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Critical Areas of Engine Lubrication

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Agenda

01 | **Overview of the five zones** where needs are very different: Valve train, cylinders, bearings, sump, turbocharger

02 | For each zone:
Discuss **challenges faced**
Understand lubricant **impact**

03 | Summary with **temperature regimes** shown for each zone

Introduction

Operating Conditions

Internal Combustion Engine

Lubricant Role

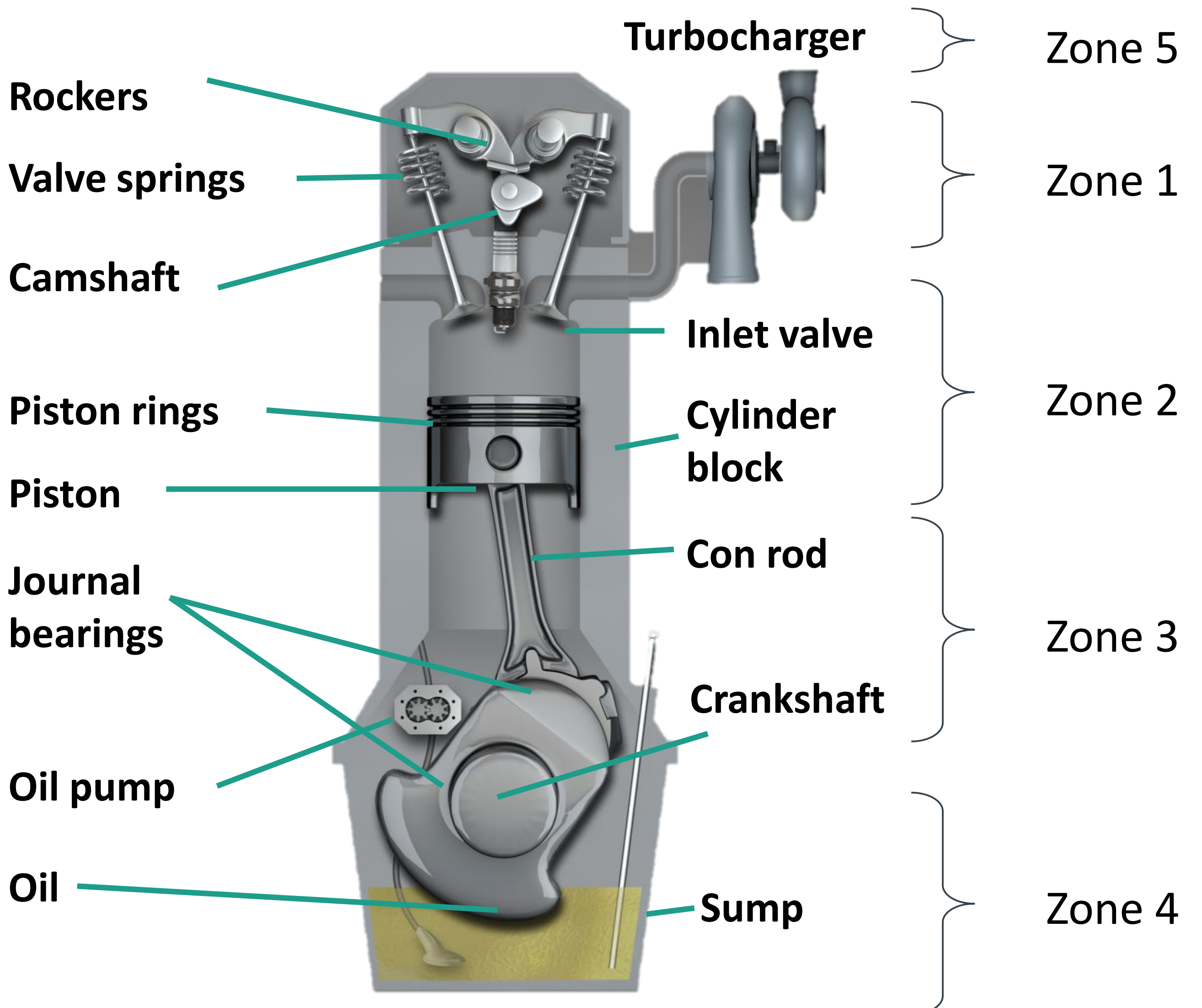
- Under regimes of high pressure and wide temperature ranges
- In the presence of water and undesirable combustion products

