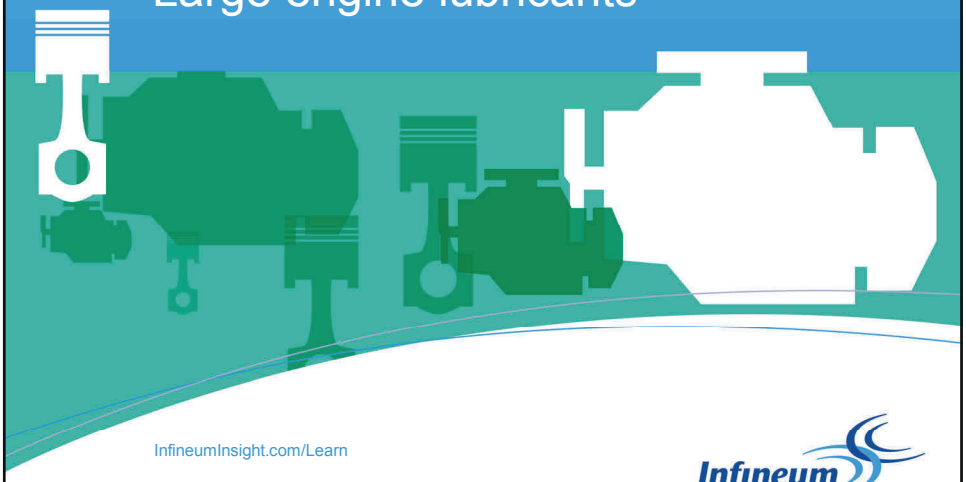
Performance you can rely on.

Large engine lubricants



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Outline

- Types of Large Engines
  - Natural Gas
  - Railroad
    - And Inland Marine
  - Marine
- What Makes Them Different?
  - Fuels
  - Design Features
  - Applications
- Lubrication Requirements
  - Comparison with Other Engine Oils
- What's New and Exciting

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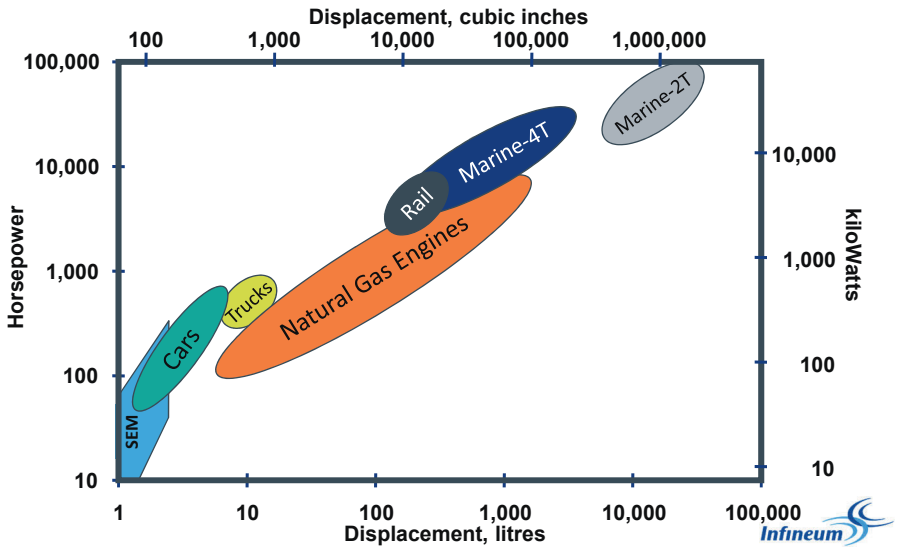
How large?



