Critical areas of engine lubrication
Agenda

• Introduce the topic
• An overview of the five zones where needs are very different:
  – Valve train, cylinders, bearings, sump, turbocharger
• Take each zone in turn to:
  – Discuss the challenges faced
  – Link to what is needed from the lubricant
• Summary with temperature regimes shown for each zone
Introduction

• The internal combustion engine is in essence a chemical and metal working ‘factory’. It operates:
  – Under regimes of high pressure and wide temperature ranges
  – In the presence of water and undesirable combustion products
• The role of the lubricant is to protect the engine from wear, neutralise and remove unwanted contaminants, and cool the engine
The role of the lubricant

- Primary role:
  - Reduce friction and wear

- Secondary roles:
  - Remove heat away from the contact
  - Carry away the debris
  - Protect surface from water
  - Neutralise acids from combustion

- Properties:
  - Resistant to the environment
  - Inert to metals and seals
Critical zones in the engine

Zone 1
- Turbocharger
- Inlet valve

Zone 2
- Cylinder block
- Con rod

Zone 3
- Crankshaft

Zone 4
- Oil pump
- Sump

Zone 5
- Rockers
- Valve springs
- Camshaft
- Piston rings
- Piston
- Journal bearings
- Oil
- Oil pump
- Crankshaft
# Critical areas of lubrication

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The goal for reducing internal friction losses is to:

- Reduce Boundary Lubrication losses via friction modifier
- Reduce the mixed elastohydodynamic losses via base stock/friction modifier
- Reduce viscosity related losses in hydrodynamic via base stock/viscosity modifier

Critical areas of lubrication:

- Fuel 100%
  - Mechanical work 20%
  - Internal friction 8%
  - Coolant 32%
  - Exhaust heat 35%
  - Auxiliaries (parasitic) 5%
  - Valve train 10-15% (75%B/25%H)
  - Piston ring assembly 40-70% (25%B/25%EHL/50%H)
  - Crank and bearings 10-25% (25%EHL/75%H)
  - Pumping 5-20% (100%H)

Performance you can rely on.
Demonstration video – Oil flow
Zone 1: valve train zone

- Rockers
- Camshaft
- Valve springs
- Valves
Valve train zone – #1 challenge: wear & friction

- Cam and tappets are key parts prone to wear:
  - Leads to reduced valve opening and power loss
- An area of very high pressure and lowest engine temperature
  - Contact zone pressures can reach $>2 \times 10^9$ Nm$^{-2}$
  - Temp $< 60^\circ$C up to $100^\circ$C
- On start-up, it can take considerable time for oil to reach the valve train
  - Must really try to protect at this time
Valve train zone – Specific wear requirements

Why is wear so important here?
• Control of adhesive (scuffing) and abrasive wear is essential to maintenance of emissions, power and fuel economy
  – Must maintain perfect valve opening / closing for best emissions control
  – Soot in oils may lead to higher levels of wear
• Modern valve trains are well designed but with increasing demands continue to require very high levels of lubricant protection
  – Longer drain intervals, thinner oils, lower phosphorus, higher loadings, etc.

Key requirements for lubricant:
• Correct anti-wear additive(s) for regime, e.g. Zinc Dialkyl Dithiophosphates (ZDDP), Extreme Pressure Additives (EP)
• Careful consideration of base oil / viscosity modifier for good low temperature characteristics and rapid flow of lubricant on start-up
  – Use of biofuel can also impact here
Valve train zone – Frictional aspects

Why worry about friction?

- Valve train is an area of high energy loss due to friction from parts which are very close together
  - Contact is mostly in the boundary regime, so lubricant viscosity plays only a small part
- Significant reductions in frictional losses can be achieved with advanced formulations and specific componentry:
  - Enables improved fuel economy and reduced CO$_2$ emissions

Key requirements for lubricants:

- Friction reduction is achieved using surface active additives such as esters, amines, molybdenum sulphide compounds
- Use of highly surface active components which requires very careful formulating
  - Wear performance must not be compromised
Background - Low temperature sludge formation

What causes sludge to form?

