Module 5
Propulsion and Power Generation of LNG driven Vessels
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Presentation
“Principles of Marine Main Engines running on LNG ”
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Contenents

1. Lecture Introduction.
2. Introduction to LNG as marine fuel.
3. Introduction to Marine Engines running on LNG.
4. Safety, Classification & Operational Issues.
5. R&D Challenges.
Lecture Introduction

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2. Introduction to LNG as marine fuel.
3. Introduction to Marine Engines running on LNG.
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The purpose of this lecture is to highlight the principles of Marine Engines running on LNG, either as pure LNG or as Dual Fuel Engines.

Over the last few years gas-fuelled engines have become more popular also in the marine industry both for on-board power generation and propulsion duties. Although the use of gas-fuelled marine engines was originally limited to the gas-shipping trade (LNG tankers) they are now being applied in other ship types as well, mainly because of easier compliance with the stricter emission limits of NOx and SOx now being introduced all over the world.

However, since LNG holds further emission advantages (smoke, particulates), it is now becoming more available and at reduced prices.
Introduction to LNG as marine fuel

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Introduction to LNG as marine fuel

LNG, stands for Liquefied Natural Gas, is natural gas cooled down to about –163 °C at atmospheric pressure and transported as a liquid. It is now rapidly becoming a widely used engine fuel in association with its growing popularity as an energy source world-wide.

There are two distinct types of gas made from LNG depending on how it is extracted:

- **“natural boil-off gas”** which is taken off the top of the LNG tanks above the liquid will have a high methane content and some nitrogen and thus have a high knocking resistance. Analysis show values typically around MN (methane number) 100 and LCV (low calorific value) between 33 – 35MJ/nm3. This is a somewhat special application typical for fuelling of LNG tanker propulsion plants.

- **“forced boil-off gas”** i.e. LNG extracted from down in the tanks and evaporated separately. This gas will contain a mixture of all hydrocarbons in the liquid and its resistance to knocking may differ from origin to origin and even from load to load, with the MN typically in the range between 70 and 80. The calorific value will be higher than natural boil-off gas and quite stable at around 38 – 39 MJ/nm3. This gas type is now becoming very popular as fuel for general shipping.
Introduction to LNG as marine fuel

Knocking stability of the LNG as marine fuel.

“Natural boil off gas” from the top of the tanks is very high in methane and has good knocking stability. It is therefore particularly well suited as an engine fuel. However, when a propulsion system is laid out for the use of this, it is important to ensure that there is always enough natural boil-off gas with sufficiently high methane content available, so that there shouldn't be any need for mixing in “forced boil-off gas” from the bottom of the tanks.

Engine installations specifically designed to be fuelled by LNG should preferably be of the “forced boil off” type with the LNG taken from deep down in the tanks and well mixed before extraction into the evaporator. This will ensure good homogeneity of the LNG taken out and hence constant gas quality. We should be aware that this type of LNG-based fuel gas will be different from the “natural boil off gas” from a tank top and the rating of the engine will have to be based on a somewhat lower MN in this case, in order to ensure knocking-free operation. Evaporator sizing must be sufficiently large in order to ensure that no gas droplets are entering the engine even under severe transient operation.
Introduction to Marine Engines on LNG

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Introduction to Marine Engines on LNG

Development of LNG fueled marine engines

• The development of the LNG fueled marine engines started in 1980 in order to develop engines for LNG carriers utilizing boil-off gas as fuel.

• The commercial engine development started in 1984, resulting in 3 engine concepts that released in between 1988-1996:
  ➢ Spark Ignited Lean Burn engine (Otto cycle)
  ➢ Diesel Ignited Dual fuel engine (Combined Otto/Diesel cycle)
  ➢ High pressure direct injection engine (Diesel cycle)

• Initial field of application were land stationary power and heat generation (COGEN)

• First marine application was in 2000 and the “prototype” LNG fuelled ship is the car-ferry “MF Glutra”

• In 2003 the commercial market started growing from the Small scale LNG project.

• In 2011 started a fast growing interest in deep-sea shipping applications. Reasons for this interest are:
  ➢ Driven by emission control legislation and fuel cost
  ➢ Large slow speed engines under development
  ➢ New ships and retrofit installations in existing vessels
Introduction to Marine Engines on LNG

Types of marine LNG engines

Three main types of LNG-burning engines are available to the marine industry, which come out of different development directions and hence with some different characteristics.

