NOx Emissions of LNG Operated Engines

Presentation at CIMAC Circle @ Marintec Shanghai on December 3, 2015

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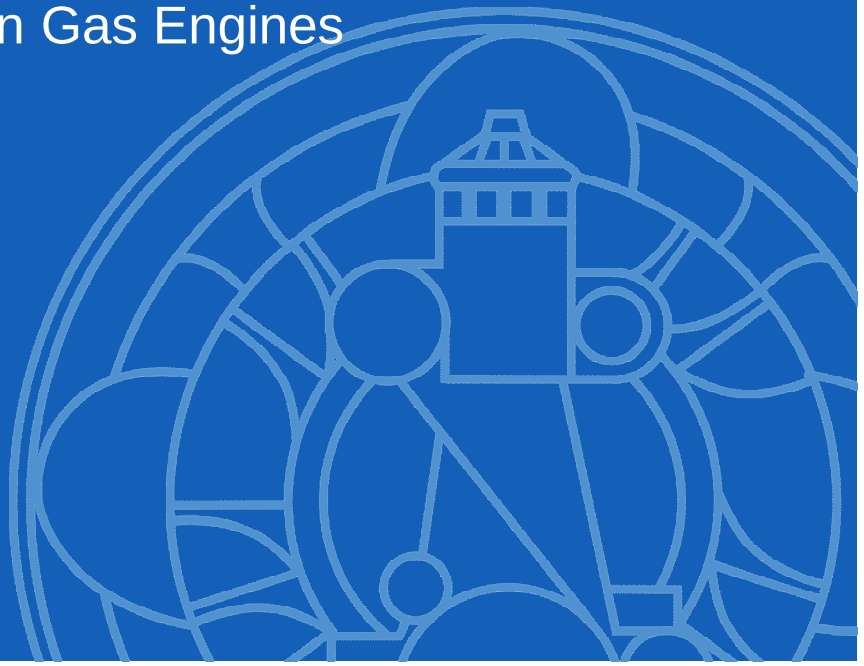
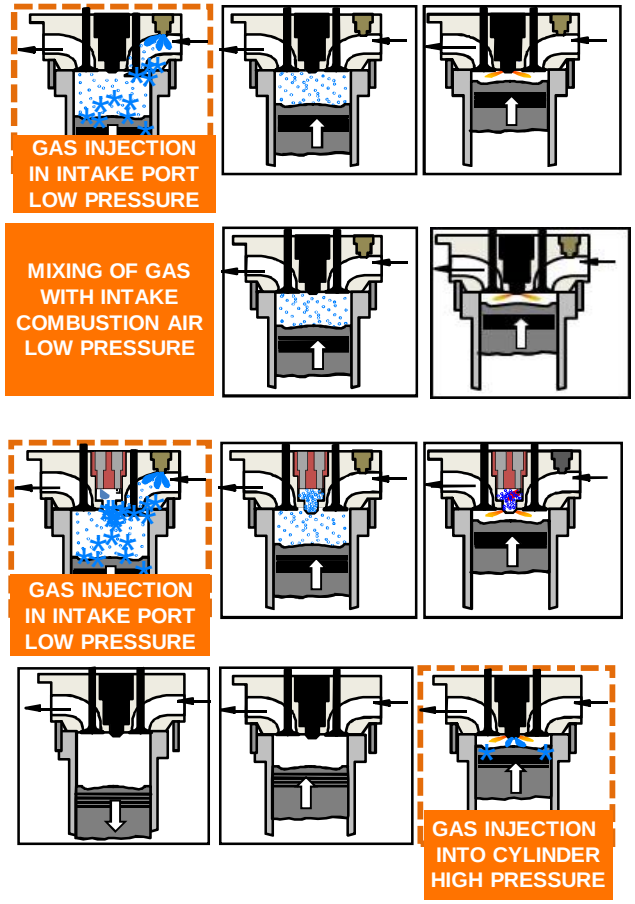


Major Gas Engines Technologies



DUAL-FUEL (DF) ENGINE

Can operate on Gas and Liquid fuel

- Ignition by Micropilot fuel – typically 1-3% of the total fuel input => low CO_2

