FEASIBILITY STUDY OF THE LOW EMISSION LNG SYSTEM

WARTSILA RT-FLEX50 DUAL FUEL

Winterthur Gas & Diesel

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Preface

The Feasibility Study of the Low Emission LNG System is focusing on LNG as fuel for Wärtsilä marine 2-stroke DF engines. The document highlights the advantages of the low pressure gas “DUAL FUEL” concept, as well as the possibility to manufacture and deliver the first 5RT-flex50DF engine in 2015.

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1 LIQUEFIED NATURAL GAS AS MARINE FUEL

1.1 Natural gas

Natural gas is a hydrocarbon mixture in gaseous state consisting primarily of methane and traces of other gases: ethane, propane, iso-butane, butane, iso-pentane, pentane, nitrogen, carbon dioxide, oxygen and other gases.

Winterthur Gas & Diesel focuses on methane, or more specifically the equivalent methane number (MN) as well as the lower heat value (LHV), when analyzing natural gas qualities intended as marine fuel in Wärtsilä 2-stroke DF engines.

1.2 LNG definition

Liquefied Natural Gas (LNG) is natural gas cooled to -162°C.

1.3 LNG influence of fuel tank sizes

At -162°C the natural gas liquefies and shrinks to about 1/600 of its original volume in gaseous state. In LNG form the heat density thereby increases and as a rule of thumb, LNG has an energy density corresponding to 60% of the energy density for diesel oil. When selecting LNG as fuel, the size of the LNG tanks has to be considered. To carry the equivalent amount of fuel energy, the LNG tank volume has to be sized about 1.7 times the volume of a diesel oil tank.

1.4 LNG tank types

Various designs for LNG tanks are existing and commercially available. Normally LNG tank types are referred to as: tank A type, tank B type, tank C type and membrane tanks. The type of LNG tank selected is influenced by the ship owner's operating profile and preference.

LNG storage as marine fuel onboard vessels is not described further in detail in this document.

1.5 LNG as marine fuel for Wärtsilä 2-stroke DF engines

Natural gas is named LNG in its liquid form, however, Wärtsilä 2-stroke DF engines are supplied natural gas in gaseous form with a supply pressure not exceeding 16 bar. LNG from the fuel storage tanks is gasified before being compressed to desired supply pressure.

2 Objectives to use LNG as marine fuel

2.1 Emission limitations

The global merchant marine industry is in the midst of a revolutionary transformation, with increasing pressure from new laws and higher environmental requirements. Increased focus on emissions from marine trade has resulted in tightening limits for nitrogen oxides (NOx) and sulphur oxides (SOx) emissions.

2.1.1 NOx emissions

NOx emission limits defined and valid today are, depending on the age of the installation, either TIER I or TIER II, with TIER III emission limits already entering into force for new buildings with keels being laid in 2016. Conventional diesel engines can comply with TIER I and TIER II limits without exhaust gas after-treatment equipment. However, to comply with the TIER III emission limits exhaust gas after-treatment, in some form, will be required for installations having conventional diesel engines installed.

2.1.2 SOx emissions and control areas

Sulphur Emission Control Areas (SECA) are already existing around the world and further SECA areas are under discussion. As per IMO regulations valid from 1 January 2015, ships trading in SECA areas have to use fuel oil with a sulphur content not exceeding 0.10% m/m, alternatively approved methods to clean the exhaust gas from SOx, to an equivalent emission level as if using a distillate with 0.10% m/m sulphur content, is accepted.

SOx emissions correlate directly to the sulphur content in the fuel being used.

2.2 MARINE FUEL PRICE FLUCTUATION

The cost of heavy fuel oil (HFO) and marine diesel oil (MDO) is heavily depending on the cost of crude oil. The cost of liquid bunker will continue to fluctuate with the crude oil prices. Due to SOx regulations, also applicable for already existing vessels, it is believed that the cost difference between HFO and MDO will increase, when ship owners operating an aged fleet might chose to switch to low sulphur distillates instead of retrofitting costly alternative methods to comply with SOx emission regulations.

