Large engines – gas, marine & railroad

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Outline

• Introduction to large engines
  – Size, applications, common concerns and oil approval processes

• Gas Engines
  – Designs, applications, fuels, combustion, engine problems, oil formulation

• Marine diesel engines
  – Designs, applications, fuels, regulations, lubricants, lubricants market

• Railroad

• Summary
How large?

Displacement; litres

KiloWatts

SEM
Cars
Trucks
Natural Gas Engines
Rail
Marine-4T
Marine-2T

*For illustration purposes only
Large engine applications

Making Money!

• Ships
  – Value of freight can be tens of millions of dollars
  – Ship charter rates can be $10,000’s / day

• Natural Gas Compression
  – Approximately $20,000 – $100,000 / day / engine
  – Value of natural gas sold through pipeline

• Recycling (Landfill or Biogas)
  – Approximately $3,500 / day / engine
    • Value of electricity ($/kW-hr) not purchased
Large engines – common concerns

• Safety
• Emissions
  – Necessary to stay in business
  – Target of increasing legislative pressure
• Reliability
  – Generate revenue
  – Minimise down-time
  – Lives could depend on it
• Durability
  – Minimize maintenance costs
  – Extend Time Between Overhaul and Oil Drain Interval
  – Lengthen profitable life of asset
• Fuel Economy
  – Reduce cost
Large engines – common oil approval processes

- No ‘Categories’
- Performance is demonstrated by field test
  - Find a suitable engine
    - Latest hardware in good mechanical conditions
    - High power output with consistent fuel supply
    - Accessible
  - Procedure
    - Sign contracts and warranties
    - Install pre-measured parts
    - Run for 4000, 7000, 8000 hours, or longer
    - Oil analysis and engine operation monitoring
    - Remove, measure, and rate parts
- Some engine manufacturers have formal approvals
  - Additional conditions
- Every customer may want their own demonstration
  - Even for the same formulation
Gas engine oils
Gas engine designs

- Reciprocating Internal Combustion Engines (RICE) operating on gaseous fuel
- Two- or four-stroke cycle
  - 2-T: Older, larger, medium-speed engines
  - 4-T: Newer, smaller, high-speed engines
- Spark ignited
  - Or ignited with a small injection of diesel fuel (dual-fuel)
- Combustion
  - Rich-Burn (stoichiometric), Lean-Burn, or Ultra-Lean-Burn
- Sizes range from ~75 – 18,000 kW
- May or may not have exhaust catalysts
# Gas engine manufacturers

## Four-stroke
- **Caterpillar Energy Solutions**
  - MaK
  - MWM
  - Deutz
- **GE**
  - Jenbacher
  - Waukesha
- **Cummins**
- **Perkins**
- **Siemens**
  - Detroit Diesel
  - Guascor
- **Rolls-Royce**
  - MTU
- **Wärtsilä**
- **MAN** (High speed and Medium speed)

## Two-stroke
- **Cameron International**
  - Ajax
  - Cooper-Bessemer
  - Enterprise
  - Superior
- **Dresser-Rand**
  - Clark
  - Ingersoll
  - Worthington

This is not a complete list of all Four-Stroke / Two-Stroke Gas Engine Manufacturers
Gas engine applications

- Gas Compression
  - Also called transmission, gathering, or pumping
  - ‘Free’ fuel

- Power Generation (electricity)
  - Co-Generation = use heat from exhaust and coolant
    - Also called Combined Heat and Power (CHP)
    - Electricity, heating, and cooling = Tri-Generation

- Recycling
  - Landfill and Biogas
  - Decomposition of organic material → methane

- Transportation
  - City buses, airport shuttles, taxis, etc.
    - ‘Clean Air Technology’
  - Agriculture, irrigation, etc.

~80% Of gas engines

Extend ODI via control of oxidation & nitration

酸-カルク & Deposit control

Enhanced antiwear

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Gas engine fuels

- **Natural Gas = Methane (CH$_4$)**
  - Pipeline Gas (sales gas, sweet gas, clean gas) has few contaminants and low sulphur
  - Compressed Natural Gas (CNG) at about 200 atm.
  - Liquefied Natural Gas (LNG) at about -162°C (-260°F)

- **Field Gas (sour gas) has more contaminants and higher sulphur content**

- **Liquefied Petroleum Gas (LPG) = propane and butane**

- **Gases from Recycling**
  - Roughly ½ methane and ½ carbon dioxide
    - Landfill Gas
      - Decomposition of municipal solid waste (MSW)
      - High silicon content – deposit control problems
      - Halogens (chlorine) and high sulphur – corrosion problems
    - Biogas
      - Decomposition of organic matter (farm, wood chips, etc.)
      - High sulphur content – corrosion issues
Natural gas engine problems 1