- Blow-by gases (containing unburned fuel and water) combine with oil droplets in the sump and are transferred into valve train area through engine breather system
- At low temperatures (especially short journeys) water / fuel is not evaporated and forms a surface emulsion which can turn to sludge
- Sludge formation in the rocker box is partially caused by poor venting of air
  - The sludge formed is soft, if heated (long journey etc.) becomes hard and brittle. This is black sludge
  - Can lead to blocked oil ways, wear and seizure

Key requirements for lubricants:

- Dispersant components can stabilise very small sludge droplets in the oil to prevent these types of emulsions / sludges from forming
- Detergent components can clean the metal surfaces, stabilise polar materials and neutralise acids
Valve train zone - Sludge formation in the rocker box

Cycles of cold and hot temperatures different sludge effects

- Deposition of emulsion at the surface in the cold phase – “white sludge”
- Further hardening / coking at higher temperature leads to “black sludge”
Valve train one – Rust control

• Rust
  – At low temperatures, e.g. stop / start driving, long periods of standing without use, water / acids condense on valve train
  – Leads to wear and possible valve sticking

• Key requirements for lubricants
  – Over-based detergents and corrosion inhibitors can help prevent rusting
Valve train zone - Deposit control

• Valve deposits
  – Due to high temperature of the valve top, oil and fuel are exposed to high temperatures, causing deposits to form
  – Leads to incorrect valve opening/ sticking, giving poorer engine performance

• Key requirements
  – Fuel/crankcase detergents prevent deposit formation / clean if formed
  – Good oxidation stability prevents deposit formation
Zone 2: piston and cylinder zone

Piston grooves into which rings are sited

Piston

Cylinder block
Piston and cylinder zone

50% of engine friction is between piston rings and liner
Background: the piston and cylinder zone

- Piston head is a high temperature zone
  - ≥ 300°C on piston crown and ≥ 200°C in top groove and getting hotter
- Oil is required to lubricate all rings to prevent seizure
- Typical detrimental process is cracking or polymerisation of the oil and fuel residue to form deposits on surfaces
- Leads to three types of phenomenon occurring
  - Ring stick
    - Deposits build-up in piston grooves surrounding the ring
    - Prevents ring movement and effective gas-tight sealing
    - Leads to loss of power, high oil consumption, increase of blow-by gases
  - Excessive wear
    - Deposits build-up behind the ring forcing it against the cylinder (“ring riding”)
    - Leads to excessive wear, oil consumption and increase in blow-by gases
  - Abrasive wear
    - Deposits break off from the piston and can score the cylinder
    - Leads to wear, high oil consumption & increase in blow-by gases
Piston deposits and ring stick – how it happens

- Deposits build up
- Varnish/lacquer
- Stuck piston ring
- Bore polish
- Blow-by gases
The piston zone – Other detrimental impacts

• **Bore polish** – piston rings forced outwards by deposits behind them (ring riding) and deposits on the piston top land polish the cylinder walls
  – Poorer oil retention, eventually increasing wear and oil consumption

• **Lacquer / varnish** – unstable oils and fuel residue can build up a film on the piston skirt and cylinder walls
  – Relatively lower temperatures vs. crown and top grooves
  – Poorer cooling of the piston and poor oil retention on the cylinder walls

• **Corrosion (wear)** – in cold conditions acids from combustion condense, causing cylinder and ring corrosion

**Key requirements for lubricants**

• Over-based detergents to keep parts clean and neutralise acids
• Dispersants prevent deposits and residues agglomerating
• Anti-wear agents to prevent piston ring and cylinder wear at the top and bottom of the piston stroke
The difference between cylinder wear and bore polish

Bore Polish
The difference between cylinder wear and bore polish

Cylinder Wear
Ash deposits (specific to gasoline engine) 1

Carbon particles from poorly burnt fuel and ash from additives in the lubricant can form combustion chamber deposits

- Leads to pre-ignition in the combustion chamber
  - The deposits become hot and ignite the fuel before the spark occurs
  - Puts strain on the engine, particularly on the bearings and crankshaft
  - Leads to uncontrolled combustion hot spots and loss of power
Ash deposits (specific to gasoline engine) 2

- Spark plug fouling
  - Deposits build up around the spark plug electrode, bridging the electrode gap and giving a weaker spark
  - Leads to poor sparking or failure to ignite the mixture, and thus loss of power