Simultaneously the availability of LNG as marine fuel is expected to increase, which may result in competitive LNG bunker prices, hopefully disconnected from the crude oil price.

WinGD is not able to predict future LNG bunker cost versus HFO / MDO cost and will not speculate about future price development.

3 Winterthur Gas & Diesel's two-stroke feasibility study

3.1 History of Wärtsilä marine gas engines

Wärtsilä's first modern 4-stroke gas engines were introduced in the late 1980s as high pressure gas-diesel (GD) engines. The concept based on the well-known diesel combustion process worked quite well, yet due to such factors as its complex and expensive gas handling system and safety concerns, the technology did not breakthrough and was applied in niche markets only.

With the introduction in the late 1990s of low-pressure dual fuel 4-stroke engines, Wärtsilä became the global DF leader. The low-pressure DF concept is based on the lean-burn principle where a lean air to gas fuel mixture is ignited by a small amount of liquid pilot fuel. The lean burn DF technology became the industry standard.

WinGD is following the industry standard, and has now applied Wärtsilä's depth of gas engine expertise and experience to its low speed two-stroke DF engines.

3.2 Low gas pressure technology versus high pressure technology

3.2.1 Low pressure DF concept

The industry standard DF concept
The low-pressure DF technology concept is based on the lean-burn principle (Otto cycle), in which fuel and air are premixed and burned at a relatively high air-to-fuel ratio.

Such a concept on 2-stroke DF engines provides benefits in form of:

- Low-pressure gas supply resulting in low investment costs and low power consumption
- Low NOx emissions, Tier III compliancy without exhaust gas after treatment
- Liquid pilot fuel quantity below 1% of total heat release
- Particulate matter emissions reduced to close to zero

Simple gas supply system.
Low-pressure DF technology requires a simple gas supply system, reducing system complexity and auxiliary power consumption. Since the fuel gas is mixed with the scavenge air before compression in the combustion chamber, the required gas pressure is below 16 bar at any operating point. Gas enters the combustion space through gas admission valves mounted on the cylinder liners, positioned at mid-stroke, well above

the scavenge air ports. As a result, the fuel supply system is relatively simple, reliable and well-proven.

Fully compliant with IMO Tier III
Thanks to its lean-burn combustion process, this technology has an inherent potential to reduce the formation of NOx by up to 90% compared to diffusion combustion of diesel or high-pressure direct injected gas-diesel engines (GD). Thus, with lean-burn Wärtsilä DF engines operated on gas, no additional exhaust gas after-treatment equipment is needed to meet IMO Tier III NOx limits.

3.2.2 High-pressure GD concept

High-pressure GD concept

The high-pressure gas technology concept is based on the diesel principle. Gas is pressurized by reciprocating compressors to a pressure of maximum 350 bar, where after the gas is cooled and led to gas admission valves located on the cylinder heads. High pressure gas is injected directly into the already compressed air in the combustion chamber (diesel principle), simultaneously a small amount of liquid pilot fuel is injected thereby igniting the high pressure gas.

Benefits of a high pressure GD concept are:

- Low sensitivity to gas quality
- Combustion according to the diesel principle, thus allowing a high mean effective pressure (MEP) and thereby high energy efficiency
- No need to de-rate GD engines, compared to similar type conventional diesel engine

At first sight the high-pressure gas concept looks appealing, however less advantageous features are not yet considered.

Gas supply system
The gas supply system is relatively complex involving expensive and energy intensive multiple stage reciprocating compressors. From a capital expense (capex) point of view the gas supply system is more expensive and also from an operational expense (opex) point of view the yearly cost of running and maintaining the high pressure gas supply system ends up being considerably more expensive than a comparable low pressure gas system.

IMO Tier III regulations
High pressure dual fuel engines of GD type, operating according to the diesel principle, do not meet IMO Tier III NOx limitations in gas mode. To be compliant with Tier III regulations, exhaust gas treatment equipment is required.

