大连海事大学
DALIAN MARITIME UNIVERSITY

船舶电控发动机
数字课程

#7 气体燃料发动机

Acknowledgements: The technical contents of this presentation are mainly from the websites and training files of Rolls-Royce, Wärtsilä & MAN Energy Solutions. Many thanks to MAN-ES.
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※ 内容提要

- 船舶代用燃料
  - LNG/LPG
  - Hydrogen
  - Ammonia
  - Methanol
  - Biodiesels
- 气体燃料发动机概述
  - LNG发动机
  - 氢气发动机
  - 氨气发动机
  - 甲醇发动机
- Wärtsilä DF发动机
- MAN ME-GI发动机

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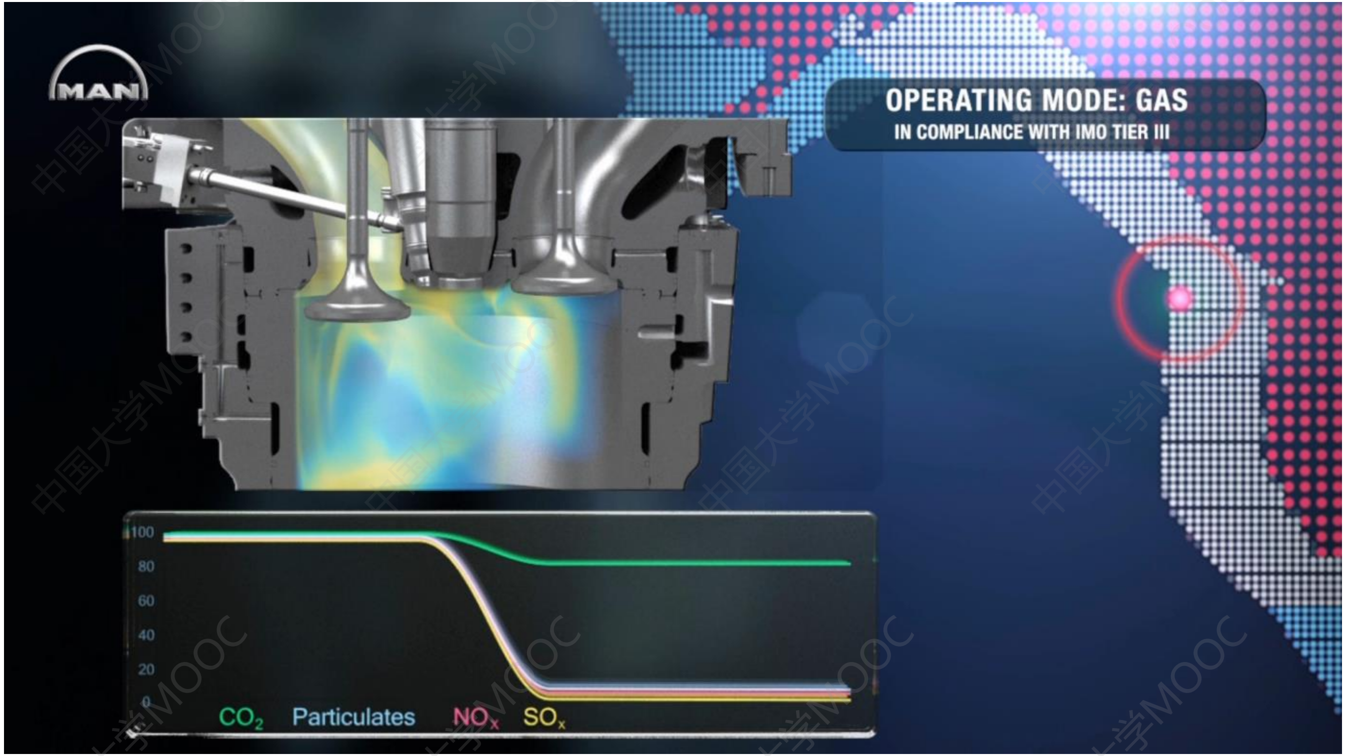
- Why LNG (liquefied natural gas)?



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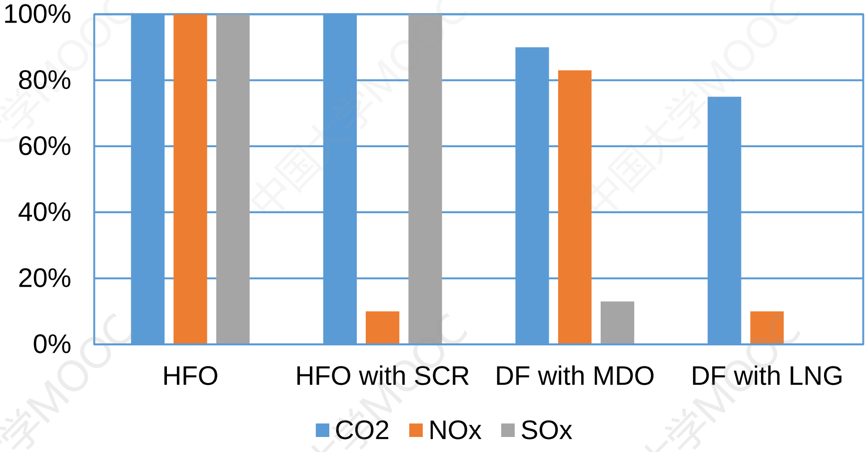
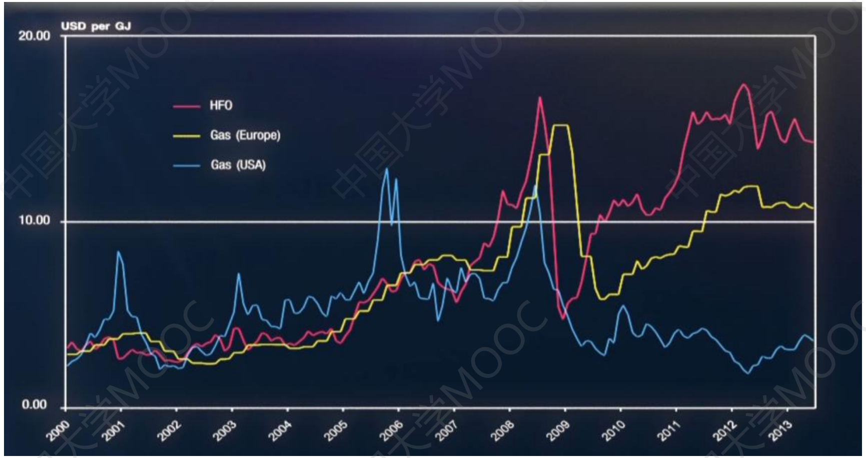
※ LNG as Marine Fuel

- Why LNG (liquefied natural gas)?
  - 资源丰富：储量400~600万亿m^3, 按当前年产量水平, 可供开采60+年
  - 清洁能源：C:H=1:4, max. energy release per unit of C emission.
  - 价格便宜