At gas operation:

- Lean Burn - very lean mixture for low NOx and low CO_2
- Low NOx emissions - typically no abatement needed

CONVERTED AND BI-FUEL ENGINE

Often converted to gas from corresponding diesel engine

Can operate on Gas and Liquid fuel

At gas operation:

- Mixing of gas with intake combustion air – typically 15-50% of the total fuel input is diesel => high CO_2
- Lean Burn but **not** very lean mixture => high NOx and high CO_2

SPARK-IGNITION GAS (SG) ENGINE

Mono fuel Gas engine – Rich or Lean Burn

- Ignition by spark plug – with very lean burn in a prechamber
- Lean Burn - **very lean** mixture for low NOx and low CO_2
- Lean Burn - low NOx emissions – typically no abatement needed
- Rich Burn – high NOx and high CO_2

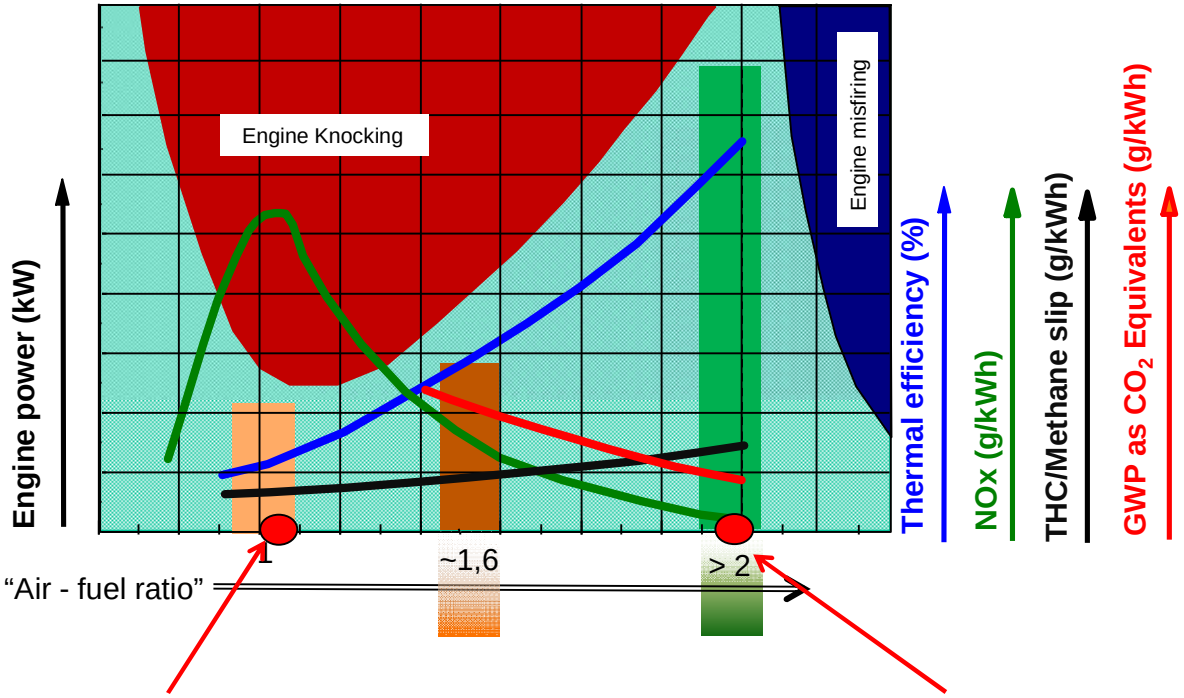
GAS-DIESEL (GD)

Can operate on Gas and Liquid fuel

At gas operation:

- Ignition by pilot fuel
- High NOx emissions – typically SCR or EGR required
- High pressure gas feed – typically pressure increase to 300 – 400 bar