- Unique combustion chemistry
  - Gaseous fuel = fully mixed flame
  - High combustion temperatures (exhaust ~590°C vs. ~470°C diesel)

- High oil oxidation and nitration

- Corrosion
  - Oxidation acids
  - Sulphur contaminants in field, landfill, and bio-gases
  - Halogens (e.g., chlorine) in landfill and waste water gas

- Deposits
  - Varnish (high temperature deposits)
  - Silicon Dioxide deposits
Natural gas engine problems 2

• Soot/insolubles
  – Comes from burning lubricant in the combustion chamber
  – In newer engine types of high BMEP using higher quality oils (less polar base stocks)

• Water formation
  – Much higher than liquid hydrocarbon fuel

• No valve lubrication from liquid hydrocarbon fuel
  – Rely on ash from burned engine oil to lubricate valves
  – Valve recession or valve guttering or valve torching
  – from siloxanes in landfill and waste water gas
Silicon deposits from landfill gas

BAD

GOOD
Component choice

- Formulation science is complex and careful choice of each chemical component added is required
- Distinctions seen in the field are not only due to specific component choice and performance but their interactions both positive and negative

<table>
<thead>
<tr>
<th>Component</th>
<th>Options</th>
<th>Comment</th>
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<tbody>
<tr>
<td>Detergent</td>
<td>Type</td>
<td>Soap for cleanliness</td>
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<tr>
<td></td>
<td>Soap levels</td>
<td>Base number for acid neutralization</td>
</tr>
<tr>
<td></td>
<td>Base number</td>
<td></td>
</tr>
<tr>
<td>Dispersant</td>
<td>Molecular weight</td>
<td>Secondary cleanliness</td>
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<td></td>
<td>Nitrogen levels</td>
<td>Wear protection</td>
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<tr>
<td></td>
<td>Derivatives</td>
<td>Dispersing small particles</td>
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<tr>
<td>Antiwear</td>
<td>Metal type</td>
<td>Protection for moving parts</td>
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<tr>
<td></td>
<td>Chain length</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Alcohol type</td>
<td>Secondary antioxidant</td>
</tr>
<tr>
<td>Antioxidant</td>
<td>Aminic/phenolic</td>
<td>Primary source of controlling oxidation/nitration</td>
</tr>
<tr>
<td></td>
<td>Temperature dependence</td>
<td></td>
</tr>
</tbody>
</table>
Gas engine oil formulations - 1

- Limited sulfated ash (detergent)
  - Defining characteristic of gas engine oils
  - Market segmented by ash level
- Too much ash is bad:
  - Combustion chamber deposits that may lead to
    - Pre-ignition, detonation, valve guttering, or valve torching
  - Spark plug fouling
  - Port plugging (two-stroke)
- Too little ash is bad:
  - Excessive valve recession
  - Insufficient acid neutralization
- Requires a careful balance:
  - Engine design
  - Fuel composition
  - Type of service
Gas engine oil formulations - 2

- Catalyst Compatible
  - *e.g.* <300 ppm phosphorus
    - Limits phosphorus from ZDDP
      - May need supplemental (non-P) antiwear additive(s)

- Oxidation and Nitration Resistance
  - Limited antioxidancy from ZDDP due to phosphorus limit
    - Need for supplemental antioxidants
  - Benefits for higher stability base stocks
    - Balanced with occasional deposit control debits

- Corrosion Control
  - Limited antirust and anticorrosion
    - Due to ash limits (detergent)
  - May need supplemental antirust and/or anticorrosion

- Typically SAE 40 grade oils (some SAE 30)
  - Limits on Brightstock
    - Implicated in deposit formation and oxidative instability
Next generation lubricant requirements

- Drive for higher quality lubricants
  - Longer ODI (even though engines are becoming more severe)
  - Improved cleanliness

- Cost dynamic between Group I and Group II base oils
  - Worldwide capacity for Group I is diminishing

- High combustion temperatures is driving the need for greater high temperature stability of the lubricant

- With (ultra) lean burn configuration and higher temperatures, the lubricant is required to provide increased oxidation control

- Increased temperatures and pressures – results in a greater amount of organic acid species being present
  - Requires greater TBN control of the lubricant
Piston designs

- Changes to Piston design and material
  - Aluminium to Steel
- Places lubricant nearer the combustion zone
  - Thermal stress
  - Increased oil oxidation
Moving to higher power engines – oxidation effects

- Increased oxidation has an impact on other used oil parameters i.e. rapid TBN depletion
Summary – gas engine oils

- Gaseous Fuel
  - Severe and unique combustion chemistry
- Sulphated Ash Limits
  - Limited Detergent
- Catalyst Compatibility
  - Limited Phosphorus Anti-wear
- Oxidation and Nitration Control
- Deposit Control
- 0.5 SASH, <300 ppm P, SAE 40 most common
- Approvals dependent on OEM
  - Proven by Field Service
Marine diesel engines
Types of marine diesel engine