• The **spark-ignited** “LNG only” engines were first developed for the land-based power industry with major requirements, simplicity and good overall performance at lowest total emissions. These engines are dependent on permanent gas supply and initially came into the marine industry as engines for short-distance ferries.

• The **diesel-ignited** gas engine with dual fuel capability was also originally developed for land power plant use where its ability to operate both on liquid and gaseous fuels at high specific power was a particular advantage. Development was originally focused on low NOx emissions at high load recently however, a focus is also on part load performance and variable speed capability. The diesel-ignited LNG engine is the first type to establish itself in the marine industry and is currently the dominating engine type in this market.

• The **direct gas injection** diesel gas engine, first came to use in the offshore industry where it’s high fuel flexibility and very high power density is of prime attraction. This concept is unique in posing no particular requirements to the self-ignition stability of the fuel gas and its Diesel operating principle ensures that the combustion of the gas fuel is very complete, but at the cost of higher NOx emissions than other gas engine types. Currently, the use in the marine industry is still limited but very promising.
Gas burning engines operate according to two different principles, the “pre-mixed” Otto- and direct-injected Diesel cycles

• Otto Gas engines:
  - Spark-ignited gas engines (“gas only”) with either carburettors or port injection of gas. These are “single-fuel” engines and therefore must meet some special redundancy requirements for marine applications.
  - Diesel-ignited gas engines with conventional low pressure gas feed (as above) but with ignition by the injection of a certain quantity of Diesel fuel, also known as the “Otto DF” or “low pressure DF” principle. These will always need a certain quantity of diesel fuel for running even in Gas mode, but on the other hand they may also run on 100% liquid fuel (diesel or HFO), i.e. dual fuel capability.

Otto Gas engines with their homogeneous combustion generally have low NOx emissions and high efficiency and will typically comply with the IMO Tier III limits without exhaust after-treatment. However, they require a certain stability of the fuel gas against self-ignition and they must be carefully developed in order to keep un-burnt gas (“methane slip”) to a minimum. Spark-ignited and diesel-ignited gas engines show some differences in this respect, especially at part load.
Introduction to Marine Engines on LNG

Marine gas engine principles

Diesel Gas engines:

- Here the fuel gas is directly injected at high pressure into the cylinder after the diesel pilot fuel has ignited. This is also known as “Diesel DF principle” or the “GD-principle”, such engines have dual fuel capability and may also run on 100% liquid fuel (diesel-or HFO).

The Diesel Gas engines have diffusion burning which ensure good capability of burning gases with low knocking stability (“low MN”) and at the same time producing low emissions (“methane slip”).

However, they require a high-pressure gas system (typically 300 bar) and additionally exhaust after-treatment (EGR, SCR) is needed to comply with IMO Tier III NOx emission limits.
Introduction to Marine Engines on LNG

Marine gas engine principles

**Spark Ignited Lean Burn gas engine (LBSI)**

- LNG only, low pressure gas supply (4-5 bar)
- High energy efficiency at high load, higher than the corresponding diesel engine
- Low emissions, meets IMO tire III
- Sensitive to gas quality (Methane Number)
- Not suitable for retrofit of existing engines
- Typical engine example: **Rolls-Royce C26: 33L9**
Introduction to Marine Engines on LNG

Marine gas engine principles

**Diesel Ignited Dual-Fuel engine (DF)**
- Dual fuel capability (LNG-MDO)
- Low gas pressure supply (4-5 bar)
- High energy efficiency at high load
- Low emissions, meets IMO tier III
- Flexibility in fuel mix
- Sensitive to gas quality (Methane Number)
- Possible for conversion of existing engines however, with extensive rebuilding
- Typical engine example: Wartsila 6L50DF
Introduction to Marine Engines on LNG

Marine gas engine principles

Lean Burn combustion (LBSI and DF)
Introduction to Marine Engines on LNG

Marine gas engine principles

Direct gas injection high pressure engine
- Multi-fuel capability (LNG-MDO-HFO)
- High pressure gas injection (300 -350 bar) 4-stoke and 2-stroke, maintaining diesel engine performance
- Need NOx reduction techniques to meet IMO tier III
- Not sensitive to gas quality (Methane Number)
- Pumping LNG to 350 bar and evaporate is simple and with low energy requirement
- Flexibility in fuel mix
- Suitable for retrofit of existing engines, simple conversion
Introduction to Marine Engines on LNG

Marine gas engine principles

Direct gas injection high pressure engine (cont’)

• Typical engine example: MAN Diesel, ME-GI models G40 to G95
Introduction to Marine Engines on LNG

Marine gas engine principles

Operating principles,
burning summary of all available types
Safety, Classification & Operational Issues

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Safety, Classification & Operational Issues

Classification Issues

• This is a comprehensive topic and only some general statements can be listed here.


