycle engine. This makes the ME-GIE engine the obvious choice, since gas quality, low methane number and knocking are not issues.

In a typical shuttle tanker, evaporation from crude oil results in approximately 200-300 m^3 liquid volatile organic compounds (LVOC) per trip. This paper presents two fuel gas supply systems that allow utilisation of the VOC energy that would otherwise be vented to the atmosphere with economic loss and environmental hazard as the consequences.

Abbreviations and Acronyms

BOG	boil-off gas
CNG	compressed natural gas
FGSS	fuel gas supply system
FPSO	floating production storage and offloading
GVT	gas valve train
LNG	liquefied natural gas
LVOC	liquid volatile organic compound
NG	natural gas
PVU	pump vaporiser unit
SVOC	semi-volatile organic compound
VLCC	very-large crude carrier
VOC	volatile organic compound

References

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MAN Diesel & Turbo
Teglholmsgade 41
2450 Copenhagen SV, Denmark
Phone +45 33 85 11 00
Fax +45 33 85 10 30
info-cph@mandieselturbo.com
www.mandieselturbo.com