※ LNG as Marine Fuel

- CH_4特点：
  - 无色，无味，无毒且无腐蚀性
  - 密度 0.42~0.46g/cm^3，热值为 52MMBtu/t(1MMBtu=2.52×10^8cal)
  - 常压下液化温度 -163℃，体积 → 1/600
  - 自燃温度 630~730℃
  - 爆炸浓度极限 5% ~15%

million British Thermal Units

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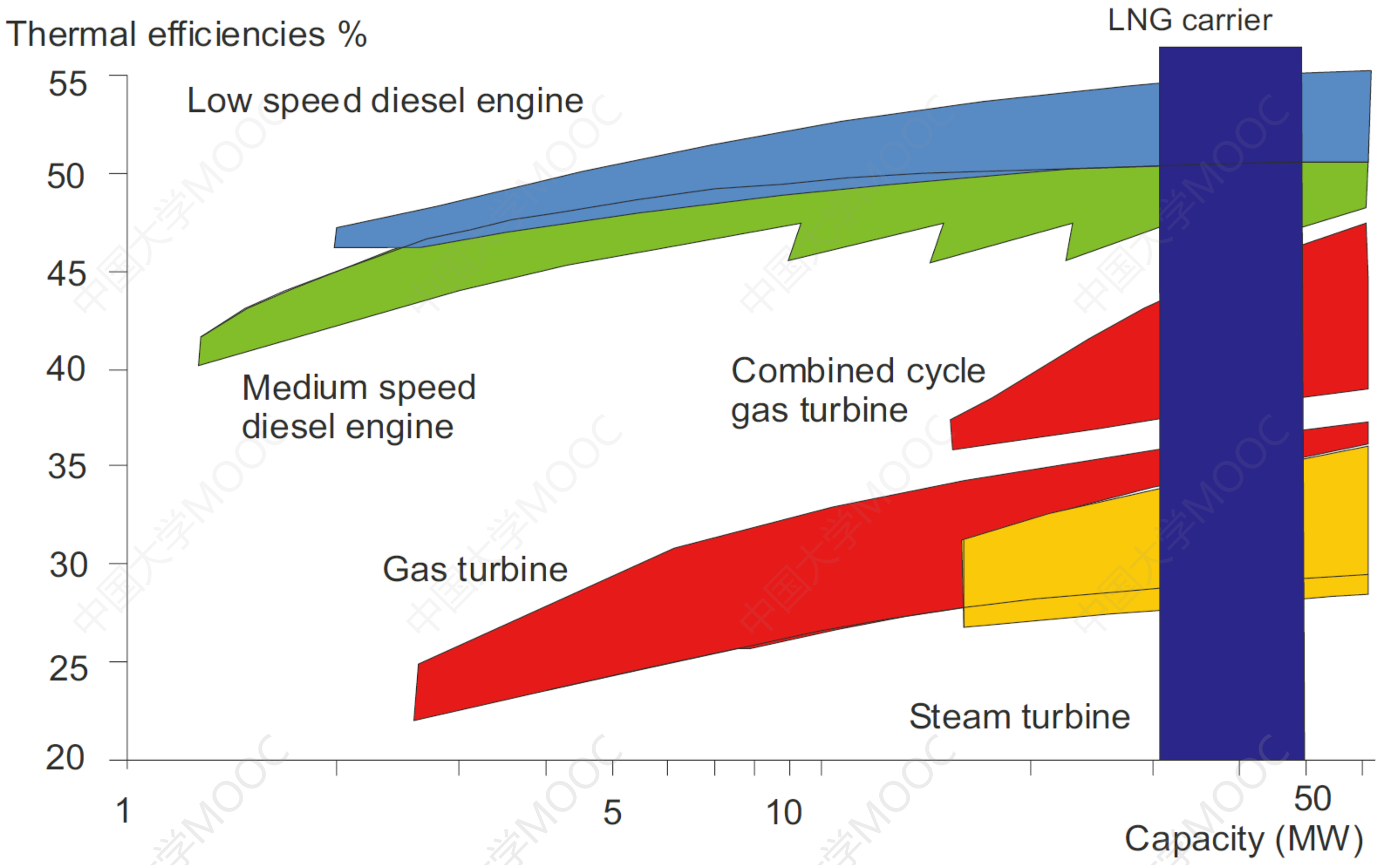
※ Sailing on LNG

- Steam Turbine
  - BOG(boil off gas) as fuel for LNG Carriers

- Gas Engine
  - LNG as fuel for all kinds of ships

- DF(dual fuel) Engine
  - LNG & Diesel as fuel for all kinds of ships

※ Sailing on LNG



- Steam Turbine
  - BOG(boil off gas) as fuel for LNG Carriers

- World fleet 2016: total number of ships, by type and size

ship type	GT<500	500⩽GT<25000	25000⩽GT<60000	GT⩾60000	total
gas carrier	38	1126	337	420	1921
…					
total	33356	39017	11615	5816	89804
http://www.equasis.org/EquasisWeb/public/PublicStatistic?fs=HomePage					