**Engine characteristics**

**Crosshead engine**
- Two-stroke
- Slow speed
- Two lubrication systems
  - Combustion zone – marine diesel cylinder lubricant (MDCL)
  - Bearings and gears – system oil
- MDCL is a once through lubricant

**Trunk piston engine**
- Conventional four-stroke
- Medium speed
- Single lubrication system
Marine engine design features
Marine fuels

• Distillate Fuel
  – A ‘cut’ of crude oil heavier than gasoline
    • Lighter than base stocks
    • Similar to home heating oil and kerosene
  – Often called MGO (Marine Gas Oil), MDO (Marine Diesel Oil)

• Residual Fuel
  – The remains after all valuable products are removed
    • Hydrocarbon – can be burned for cheap energy
  – Heavier than bright stock
    • A little lighter than asphalt
  – High asphaltene content
    • Gets into TPEO via blow-by
  – Also called HFO, heavy fuel, bunker fuel, No. 6 diesel, IF 380, etc.
A great challenge for future formulations – status quo is not an option
# Marine lubricant characteristics

<table>
<thead>
<tr>
<th>Feature</th>
<th>4-Stroke TPEO</th>
<th>2-Stroke System Oil</th>
<th>2-Stroke MDCL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel compatibility</td>
<td>★★★★★</td>
<td>★★★★★</td>
<td></td>
</tr>
<tr>
<td>Thermal stability</td>
<td>★★★★★</td>
<td>★★★★★</td>
<td>★★★★★</td>
</tr>
<tr>
<td>Rust protection</td>
<td>★★★</td>
<td>★★★★★</td>
<td></td>
</tr>
<tr>
<td>Oxidation resistance</td>
<td>★★★★★</td>
<td>★★★★★</td>
<td>★★★★★</td>
</tr>
<tr>
<td>Water shedding</td>
<td>★★★★★</td>
<td>★★★★★</td>
<td></td>
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<tr>
<td>Load bearing</td>
<td>★★★</td>
<td>★★★★★</td>
<td></td>
</tr>
<tr>
<td>Anti-wear</td>
<td>★★★</td>
<td>★★★★★</td>
<td>★★★★★</td>
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<tr>
<td>TBN retention</td>
<td>★★★★★</td>
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<tr>
<td>High temp diesel detergency</td>
<td>★★★</td>
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<td></td>
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<tr>
<td>Neutralisation Efficiency</td>
<td>★★★</td>
<td>★★★★★</td>
<td>★★★★★</td>
</tr>
<tr>
<td>Spread ability</td>
<td>★★★★★</td>
<td></td>
<td>★★★★★</td>
</tr>
</tbody>
</table>
Requirements of trunk piston engine oils

- A modern Trunk Piston Engine Oil (TPEO) must have:
  - Base Number Durability
    - Neutralise Sulphur Acids from Fuel Combustion
    - Maintain Base Number in modern marine engines with low oil consumption
  - Fuel Compatibility
    - Disperse residual fuel and its combustion products
    - Asphaltene Handling
  - Water-Handling (Good Demulsibility and Water-Shedding)
    - Shed water and retain additives in centrifugal separators
  - Cleanliness
    - Control deposits in Piston Under Crown (PUC) and Piston Ring Grooves
  - Liner lacquer control with low sulphur fuels
Critical properties of cylinder lubricants

• Base number matched to sulphur content in fuel and engine operation
  – Effective neutralisation of acidic products of combustion
  – Minimise deposits e.g. Piston Undercrown, Lands, Grooves, Rings
• Optimised viscosity for wear control and spreadability
  – Importance of viscosity index
  – Maintaining lubricant oil film thickness
• Resistance to thermal stresses
  – Control of lubricant breakdown
  – Minimise piston groove deposits
• Detergency and dispersant functionality
  – Ability to control piston deposits
### TPEO industry trends and drivers

#### Trends
- Implementation of 2020 Global Fuel S cap (0.5%)
- Tighter emission regulation of SOx
- LNG engine gaining popularity
- Poor quality of residual fuel oil
- Group II base oil considered for Marine
- Bright stock availability more challenging with decreasing output of Gp I oil
- Higher output of new engines with decreasing consumption of lubricant

#### Challenges
- Unknown impact and ways to meet legislation
- Change of lubricant demand
- Use of Scrubber or compliance to regulation
- All fuel options open (MDO, HFO, LNG etc.)
- New formulation for LNG expected
- Robust asphaltene handling properties required
- Replacement material desirable
- More stress on lubricating oil: TBN retention, oxidation control