Large engine applications

- **Making Money!**
  - Ships and Trains
    - Value of freight can be tens of millions of dollars
  - Natural Gas Compression
    - Approximately $20,000 – $100,000 / day / engine
      - Value of natural gas sold through pipeline
  - Power Generation (Electricity)
    - Difference between electricity price and fuel cost

Large engines – common concerns

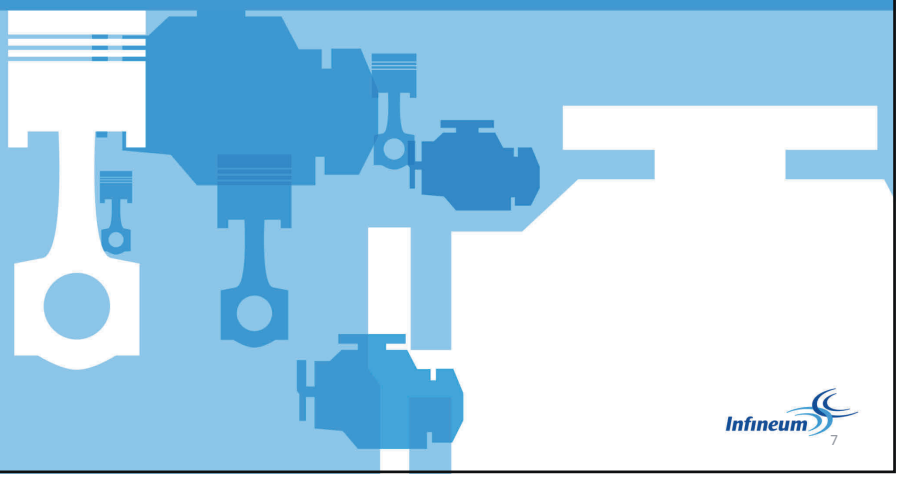
- Safety
- Emissions
  - Necessary to stay in business
  - Target of increasing legislative pressure
- Reliability
  - Generate revenue
  - Minimize down-time
  - Lives could depend on it
- Durability
  - Minimize maintenance costs
  - Extend Time Between Overhaul and Oil Drain Interval
  - Lengthen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

Specific limits not reviewed here

Large engine oils – common systems

- No ‘Categories’ or formal industry rules
  - Although most circumstances follow similar procedures
- Performance is demonstrated by field test
  - Under actual operating conditions
  - No special modifications to increase or decrease severity
  - Typical procedure
    - Sign contracts and warranties
    - Install pre-measured parts
    - Run for required duration (typically one year)
    - 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

Natural gas engine oils



Gas engine designs

- Engines operating with gaseous fuel ←
- → – This is what makes them different!
- Reciprocating Internal Combustion Engines (RICE)
  - Sizes range from ~100 to ~10,000 HorsePower (75 – 7500 kW)
- 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)
- May or may not have exhaust catalysts
  - If so, phosphorus in lubricants is limited

Gas engine fuels

- Natural Gas = Methane (CH_4)
  - Pipeline Gas (sales gas, sweet gas) has few contaminants
  - 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
  - Sulfur, water, carbon dioxide, *etc*.
- Liquefied Petroleum Gas (LPG) = propane and butane
- Gases from Recycling
  - Decomposition of organic material ➔ methane
  - Roughly ½ methane and ½ carbon dioxide
  - Significant contaminants: sulfur, chlorine, silicon, *etc*.
    - Exact composition varies

Gas engine manufacturers

Four-stroke

- Caterpillar / MaK
- Cummins
- Detroit Diesel / MTU
- Deutz
- Guascor
- Jenbacher / GE
- MAN
- Rolls-Royce
- Wärtsilä
- Waukesha / GE

Two-stroke

- Cameron International
  - Ajax
  - Cooper-Bessemer
  - Enterprise
  - Superior
- Dresser-Rand
  - Clark
  - Ingersoll
  - Worthington