The capex and opex cost of exhaust gas treatment equipment need to be taken into consideration when calculating the total lifetime cost of an installation.

Safety concern
High pressure gas onboard marine installations often raises safety concerns amongst ship owners.

3.3 WinGD selects low-pressure gas DF technology

WinGD is following the industry standard and has applied the low-pressure gas concept on Wärtsilä 2-stroke DF engines. One of the main criteria's selecting the low-pressure gas concept when developing Wärtsilä 2-stroke DF main engines was to be compliant with, until yet, known emission regulations without the need for exhaust gas after treatment equipment.

3.4 RT-flex50DF readiness

After extensive research and development activities carried out in the time frame 2011 – 2013, the introduction of RT-flex50DF was officially announced and in November 2013 a customer event demonstrating a running 6RT-flex50DF engine was held in Trieste, Italy. The event was highly appreciated and the Wärtsilä 2-stroke DF technology concept received positive reviews from the marine industry.

3.5 Engine production readiness

Low speed Wärtsilä 2-stroke engines are produced under license with most manufacturers concentrated in Asia. The engine manufacturer's production readiness had to be ensured simultaneously when marketing the new technology.

With the first Wärtsilä 5RT-flex50DF engines contracted WinGD evaluated potential engine manufacturers with capacity, willingness and ability to build DF engines, meeting the agreed delivery time.

In order to test DF engines in gas mode, relatively large quantities of natural gas is required. When starting the screening of potential engine manufacturers, no engine manufacturer had required gas handling equipment available at their factories. Therefore, availability of LNG / natural gas supply infrastructure and a commitment to invest in stationary factory gas plant equipment were two criteria of high importance when choosing the engine manufacturer.

Amongst several potential licensees, Yuchai Marine Power Co., Ltd (YCMP), located in Yuchai, P.R. China, met the requirements to manufacture the first Wärtsilä 5RT-flex50DF engines. The gas supply infrastructure was arranged be the local government in Douman, which committed to build a natural gas pipeline from an LNG terminal nearby to YCMP's factory. The engine manufacturer YCMP committed to upgrade its factory facilities making it possible to test run Wärtsilä low-pressure 2-stroke DF engines in diesel and gas mode.

Despite a tight schedule: gas supply infrastructure, engine production and factory facility upgrades required for running on natural gas could be ensured, according the desired delivery time.

3.6 Onboard gas related ancillary equipment

When focusing on gas ancillary equipment, the low-pressure gas DF concept for Wärtsilä 2-stroke engines is, in principle, similar to the Wärtsilä 4-stroke DF concept. Though, due to a slightly higher gas supply pressure required for Wärtsilä 2-stroke DF engines, gas related ancillary equipment need to comply with a higher pressure class.

Between the gas compressor station and the main engine inlet, a gas valve unit (GVU) is controlling the load dependent gas pressure in the gas manifold, which distributes gas to each gas admission valve mounted on the cylinder units. The GVU required some re-engineering to meet pressure class requirements.

LNG tanks and other gas equipment required in the ancillary system is commercially available and is therefore not further evaluated in this feasibility study.

4 Concluding words

- The low-pressure gas 2-stroke DF engine technology was ready for the market

4.1 Low-pressure gas DF technology – the industry standard

The low-pressure 2-stroke DF gas technology with its strenghts: simple gas supply system, fully compliant with IMO Tier III, low capex and competitive opex is concluded being the superior choice for environmentally friendly propulsion solutions.

Wärtsilä 2-stroke DF engines are available for a variety of vessel types, i.e. LNG carriers, chemical tankers and container ships, just to mention some few. The low-pressure 2-stroke DF technology holds excellent potential for vessels operating in emission control areas, something recognized by Tärntank whose fleet is operating the majority of time in emission control areas in Northern Europe (along the Norwegian coast, on the North Sea and, on the Baltic Sea and Gulf of Bothnia).