Key requirements for lubricants to control ash / carbon deposits in gasoline engines

- Good detergency from the fuel and the lubricant
- Lubricants with the correct amount of ash (this needs careful balance of performance needs)
Zone 3: bearings

- Journal bearings
- Connecting rod
- Oil pump
- Crankshaft
Primary bearing issues - Wear

- Start-up: most severe period for bearings moving from boundary to hydro-dynamic lubrication. Immediate supply is essential to stop wear.
Lubricant impact in bearings

Types of wear which can occur

- Abrasive wear: wear metals / dust / sand etc. can get lodged between or embedded in the bearing surfaces, leading to wear
- Chemical attack: acidic combustion products can corrode soft metals, leading to bearing collapse

Key requirements for lubricant

- Basic needs focus on non-shearing viscosity:
  - Good flow/viscosity characteristics especially on start-up – immediate supply of oil to the parts
  - Sufficiently thick oil film at higher temperature / shear to provide the level of support required. Viscosity modifier / base stock choice is very important
  - Anti-wear, anti-corrosive additives, overbased detergents can help
  - Vital to have well maintained filter system to keep oil free from debris
- Current drivers to reduce viscosity to improve fuel economy leads to film thickness reduction and gives greater potential for wear
Zone 4: sump and oil pathways
Sludge formation in the sump

- Sludge forms in a similar route previously described
- Leads to viscosity increase, blocking of oil ways and oil starvation
Viscosity increase of lubricant in sump

- High temperature oxidation
  - Components of the oil, additive package and viscosity modifier can oxidise and then add together at high temperatures to form large molecules that thicken the oil
- Soot loading (diesel & gasoline direct injection (DI))
  - High levels of soot can be generated in overloaded / over-fuelled diesel engines and in direct injected gasoline engines (lower levels)
  - Soot contamination increases oil viscosity by aggregation
  - Modern engines can generate higher soot levels, although this seems to have stabilised (for the time being…)
- Leads to poor pumpability, poor start-up, oil starvation & wear

**Key requirements for lubricant**
- Good oxidation stability to prevent oxidation & large molecules forming
- Good dispersant components to prevent soot aggregation
Viscosity decrease of lubricant in sump

• Shear stability of lubricant. Two types linked mostly to viscosity modifiers:
  – Permanent viscosity loss
    • Due to mechanical / thermal / oxidative breaking-up of the polymer molecules
    • Measured by the Kurt Orbahn / Bosch Injector test
  – Temporary viscosity loss
    • Is reversible, and due to the effect of shear stress on polymer orientation
    • Measured by High Temperature High Shear test
  – More information in the viscosity modifier presentation

• Fuel dilution
  – Excessive fuel due to poor fuelling system or short journeys results in thinning of the oil
  – Leads to lower film thickness and greater wear

**Key requirements for lubricant**
  – Careful choice of viscosity modifier with the right level of shear stability
  – Correct fuel management
Oil thickening and thinning

Viscosity modifier and polymeric components undergo similar reactions to thin or thicken the lubricant.
Lubricant effects in the turbocharger

- Primary need is for cooling and turbo shaft bearing lubrication:
  - High oil flow requirement at high temperature
  - Can lead to deposits on the shaft which connects turbine and compressor, especially if engine is stopped at high temperature
    ➢ Has been successfully prevented with engine-off pumps

- With closed crankcase ventilation now more standardised, intake deposits can also be a problem:
  - Oil mist passed into intercooler and turbo compressor through engine breather system forming deposits on hot metal surfaces
    ➢ Coagulators are used to help filter oil droplets from the air

Key requirements for lubricant

- Lubricant with the required oxidation performance to help prevent coking in the turbo surfaces and journal bearings
- Careful design of lubricant viscosity, volatility and misting properties
- Excellent pumpability on start-up to reach turbo parts quickly
Summary – the critical areas of lubrication

- Sludge
- Valve train wear
- Rust
- Intake deposits
- Ring stick
- Bore polish
- Bearing wear
- Viscosity increase
- Pre-ignition
- Piston deposits
- Bore wear
- Shear stability
- Oil consumption
- Sludge
- Compressor deposits
- Shaft Deposits

Temperatures:
- 200 to 350°C
- 100 to 180°C
- 30 to 100°C
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