Typical gas engine parameters

Manufacturer	Caterpillar	Waukesha	Ingersoll-Rand
Engine Model	G3516	VHP L5794	KVR
Cycle	4-T	4-T	2-T
Ignition	Spark	Spark	Spark
Breathing	Turbo-	Turbo-	Turbo-
Cylinders	16	12	16
Bore, mm (in)	170 (6.7)	216 (8.5)	432 (17)
Stroke, mm (in)	190 (7.5)	216 (8.5)	559 (22)
Displacement, L (cu in)	69 (4211)	95 (5796)	1309 (79,897)
Weight, kg (k lbs)	7545 (17)	10,000 (23)	140,000 (310)
Sump, L (gal)	360 (106)	720 (190)	7740 (2044)
Speed, rpm	1200	1200	330
Power, kW (Hp)	1010 (1360)	1029 (1380)	4470 (6000)

$300,000 – $1,000,000+

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Natural gas engine problems

- 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
  - Sulfur and other contaminants in sour gases
- Deposits
  - Varnish (high temperature deposits)
  - Siloxanes (silicon compounds) from landfill gas
- Water formation
  - 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 ➔

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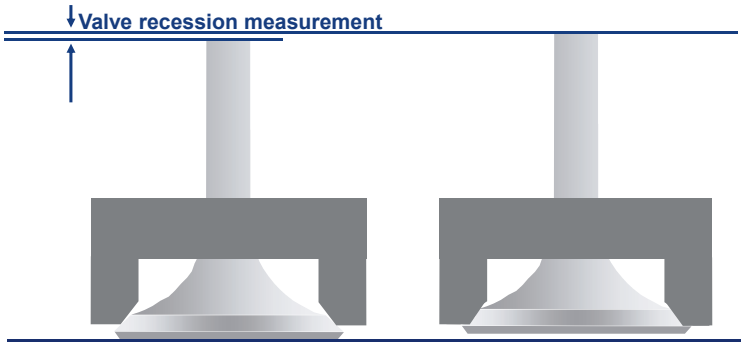
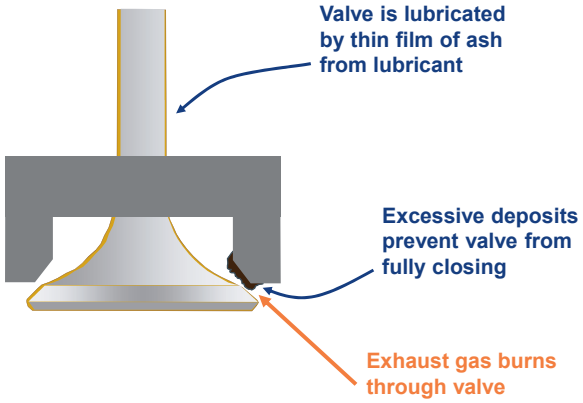
Valve recession



- Eventually, valve doesn't open properly
  - Loss of power
  - Pre-mature engine overhaul
  - High maintenance costs
- Need to lubricate valve contact with engine oil ash ➔

Valve guttering and torching



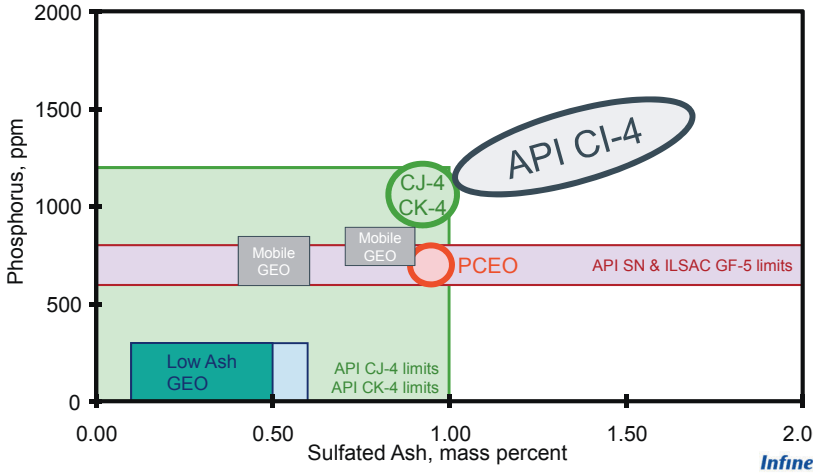
- Guttering: Beginning (or a little bit)
- Torching: Completely through