- Protect engine from wear
- Neutralise and remove unwanted contaminants
- 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 environment
  - Inert to metals and seals

Critical Engine Zones



Critical Areas of Lubrication

Critical Areas of Lubrication	Focus Areas
Zone 1: Valve train area	Wear, friction, rust, deposits and sludge
Zone 2: Piston and cylinder zone	Deposits, ring stick, ring and cylinder wear, bore polish, rust/corrosion
Zone 3: Bearings	Abrasive and corrosive wear, oil film thickness retention
Zone 4: Sump and oil ways	Emulsion, sludge, oil oxidation, filter blocking, shear
Zone 5: Turbocharger	Turbo shaft and compressor deposits, oil oxidation

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Critical Areas of Lubrication

Fuel 100%

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

Reducing internal friction losses goals

- Reduce boundary lubrication losses via friction modifier
- Reduce mixed elastohyrdodynamic losses via base stock/friction modifier
- Reduce viscosity related losses in hydrodynamic via base stock/viscosity modifier

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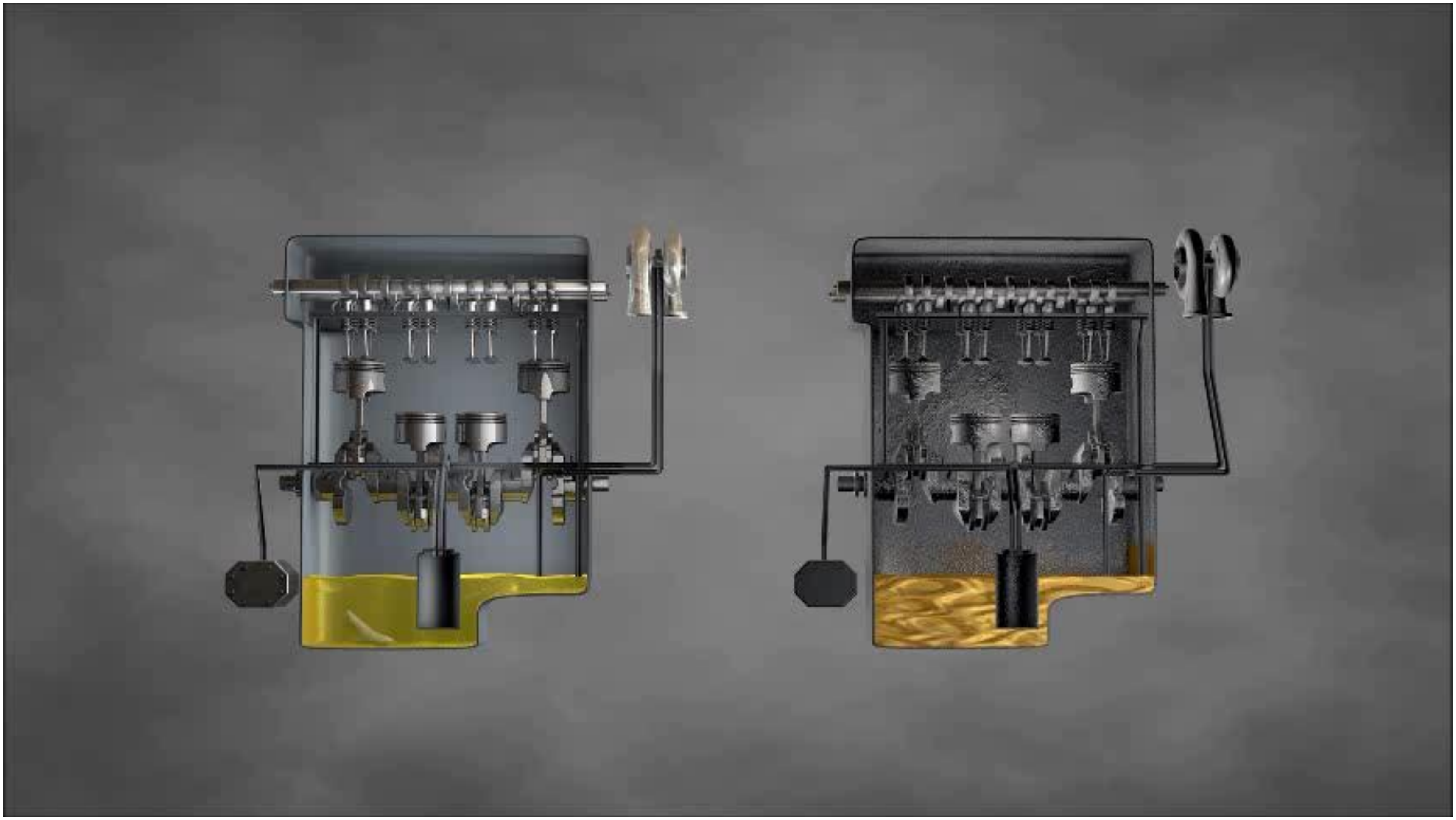
Oil Flow