Performance you can rely on.
Group II base oil use in TPEO - asphaltene stabilisation

- Asphaltenes are present in Heavy Fuel Oil (HFO)
- Position of equilibrium depends upon “solvent system” and structure
- Dispersants need to form stronger inter-molecular interactions with asphaltene than asphaltene intra-molecular interactions

# MDCL industry trends and drivers

## Trends

- Implementation of 2020 Global Fuel S cap (0.5%)
- Tighter emission regulation of SOx
- Engine designed with long stroke
- Slow steaming/ Fuel economy
- Stricter REACH/GHS legislation for TPP coming soon
- EGR/SCR installed due to NOx regulation
- Competition for cylinder oil becoming more fierce, cost control is pivotal

## Challenges

- Unknown impact and ways to meet legislation
  - Change of lubricant demand
  - Use of Scrubber or compliance to regulation
  - All fuel options open (MDO, HFO, LNG etc.)
- Solution to cold corrosion highly desirable!
- Label-free MDCL will be a significant differentiator from peers
- Soot control, lower ash content
- Constant optimization on treat cost

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Challenges for MDCL lubricants: a question of BN

- The reality of choosing the correct MDCL lubricant is not so straightforward, 100BN may be the correct lube oil choice in some instances, but this is not always the case.

- Other factors have an influence:
  - Engine model
  - Fuel sulphur content
  - Engine operation
  - Engine Modifications
  - Feed Rate Factors
  - Type of Fuel in Use

- Each of these factors are likely to have an impact on the lubricant choice and engine operators will need to choose the lubricant that best suits their engine and operation and fuel types:
  - The OEMs have issued guidelines which assist in deciding the best lubricant to choose.
What’s new and exciting

- **Emissions**
  - IMO global fuel S cap of 0.5% announced for 2020
  - Use of multiple fuels
    - Low sulphur fuel for Emission Control Areas
      - Distillate, HFO, LNG
    - High sulphur fuel in conjunction with scrubber systems

- **Need for multiple lubricants?**
  - Suitable for use in wide range of fuel scenarios

- **Sulphur has been (and will be) be joined by other regulated species** – NOx, PM (~2025), and smoke
What’s new and exciting

• Energy efficient shipping
  – Use of rotor sail technology, reduced drag on hull, hybrid engines
  – Introduction of plug in hybrid and pure electric engines on short crossings

• ‘Slow Steaming’ – reduced speed increases fuel economy
  – Engines not designed for low loads
  – Lubrication problems abound

• Changing Lubricant Components
  – Group II base stocks – difficult to disperse asphaltenes
Railroad engine oils
Railroad on one page

- ‘Railroad’ includes marine (inland waterways), power generation, etc.
  - Anything using engines from ‘railroad’ engine manufacturers
- Large Diesel Engines (~1500 → 4400 → 6000 Hp) (1100 – 4500 kW)
- Emissions standards lag 9 – 14 years behind on-highway
  - So do engine designs and engine oil formulations
- Two Significant Manufacturers
  - Electro-Motive Diesels (EMD) – bought by Caterpillar in 2011
    - Mostly 2T – older designs used silver bearings (not anymore)
  - General Electric (GE)
    - 4T
- Engine Oils Must be Zinc-Free
  - For Backwards Compatibility with silver bearings
  - Otherwise, uses standard formulation approaches
  - Oil quality referenced as ‘Generation’ (currently Gen 5 or 6)
- Engine oils must be approved by OEM (additive company arranges)
  - ‘Full’ approval by field test
  - Base Oil Interchange Guidelines (BOIG) by bench tests
What’s new and exciting

• Ultra-Low Sulphur Diesel (ULSD) required in many regions
  – United States since 2012
  – Reduces need for lubricant Base Number

• Next emissions reduction effective 2015
  – Reductions in NO\textsubscript{X} and Particulates

• New engine designs expected
  – Timeline for testing?

• Emissions technologies expected
  – Exhaust Gas Recirculation (EGR)
  – Diesel Particulate Filters (DPF)
  – Miller Cycle (valve timing)
  – Selective Catalytic Reduction (SCR) not expected

• Alternative technologies being considered
  – Liquefied Natural Gas (LNG)
  – “Gen-sets” – multiple small engines in place of one large engine
Summary
Large engine lubricants

- LELs have special requirements, based on:
  - Fuel
  - Engine design
  - Type of service
  - Approved through field performance

- Gas Engine Oils require
  - Limited sulphated ash and phosphorus
  - High oxidation and nitration stability
  - Deposit control

- Marine Oils require
  - Base number matched to fuel sulphur and engine operation
  - Asphaltene-handling (TPEO)
  - Water-handling
  - Base number retention (TPEO)

- Railroad Oils require
  - Zinc-free
  - OEM approval letters
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