Gas engine oils

- Segmentation by Ash (Sulphated ASH = SASH)
  - Ashless < 0.1 SASH Older 2-stroke
  - Low ash 0.1 – 0.5 SASH (→ 0.6) Most common
  - Medium ash 0.5 – 1.0 SASH High sulfur gas / some OEM's
  - High ash > 1.0 SASH Very high sulfur gas
- Catalyst Compatable
  - <300 ppm phosphorus
- Viscosity Grades
  - SAE 40 Most common
  - SAE 30 Low temperature operation
  - SAE 15W-40 Buses, trucks, shuttles, on-highway

Comparison of engine oils

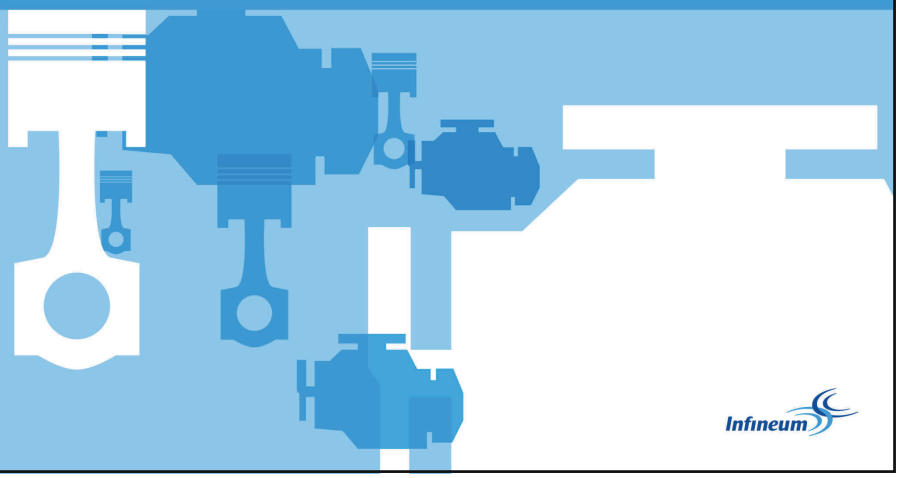
- Gas Engine Oils are lower in ash and phosphorus
  - For deposit control and catalyst compatibility



What's new and exciting

- Increasing use of natural gas
  - New reservoirs
  - Lower cost
  - Better emissions
- Increased interest in gaseous fuels for transportation
  - Fleets with fixed re-fueling points
    - Taxis, buses, local trucking, locomotives
  - Larger infrastructure projects considered
- Higher power density
  - New engine materials and increased pressures & temperatures
- More engine manufacturers getting involved
  - Different designs being introduced
  - Lubrication requirements not always known
- Emissions regulations steady for now
  - But certainly will be targeted in future

Railroad engine oils (and inland marine)



Railroad summary

- "Railroad" includes inland marine, power generation, etc.
  - Anything using engines from 'railroad' engine manufacturers
- Large Diesel Engines (~1500 → 4400 → 6000 Hp) (1100 – 4500 kW)
- Emissions ("Tier") and engine designs lag 9 – 14 years behind on-highway
- Two Significant Manufacturers
  - Electro-Motive Diesel (EMD) – bought by Caterpillar in 2011
    - Mostly 2-stroke – older designs used silver bearings (not anymore)
  - General Electric (GE)
    - 4-stroke

➔ Engine Oils Must be Zinc-Free for Backwards Compatibility with silver bearings

  - Otherwise, similar types of additives to on-highway diesel engine oils
  - Oil quality referenced as "Generation" (currently Gen 5, 6, or 7)
    - "Generation" matched to fuel sulfur and engine design
- Engine oils must be approved by OEM (additive company arranges)
  - 'Full' approval by field test
  - Base Oil Interchange Guidelines (BOIG) by bench tests