Demonstration video



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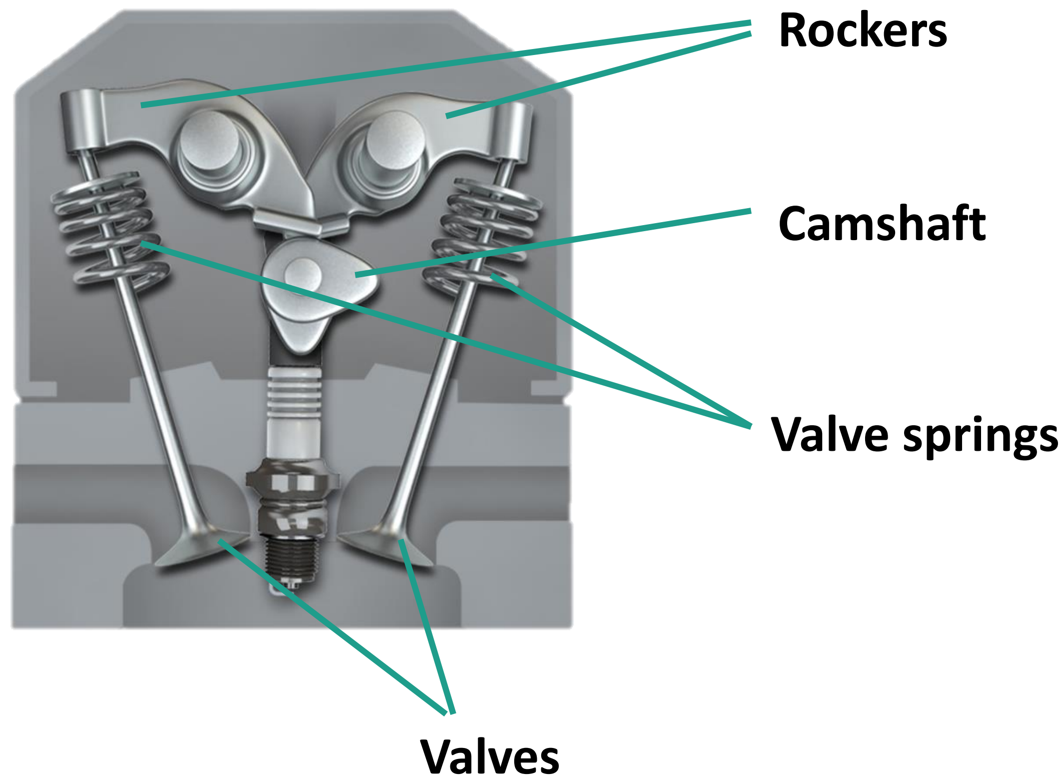
Overview