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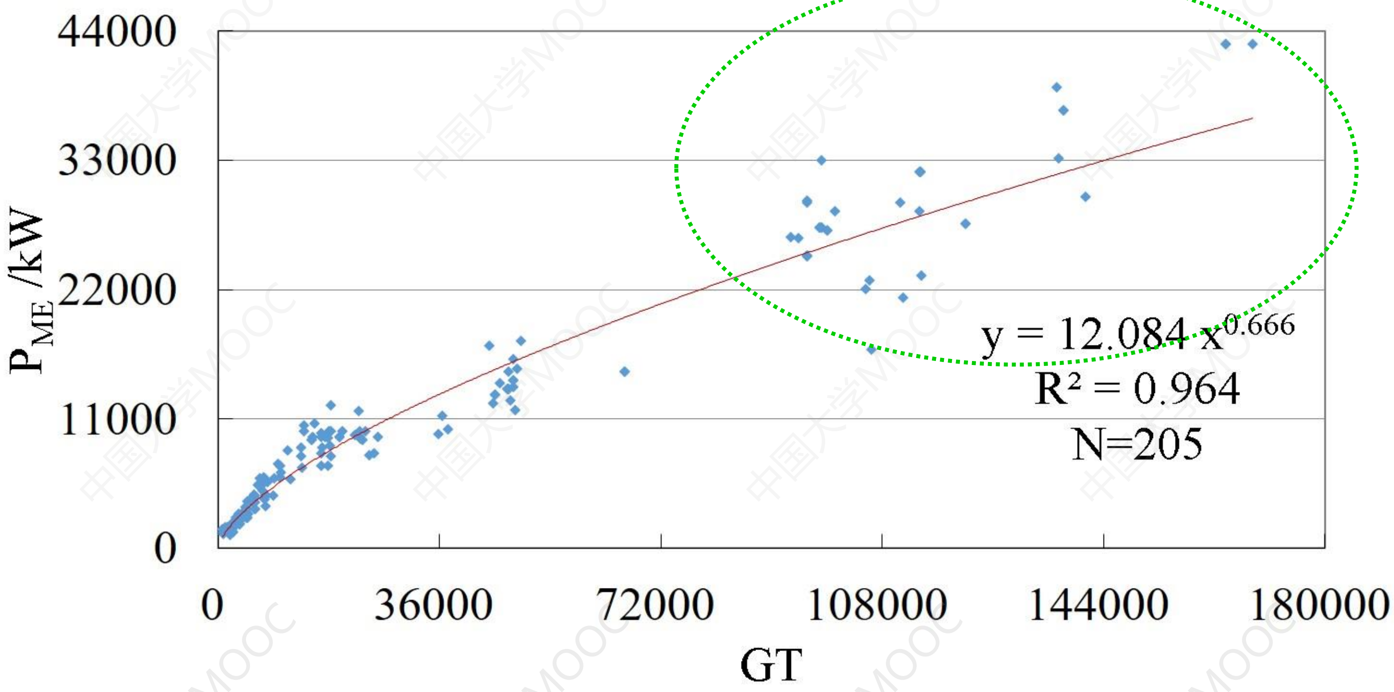
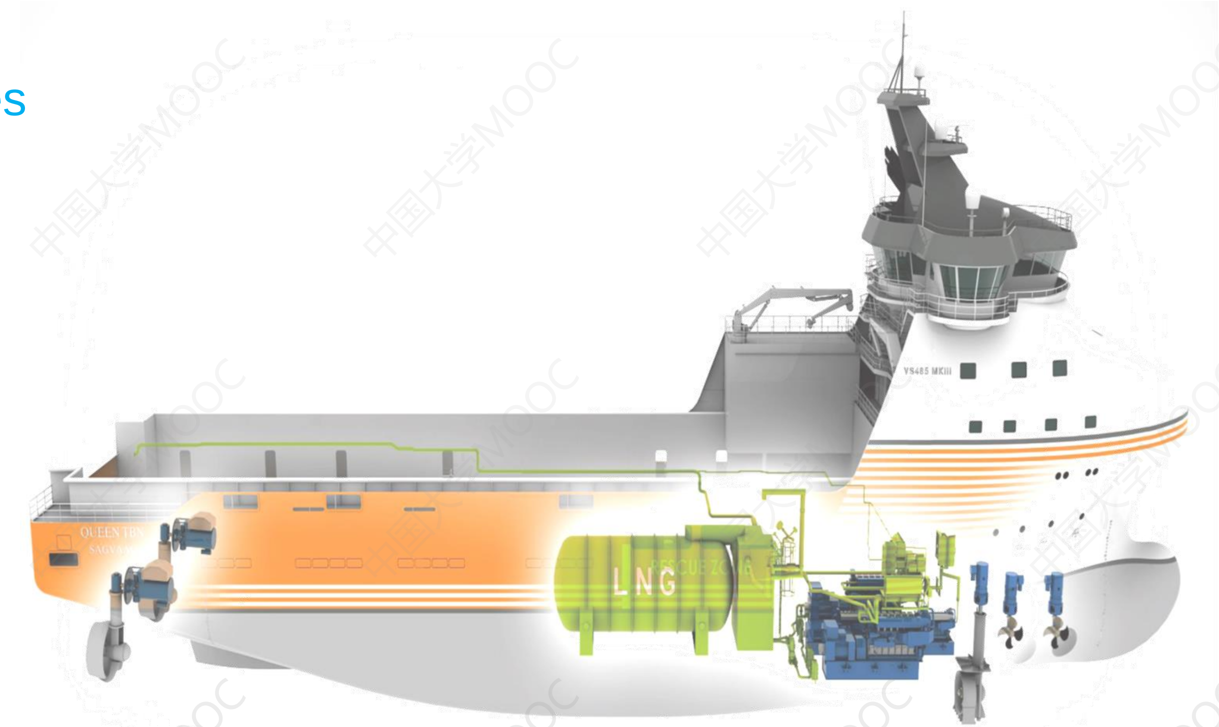
- Steam Turbine



液化气船主机功率-总吨关系

- LNG Engine
  - Pure Gas Engines
    - 4S
  - LP DF Engines
    - 4S
    - 2S
  - HP DF Engines
    - 4S
    - 2S



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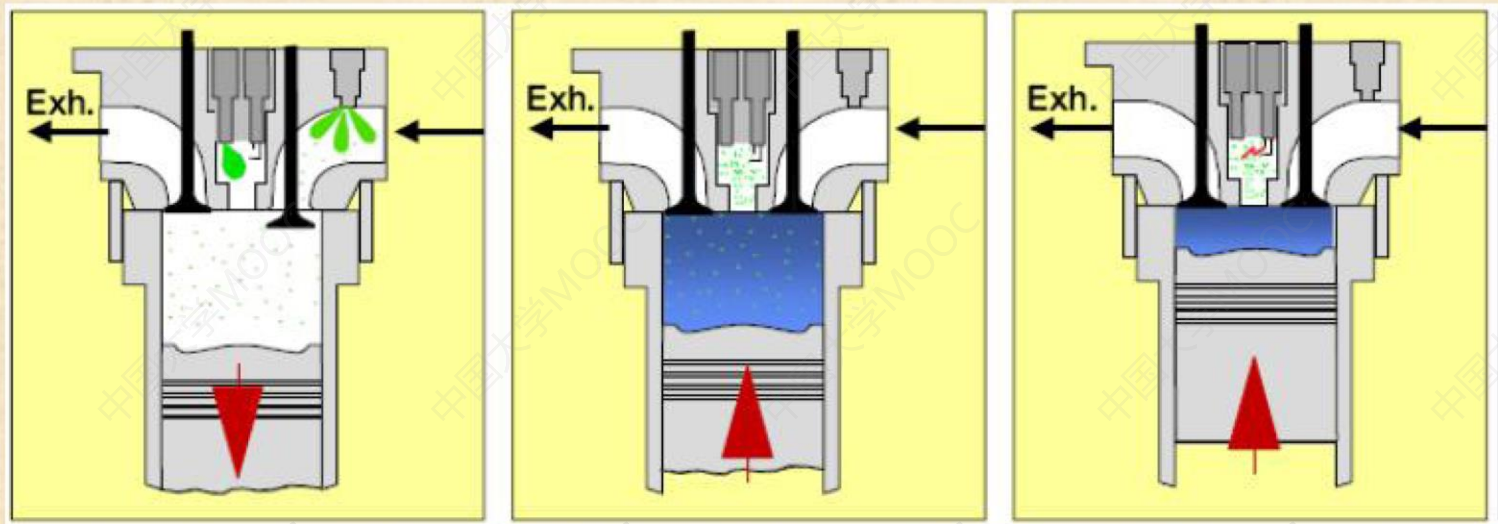
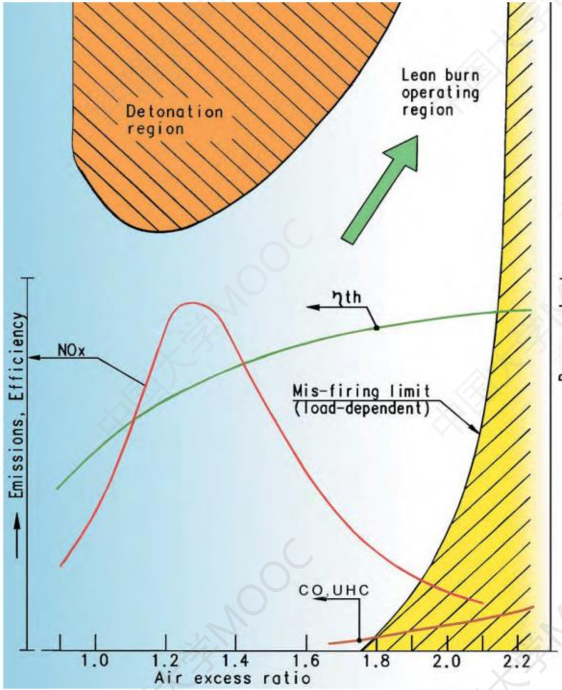
- Pure Gas Engines - 4S
  - LNG as fuel for all kinds of ships