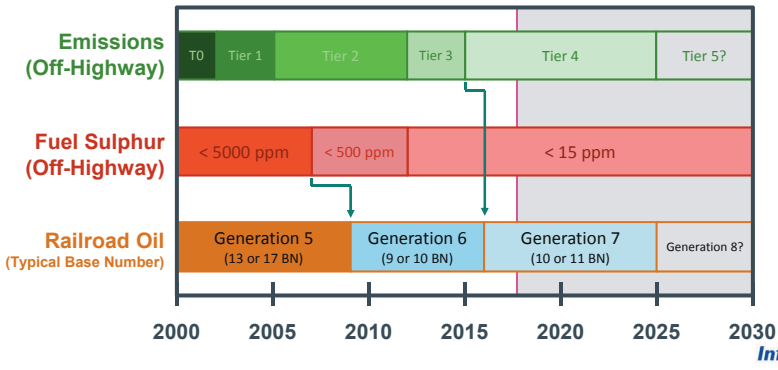
Typical railroad engine parameters

Manufacturer	Electro-Motive Diesel	General Electric
Engine Model	16-710G3C-T2	GEVO
Cycle	Two-stroke	Four-stroke
Ignition	Compression	Compression
Breathing	Turbo-Charged	Turbo-Charged
Cylinders	16	12
Bore, mm (in)	230 (9-1/16)	250 (9.8)
Stroke, mm (in)	279 (11)	320 (12.6)
Displacement, L (in^3)	186 (11,353)	188 (11,503)
Weight, kg (lb)	18,000 (40,000)	19,000 (42,000)
Sump, L (gal)	1650 (436)	1440 (380)
Speed, rpm	900	1050
Power, kW (Hp)	3280 (4400)	3280 (4400)

$1,000,000 – $2,500,000

Railroad “Generations” and timing

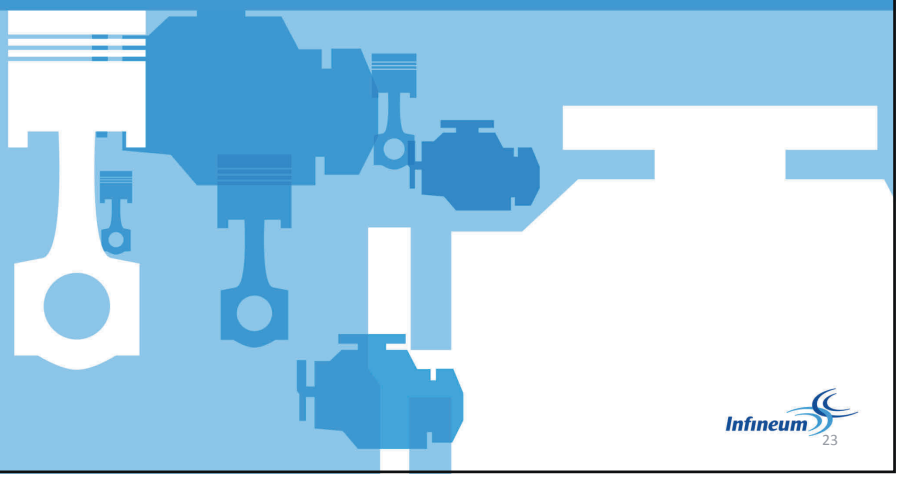
- Almost any “Generation” can be used with any fuel in any “Tier” engine
  - But there will be trade-offs
  - Certain combinations make more sense, based on operational results