Valve Train
Zone 1



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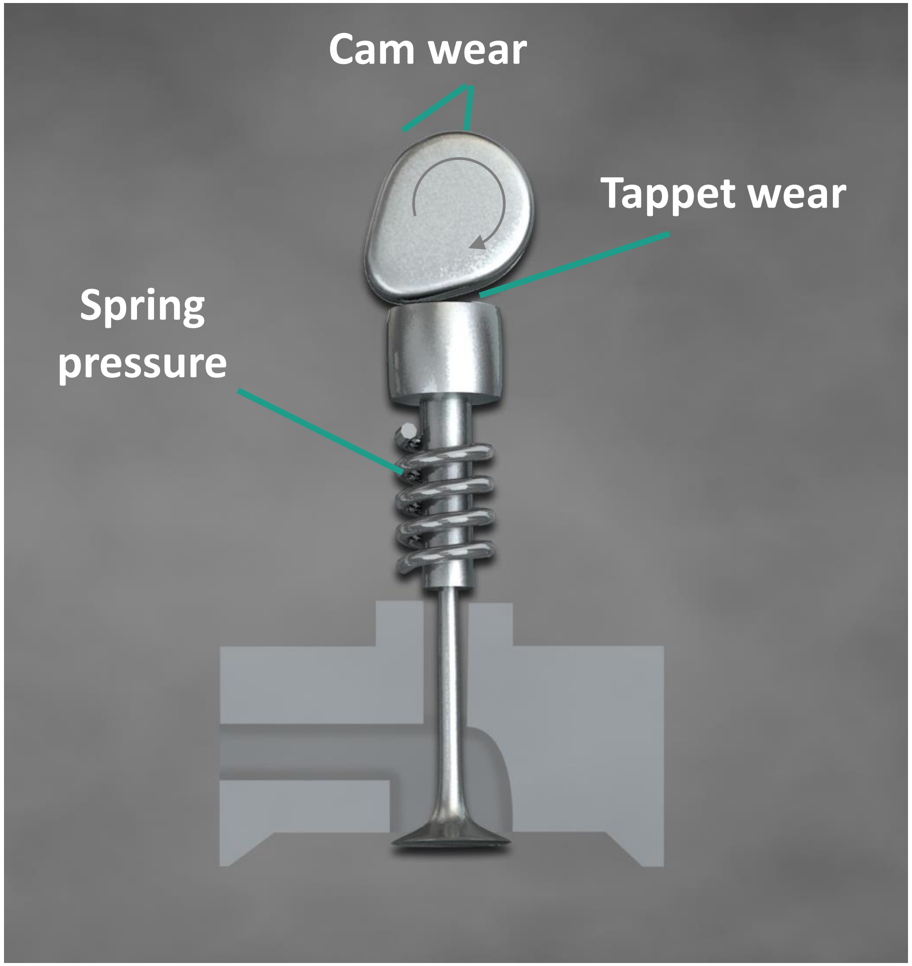
First Challenge: Wear and Friction

Valve Train Zone 1

- Cam and tappets are key parts prone to wear:
  - Leads to reduced valve opening and power loss
- High pressure area and lowest engine temperature
  - Contact zone pressures can reach >2 x 10^9 Nm^{-2}
  - Temp < 60°C up to 100°C
- On start-up, can take considerable time for oil to reach valve train
  - Focus to protect at this time



Specific Wear Requirements

Valve Train Zone 1

Why is wear so important here?

- Control of adhesive (scuffing) and abrasive wear 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

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Frictional Aspects

Valve Train
Zone 1

Why worry about friction?

- Valve train is area of high energy loss due to friction from parts which are very close together
  - Contact is mostly in the boundary regime, 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 CO2 emissions

Key requirements for lubricants:

- Friction reduction 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

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Low Temperature Sludge Formation

Background

What causes sludge to form?