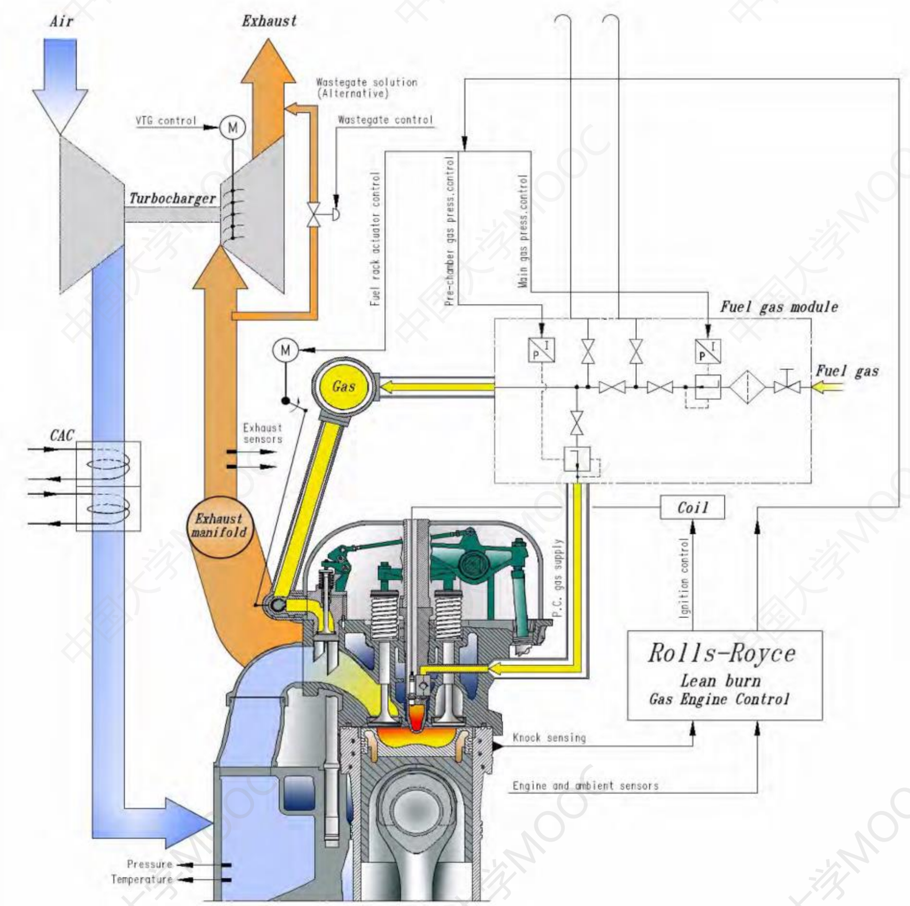


进气过程中 燃气喷入 Gas injected during intake stroke	燃气和空气一起被压缩 Gas & Air Compressed in compress stroke	电火花塞点火点燃混合气体 Electric spark ignition of gas mixture