What’s new and exciting

- Ultra-Low Sulfur Diesel (ULSD) required in many regions (USA since 2012)
  - Reduces need for lubricant Base Number
- Latest emissions reduction effective 2015
  - Reductions in NO_X and Particulates
- New engine designs introduced with added emissions technologies
  - Exhaust Gas Recirculation (EGR)
  - Diesel Oxidation Catalysts (DOC) and Diesel Particulate Filters (DPF)
  - Miller Cycle (valve timing) and combustion optimization
  - Selective Catalytic Reduction (SCR) not used
- Generation 7 engine oil specification issued by industry body (2016)
  - More compatible with EGR systems
  - While controlling ash for DOC and DPF
- Alternative technologies being considered
  - Liquefied Natural Gas (LNG)
  - ‘Gen-sets’ – multiple small engines in place of one large engine

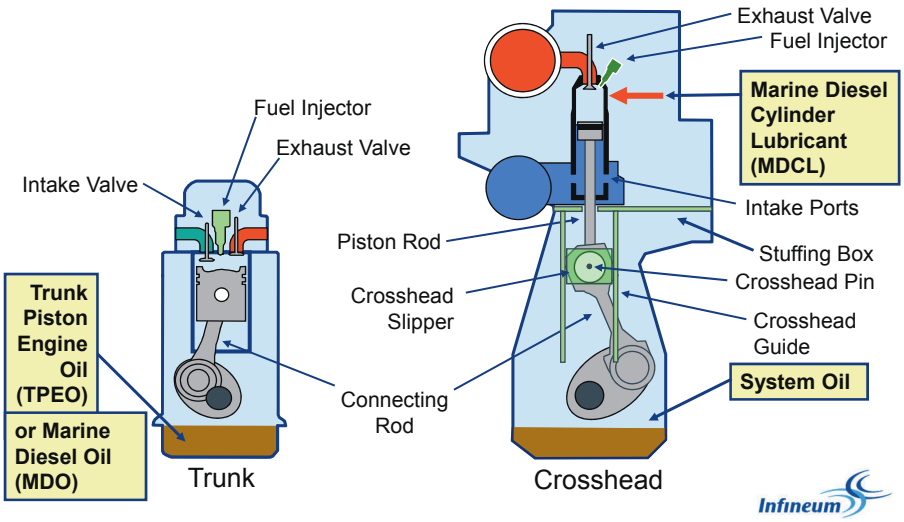
Marine engine oils



Marine engines

- Marine Engine Designs
  - ➔ Trunk Piston Engines
    - Four-stroke
      - – Medium speed 300 – 700 rpm ~3500 – 22,000 Hp
    - ➔ Trunk Piston Engine Oil (TPEO) for high sulfur residual fuels
    - ➔ Marine Diesel Oil (MDO) for low sulfur distillate fuels
  - ➔ Crosshead Engines
    - Two-stroke
      - – Slow speed 60 – 100 rpm ~12,000 – 110,000 Hp
    - ➔ Marine Diesel Cylinder Lubricant (MDCL) for upper part of engine
    - ➔ System Oil for lower part of engine
- Marine Lubricant Filter Systems
  - ➔ Centrifugal Purifiers
- Marine Fuels
  - – Distillate
  - ➔ Residual
- Marine Engine Lubrication Requirements