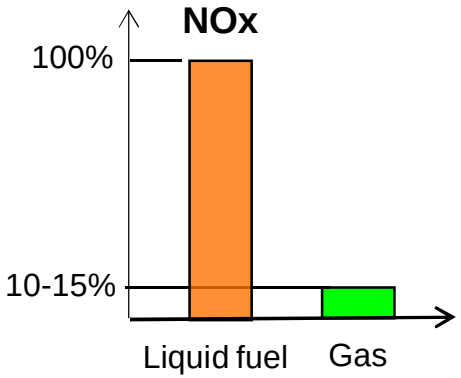
Gas Engine Combustion – Typical Influence of Air-to-Fuel Ratio

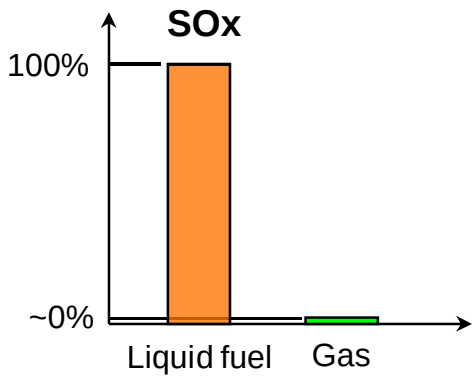


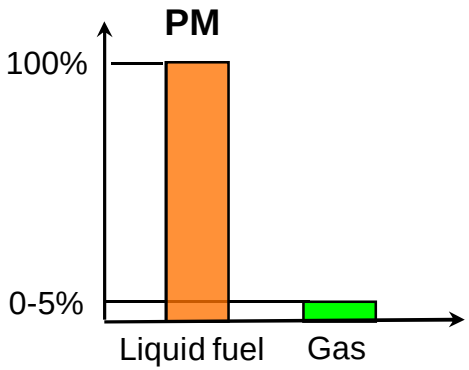
Typical converted engine
- Accept efficiency / CO2 penalty
- Treat high NOx with SCR
- Some THC/methane slip (catalyst not effective)

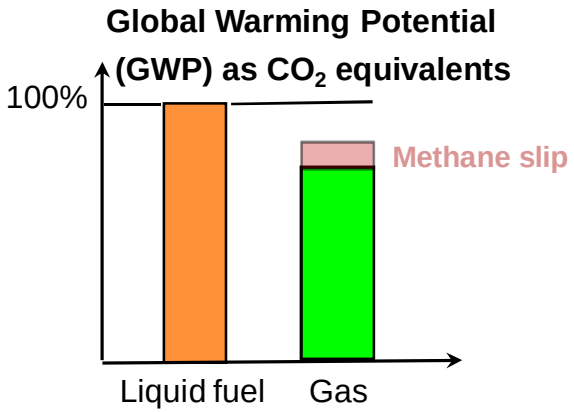
Modern purpose designed gas / DF engine
- High efficiency / low CO2
- NOx mostly compliant by primary methods
- Some THC/methane slip (catalyst not effective)
- GWP lower than diesel reference

Typical Low Emissions from Lean Burn Gas Engines









Lean Burn Gas Engines comply already today with the proposed Stage 1 and Stage 2 of the Chinese Inland Waterways Emission Regulation

Some Dual-Fuel Applications

Power Plants

DF Power plants
- 67 installations
- 354 engines
- Output 4600 MW
- Online since1997

Merchant

LNGC
- 145 vessels
- 585 engines

Multigas Carrier
- 5 vessels
- 20 engines

Conversion
- 1 chemical tanker
- 2 engines

Ro-Ro
- 2 vessels
- 8 engines

Offshore

OSV's
- 31 vessels
- 96 engines

Production
- 2 platforms
- 9 FPSO's
- 1 FSO
- 40 engines

Cruise & Ferry

LNG cruise ferry
- 1 vessels
- 4 engines
- Complete gas train

LNG ferries
- 5 ferries
- 20 engines
- Complete gas train

Navy

Coastal patrol
- DF-propulsion
- DF main and auxiliary engines

Others

Tug
- 2 vessel
- 2 engines each
- Mechanical drive

Guide ship
- 1 vessel/engine

IWW
- 2 vessel
- 3 engines

→ 6 segments → > 1'000 engines → > 10'000'000 running hours