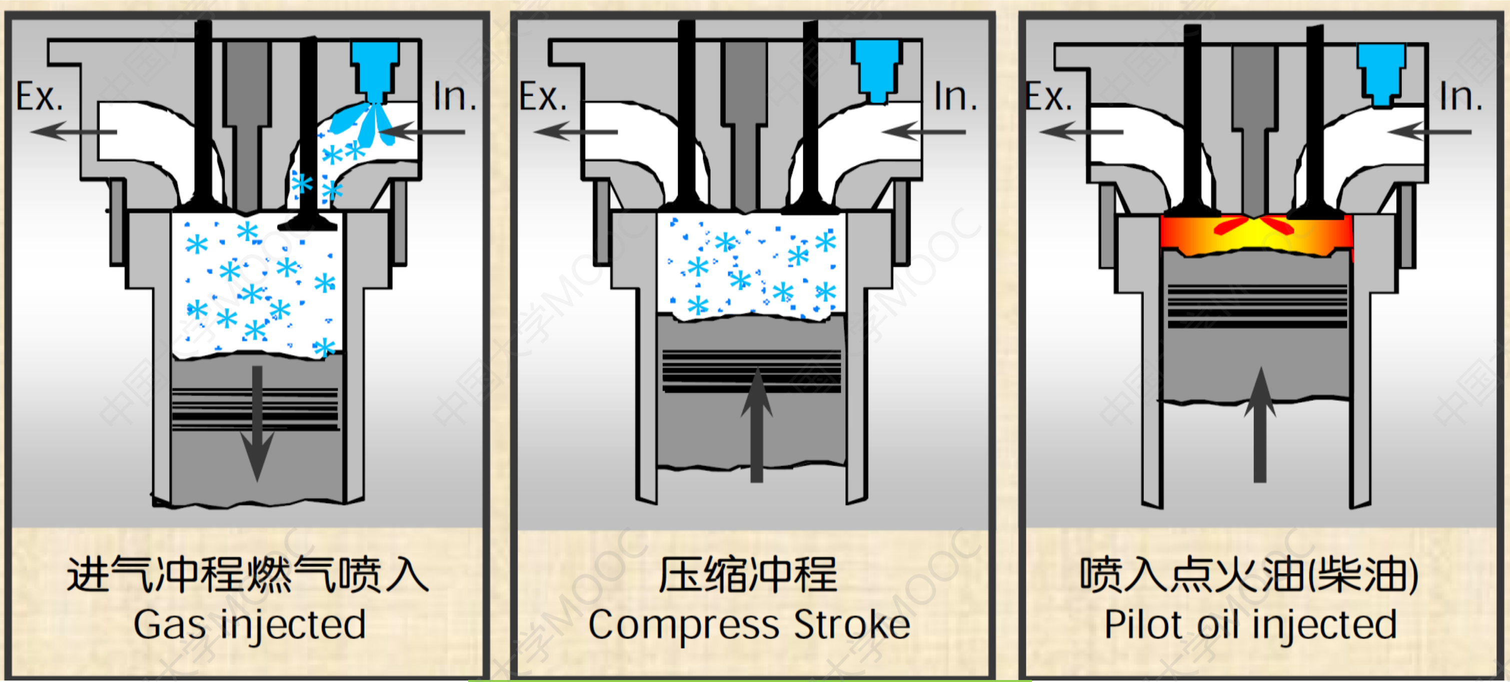
Spark Ignited Pure gas engine

- Pure Gas Engines - 4S
  - Rolls-Royce Bergen B32/35:40



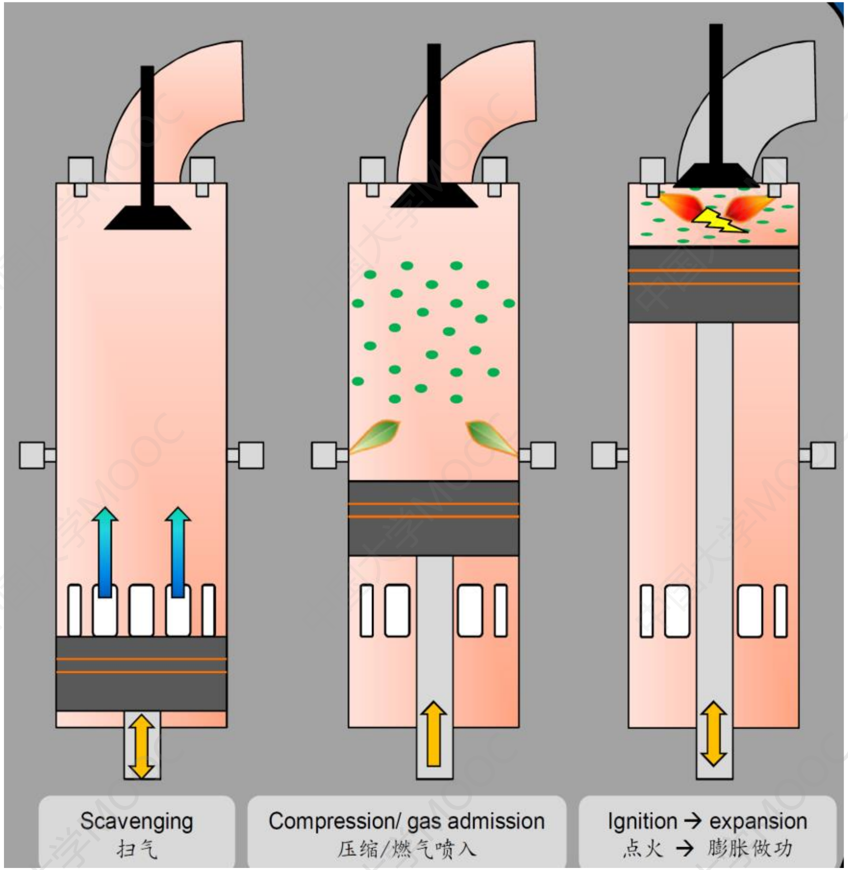


- DF Engine - 4S
  - LNG & Diesel as fuel for all kinds of ships



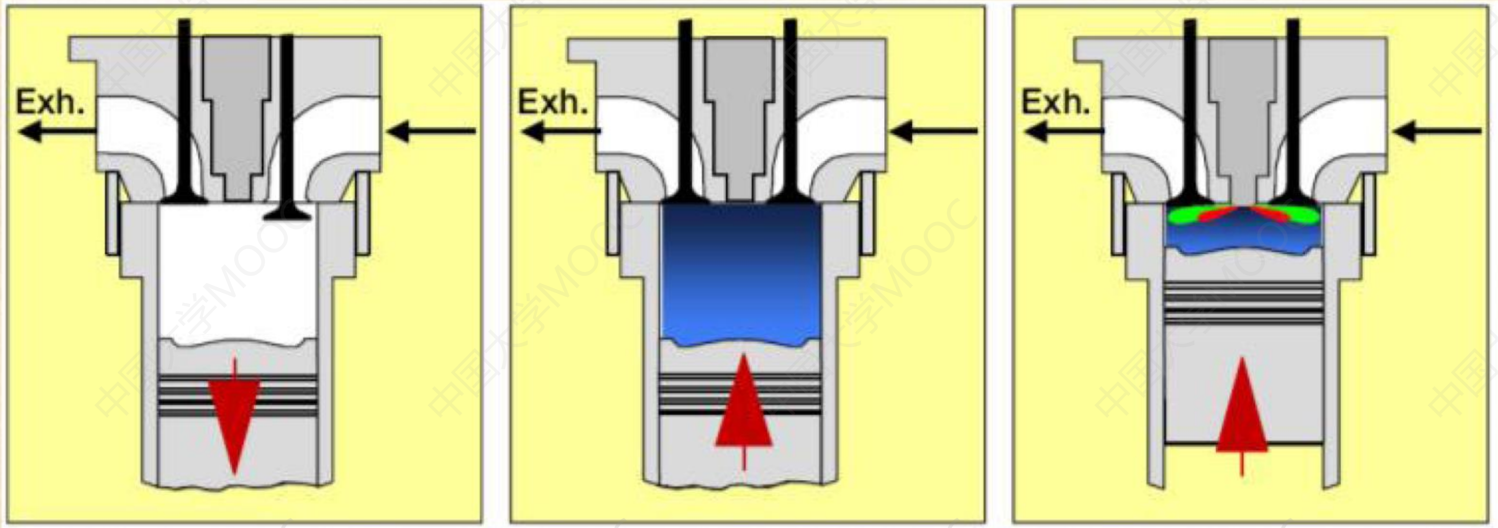
Low Pressure Dual Fuel engine

- DF Engine - 2S
  - Low Pressure DF 2S engine
  - LNG & Diesel as fuel
  - Gas admission at mid-stroke
  - Ignition by pilot fuel
  - Pre-mixed Lean-burn (<16bar)
  - As per Otto process
  - NOx Tier III compliance