Marine engine design features



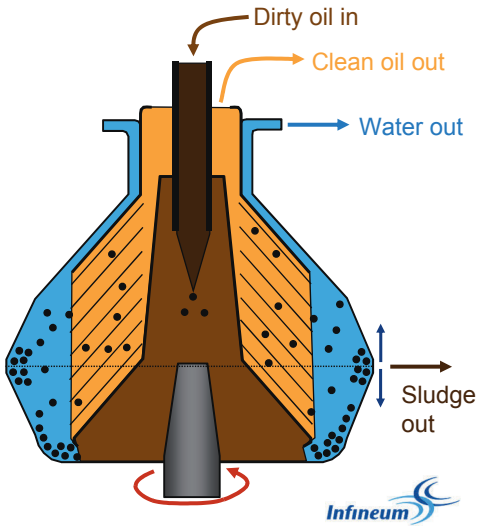
Typical marine diesel engines

Type	Trunk Piston	Crosshead
Manufacturer	MAN	Wärtsilä
Model	9L58/64	14RTA96C
Cycle	Four-stroke	Two-stroke
Cylinders	9	14
Bore, mm (inches)	580 (23)	960 (38)
Stroke, mm (inches)	640 (25)	2500 (98)
Displacement, litres	1522	25,334
Cubic inches	92,868	1,545,964
Weight, tonnes	162	2300
Sump, litres	16,000	44,000
gallons	4,000	12,000
Speed, rpm	400	102
Power, kW	11,790	84,420
Hp	15,811	114,800
Torque, N-m	281,459	8,014,341
Ft-lbs	207,594	5,911,075

← $15,000,000 – $30,000,000 →

Centrifugal purifier

- Used oil introduced
  - Oil, Dirt, Sludge
  - Water
- Purifier spins
  - Centrifugal force
- Separation by Density
  - Lowest density = Oil
    - Removed as liquid
  - Medium density = Water
    - Removed as liquid
  - Highest density = Sludge
    - Accumulates as solid
    - Periodically "shoots" to remove
    - Older units must be cleaned
- Requires lube oil to have good water-handling properties



Marine fuels

- Distillate Fuel
  - Also called Marine Diesel Oil (MDO) or Marine Gas Oil (MGO)
  - Similar to on-highway diesel fuel
    - A little higher viscosity
    - A little more sulfur
- Residual Fuel
  - Also called Heavy Fuel, Bunker Fuel, No. 6 Diesel, IF 700, etc.
  - 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 sulfur content
    - 3.5 – 4.5 %
  - High asphaltene content
    - Gets into TPEO and System Oil *via* blow-by

Requirements for crosshead engines

- MDCL

  Performance
  - Neutralize sulfur acids from fuel combustion
  - Ring and liner wear control (corrosive wear)
  - Control piston deposits
  - Control liner lacquer (varnish)

  Formulation
  - High base number
  - High viscosity
  - Good ‘spreadability’
  - Thermal and oxidation resistance
- System Oil
  - Thermal and oxidation resistance
  - Asphaltene compatibility

Requirements for trunk piston engines

- Everything a Heavy-Duty Diesel Oil Does!
  - In a more severe environment
- Plus:

- Neutralize Sulfur Acids from Fuel Combustion
  - High base number
- Fuel Compatibility
  - Disperse residual fuel and its combustion products
  - ‘Asphaltene-Handling’
- Water-Handling
  - Good demulsibility (water-shedding)
  - Additive retention in centrifugal purifier

Typical marine oils

	Viscosity	Base Number
System Oil	SAE 30 (or 40)	5 – 7
Cylinder Lubricant	SAE 50	70 – 100 ~40 for low sulfur fuels
Marine Diesel Oil	SAE 40 (or 30)	~15
Trunk Piston Engine Oil	SAE 40 (or 30)	40 – 55

What's new and exciting

- Emissions
  - Emission Control Areas (ECAs) exist and expanding
  - Use of multiple fuels
    - Low Sulfur for emission compliance in ECAs
    - High Sulfur for reduced cost outside ECAs
  - Need for multiple lubricants?
    - Still in debate
    - Data being gathered
  - Sulfur will be joined by other regulated species – NO_X, PM, and smoke
- Fuel Economy
  - "Slow Steaming" – reduced speed increases FE
  - Engines not designed for low loads
  - Lubrication problems experienced
- Changing Lubricant Components
  - Group II base stocks – difficult to disperse asphaltenes

Large engine lubricants (LEL)

- LELs have special requirements, based on:
  - Fuel
  - Engine design
  - Type of service
- Gas Engine Oils require
  - Limited sulfated ash and phosphorus
  - High oxidation and nitration stability
  - Deposit control
- Railroad and Inland Marine Oils require
  - Zinc-free
  - OEM approval letters
- Marine oils require
  - High Base Number
  - Asphaltene-handling
  - Water-handling
- LELs are approved through field performance