• Many of the internationally recognized Classification Societies have issued their specific sets of rules for MGE installations, which are either already applicable or out as preliminary drafts.

• The dominating philosophies in the current safety rules for MGEs are that of avoiding danger of explosion, as well as maintaining the ship operational; i.e. redundancy of propulsion power in case of a shut-down in the gas supply system (because of leakage or other reasons).
Safety, Classification & Operational Issues

Safety Issues

The following key points must be carefully addressed during engine room design and dual fuel engines installation:

• Explosion prevention. Two main options are available, selection is based on the design principle.
  ➢ Engines should have double-walled Gas feed piping, and this piping must be provided with venting of the space between the inner and outer pipe walls to a gas detection system. Alternatively, this space may be pressurized with nitrogen and monitored by pressure sensors.
  ➢ To place the engines in separate gas-tight and ventilated engine rooms which each has its own gas supply, required number of air exchanges per hours, is protected with gas sensors and has the required pressure-relief and escape ducting etc.
Safety, Classification & Operational Issues

Safety Issues (cont.)

- Use of EX-Proof Electrical Equipment.
- Design of a dedicated ventilation system and of a separate emergency relief system.
- Design of LNG bunker station according to IGF and Class Rules.
- Appropriate Fire Fighting and Life Saving Measures.
- Availability of at least two different (preferably opposite) escape ways from LNG designated areas.
- Establishment and constant monitoring of “Safety Zone” during LNG bunkering operations.
Safety, Classification & Operational Issues

Operational Issues

• The main LNG fueled engine must meet all relevant Class/ IACS rules regarding its design.

• Although of importance for marine drives, so far no specific transient response- or variable speed requirements have been put down yet in the Class rules for marine gas engines in mechanical propulsion applications.

• It should be bear in mind the importance of the transient load capability when a Gas Engine is selected for marine propulsion. This is because most marine duties will include transient load changes as well as part- and low load operation, even over extended periods. The following capabilities of the three types of engines are recorded:
  - Direct injected Gas engines (any type) generally have better transient and governing characteristics than mixture-charged (“carburetted”) engines. They may also have practical advantages in fulfilling the requirements of double-walled gas piping systems for the installation in conventional engine rooms (“Gas safe”).
  - Diesel-ignited gas engines (“Low-pressure DF”) are best used in steady medium- to high load applications and with more than one engine connected to a suitable load management system to ensure this and limit the transients.
  - Diesel gas engines have part load and transient response characteristics similar to Diesel engines provided the fuel gas system is capable of handling such variable demand.
R&D Challenges

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R&D Challenges

R&D challenges

• Engines and systems:
  ➢ Part load efficiency optimization
  ➢ Methane slip reduction
  ➢ Fuel gas quality
  ➢ Production Cost reduction

• Fuel handling and storage:
  ➢ Better storage tank solutions, regarding space onboard and cost
  ➢ Improved fuel handling systems – bunkering logistics
  ➢ Simpler and more robust fuel system design without reducing safety (space and cost)

• Commercial challenge:
  ➢ Cost elements need to be scaled, this means more actors in the market!
Summary and Conclusions

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Summary and Conclusions

- LNG is considered to be the most promising alternative marine fuel.
- Using LNG as ship fuel, harmful exhaust emissions are reduced significantly.
- LNG is available worldwide in large scale, and can be further distributed to small scale fuel market.
- Proven engine technologies are available for medium speed natural gas engines, and under development for slow speed 2-stroke engines.
- Energy efficiency is equal and even better using LNG compared to MDO/HFO.
- LNG fuelled engines are environmental friendly, and meet all the known emission requirements (IMO tier III), without exhaust gas cleaning.
- Engine R&D challenges are related to part load efficiency, methane slip and variable gas composition (Methane number).
- The main challenges using LNG are availability and on-board fuel storage and handling systems.
- LNG fuelled ships require significant higher capital investment in fuel system – typical 8-15% additional cost, which can be justified by lower operating costs (emissions and fuel).
Thank you for your attention!

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Picture provided by Wartsila