Low Pressure Dual Fuel engine

- DF Engine - 4S
    - LNG & Diesel as fuel for all kinds of ships

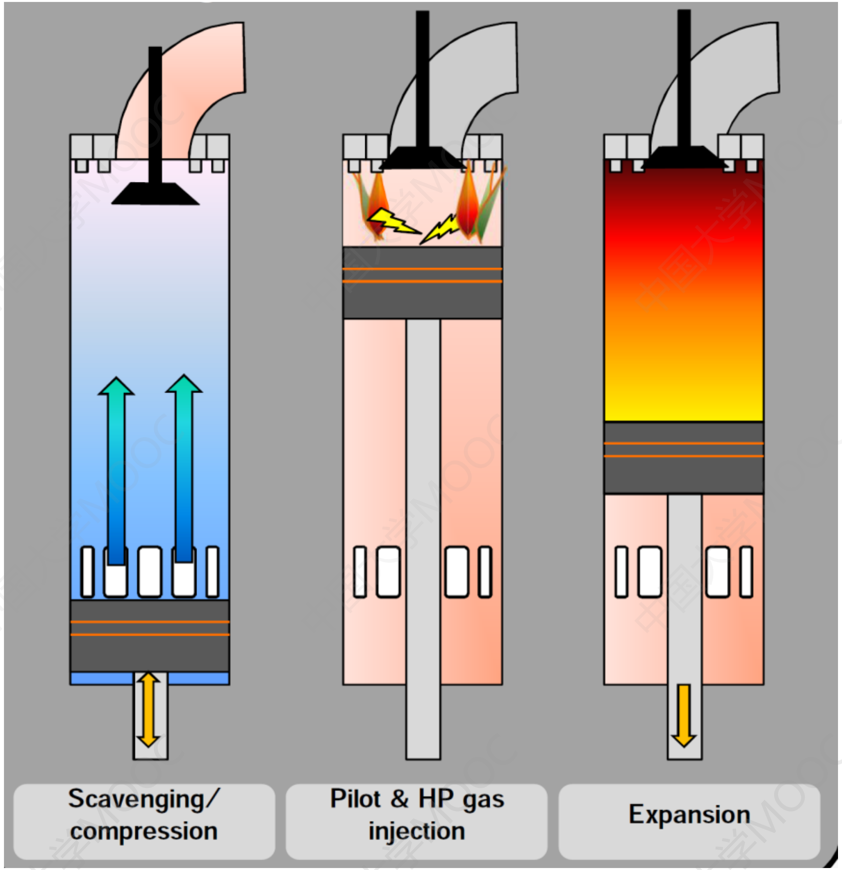


进气过程中空气进入 Air in during intake stroke	压缩过程仅压缩空气 Only air compressed during compress stroke	喷入点火油和燃气 Pilot oil and Gas injection

High Pressure Dual Fuel engine

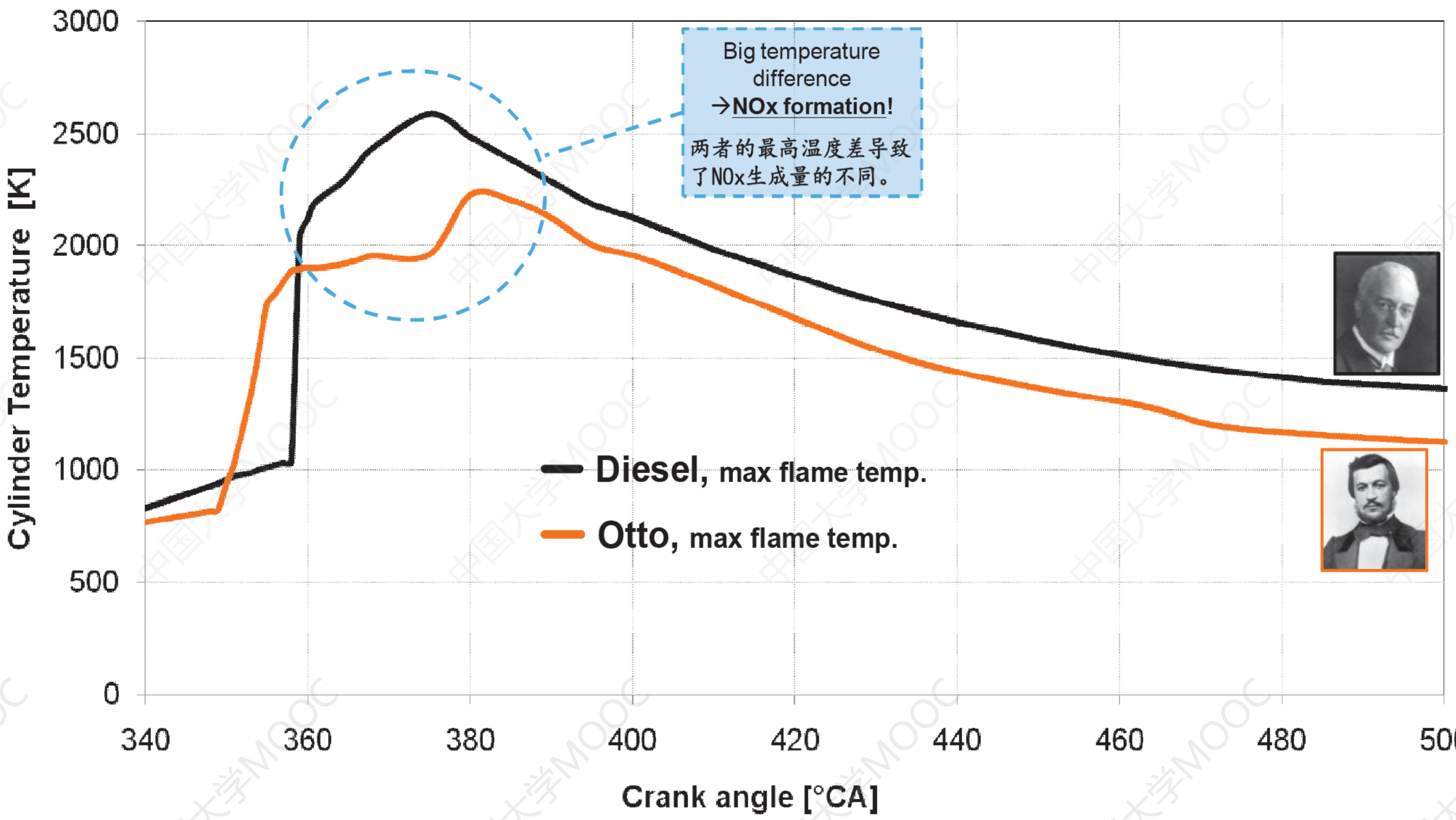
※ Sailing on LNG, Gas Engine

- DF Engine - 2S
  - High Pressure DF 2S engine
  - LNG & Diesel as fuel
  - Direct Injection (300 bar)
  - Diffusion Combustion
  - As per Diesel process
  - Requires SCR or EGR to fulfill IMO NO_x Tier III standard