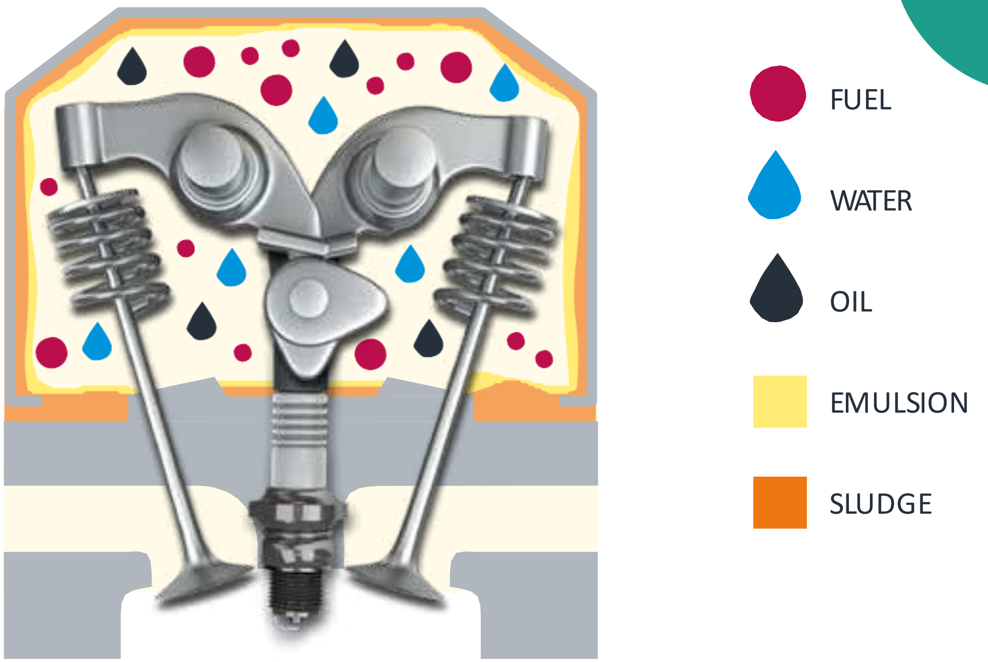
- Blow-by gases (containing unburned fuel and water) combine with oil droplets in sump and are transferred into valve train area through engine breather system
- At low temperatures (especially short journeys) water / fuel is not evaporated and forms a surface emulsion which can turn to sludge
- Sludge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

Sludge Formation in Rocker Box

Valve Train
Zone 1



Cycles of cold and hot temperatures different sludge effects

- Deposition of emulsion at the surface in the cold phase or “white sludge”
- Further hardening / coking at higher temperature leads to “black sludge”

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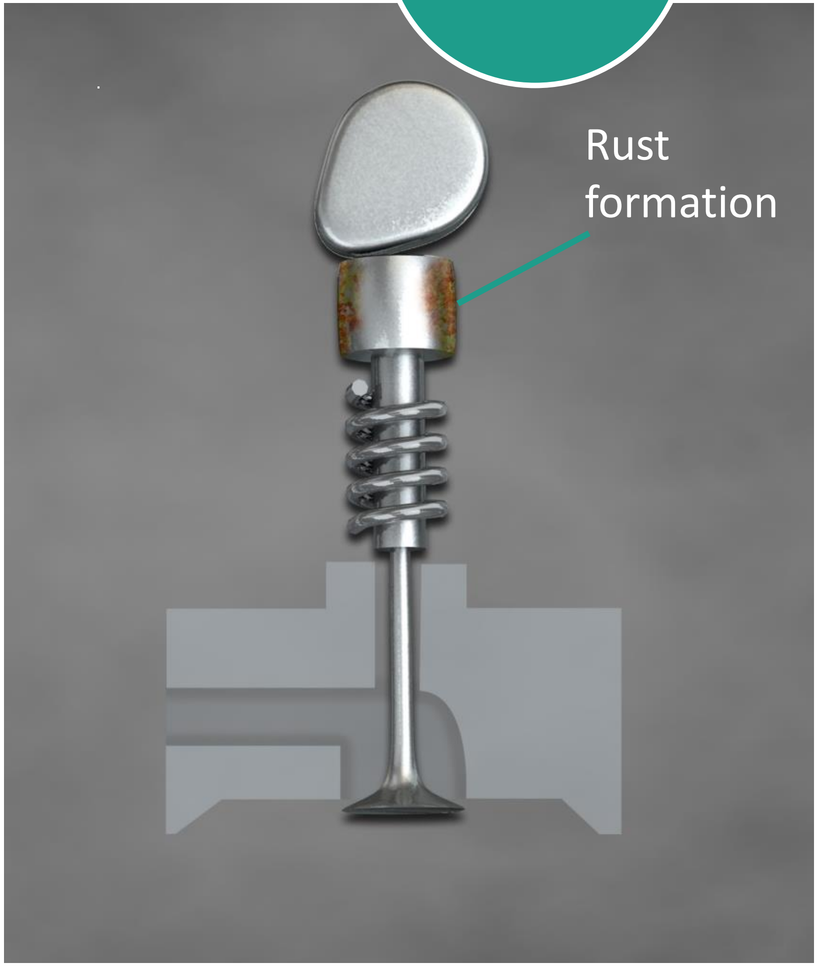
Rust Control