High Pressure Dual Fuel engine

※ Diesel cycle vs. Otto cycle



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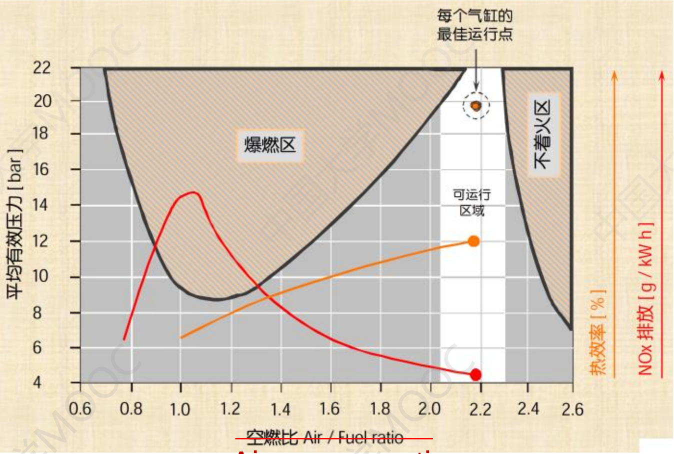
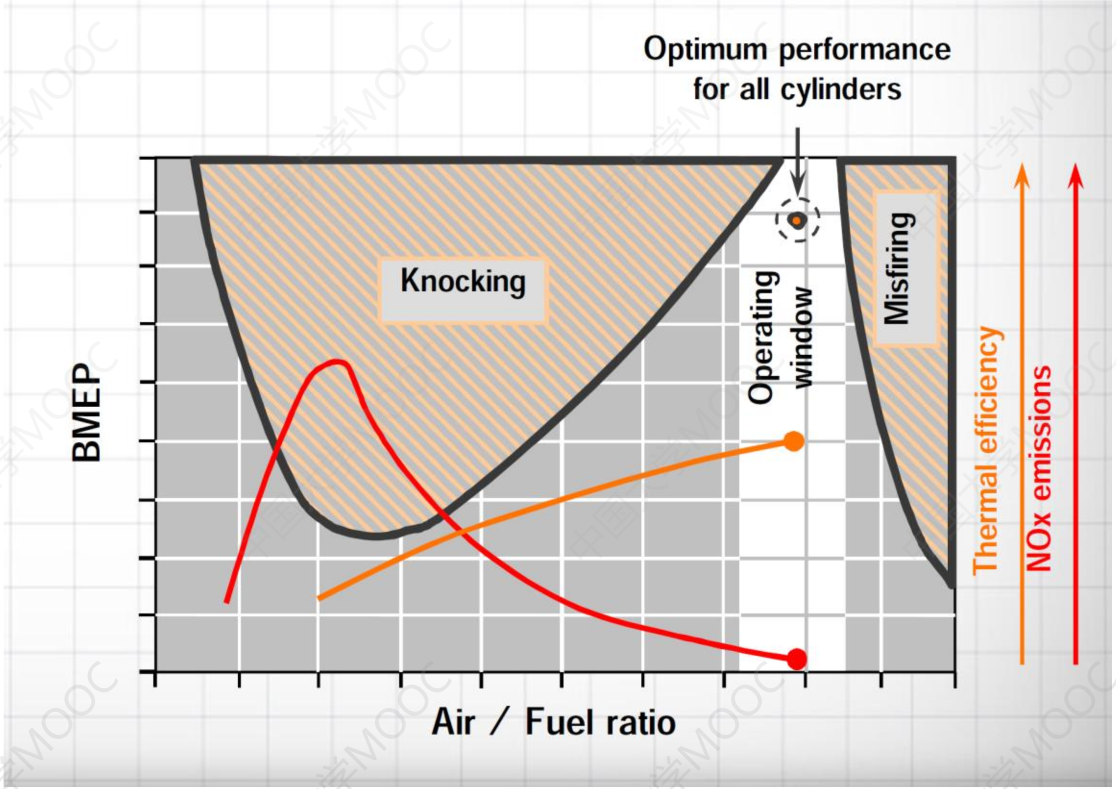
※ Pre-mixed Lean-burn

- LP DF Engine
  - Methane Number
  - ~~Cetane Number~~
  - ~~Octane Number~~



Air excess ratio



※ Pre-mixed Lean-burn

- Theoretically, for complete combustion, Air/Fuel ratio=14.7
- For lean-burning, air excess ratio=2.2, AF ratio>30
  - Complete combustion due to excessive air ---> $\eta_t\uparrow$
  - Fuel-air mixture adiabatic exponent k ↑, thermal loss of cylinder liner ↓ as burning happens in the middle of combustion space ---> $\eta_t\uparrow$
  - Low flame temperature during lean-burning leads to less thermal loss ---> $\eta_t\uparrow$, $NO_x\downarrow$?

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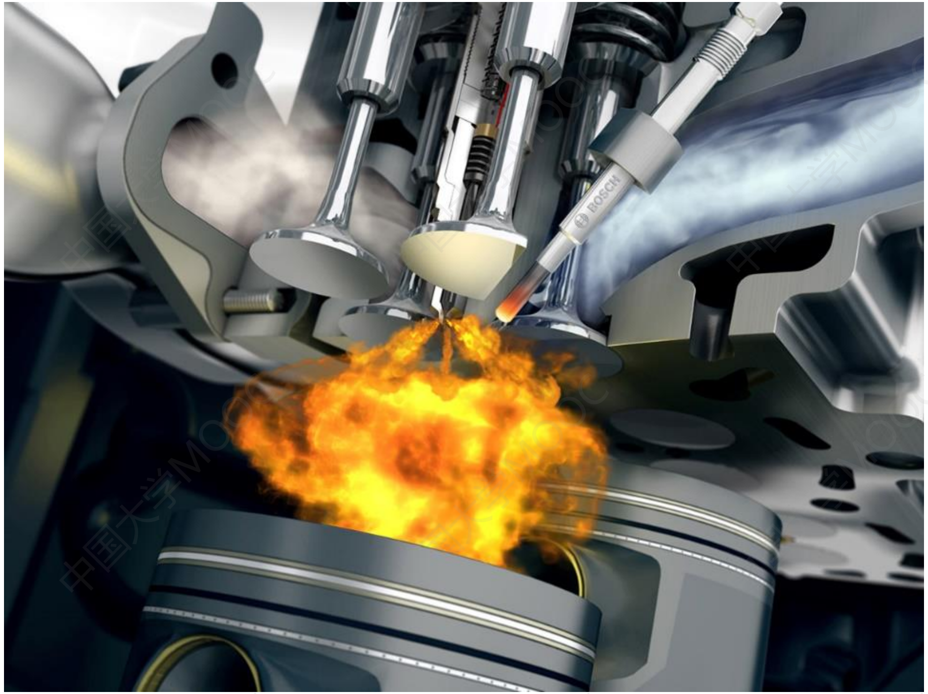
※ Formation of NO_x

- Conditions of NO_x formation
  - High temperature(>1800K)
  - Ample oxygen
  - Ample residence time



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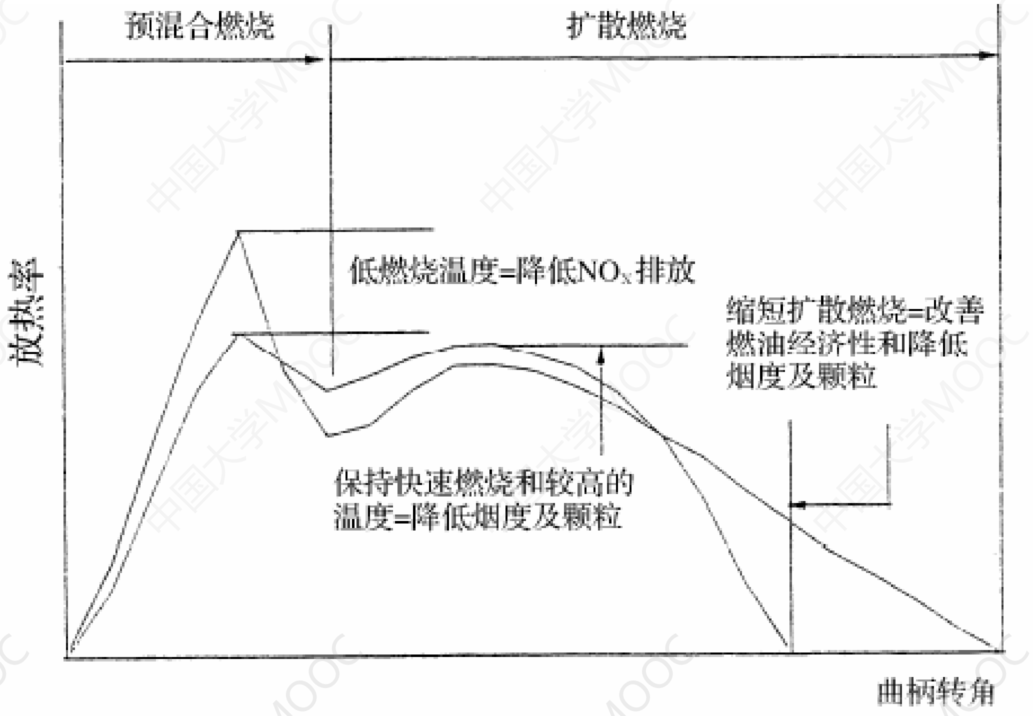
※ Formation of NO_x

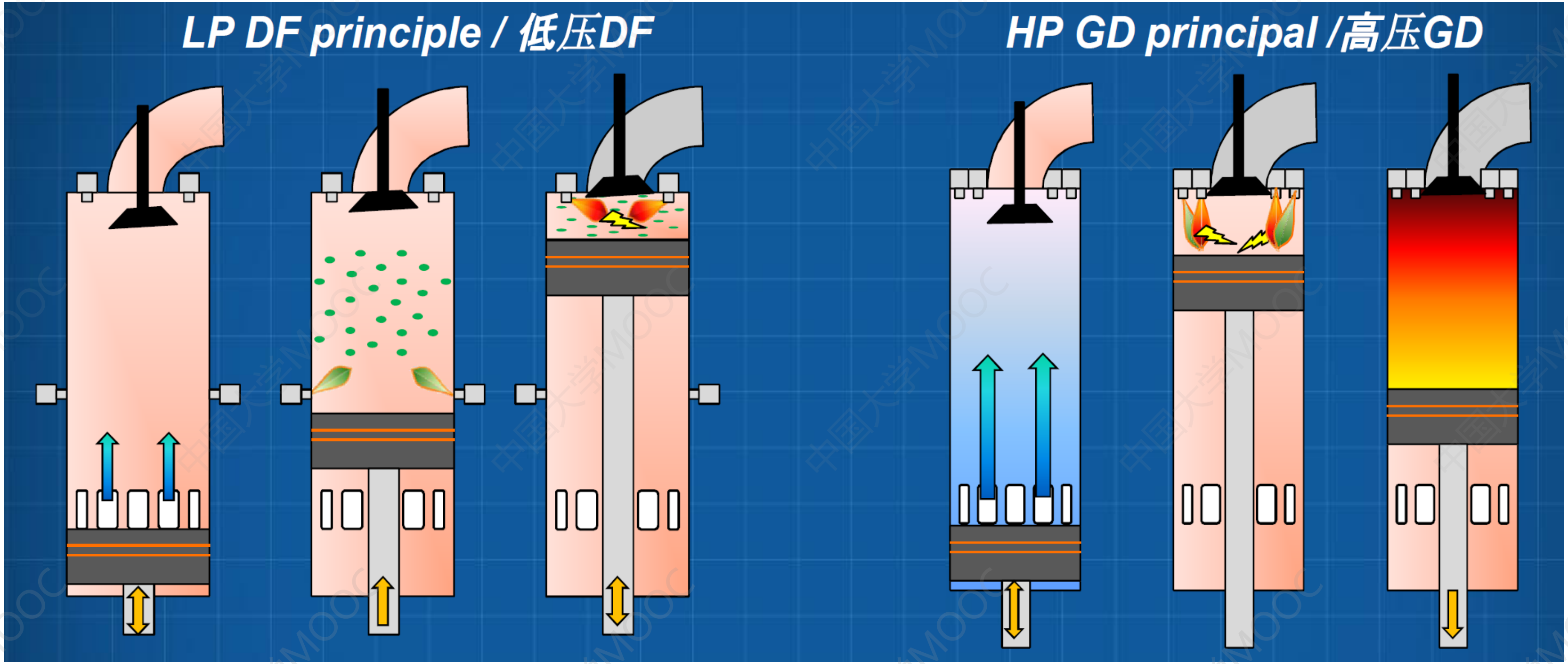
- IC Engine
  - ○ $\downarrow T_{pre\text{-}mix} \rightarrow NO_x\downarrow$
  - ○ $\uparrow T_{diffusion} \rightarrow PM\downarrow$

- Measures to reduce NOx
  - ○ Lowering the compression ratio ---> $\eta_t\downarrow$
  - ○ Retarding ignition timing ---> $\eta_t\downarrow$
  - ○ Enriching the air fuel mixture ---> lean-burn
  - ○ Reducing the amount of O_2 in the cylinder ---> EGR



- DF Engine - 2S

Wärtsilä vs. MAN-ES



Methane slip

※ Hydrogen as Marine Fuel

- Hydrogen
  - The simplest and most abundant element on earth
  - Offers the best energy-to-weight storage ratio of all fuels
  - Exists in compound forms, energy required for its extraction
  - Liquefied at -253℃
  - Carbon-free → No CO2, but NO_x emissions for hydrogen-fuelled engines
  - High auto-ignition temperature (585℃) → ideal for spark ignition engines
  - Low flammability limit → ideal for lean combustion
  - Low ignition energy and wide flammability limits → pre-ignition and knock

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※ H_2 Engines

- Pure hydrogen engines
  - Spark ignition mode
    - Port-fuel-injection (H_2)
    - Direct-injection (H_2)
    - Direct-injection (LH_2)
  - Compression ignition mode
    - Surface ignition by a glow plug
    - Pre-injection with pilot hydrogen or diesel into a pre-chamber
- Dual-fuel engines
  - Hydrogen-enriched hydrocarbons (LNG, biodiesels) and alcohols

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※ Ammonia as Marine Fuel

- Ammonia
  - Liquefied at -33℃
  - Carbon-free → No CO_2, but NO_x emissions for ammonia-fuelled engines
  - High auto-ignition temperature (651℃) → ideal for spark ignition engines
  - Low flammability limit → ideal for lean combustion
  - Low ignition energy and wide flammability limits → pre-ignition and knock

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※ NH_3 Engines

- Pure ammonia engines
  - Spark ignition mode
  - Compression ignition mode
    - Surface ignition by a glow plug
    - Pre-injection with pilot ammonia or diesel into a pre-chamber
- Dual-fuel engines
  - Ammonia-enriched hydrocarbons (LNG, biodiesels) and alcohols

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※ Methanol as Marine Fuel

- Methanol
  - CH_3OH
  - Boiling at 65℃
  - High auto-ignition temperature (464℃)

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※ CH_3OH Engines

- Spark ignition engines
  - Pure methanol
  - Methanol-gasoline blends
  - Methanol-diesel blends
- Compression ignition engines
  - Methanol-diesel blends
  - Dual-fuel mode
  - ❖Not viable for pure methanol due to low cetane number and long ignition delay

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