Valve Train Zone 1

- **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

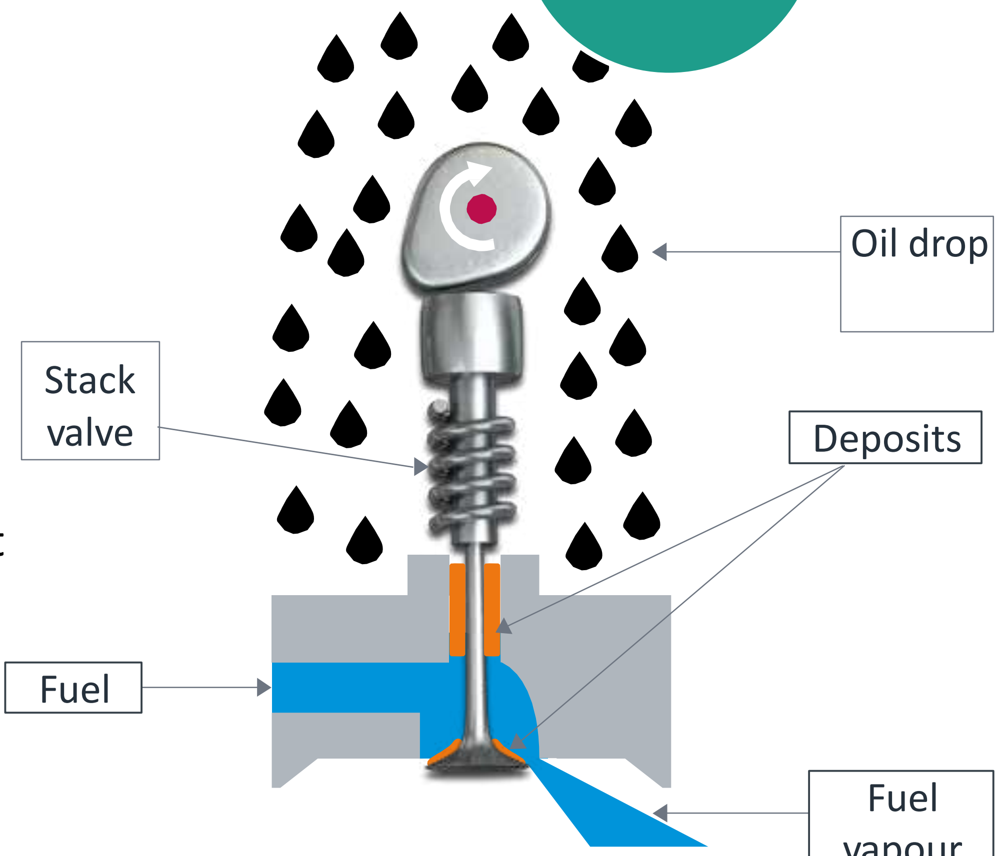
- **Key requirements for lubricants**
  - Over-based detergents and corrosion inhibitors can help prevent rusting



Deposit Control

Valve Train Zone 1

- **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



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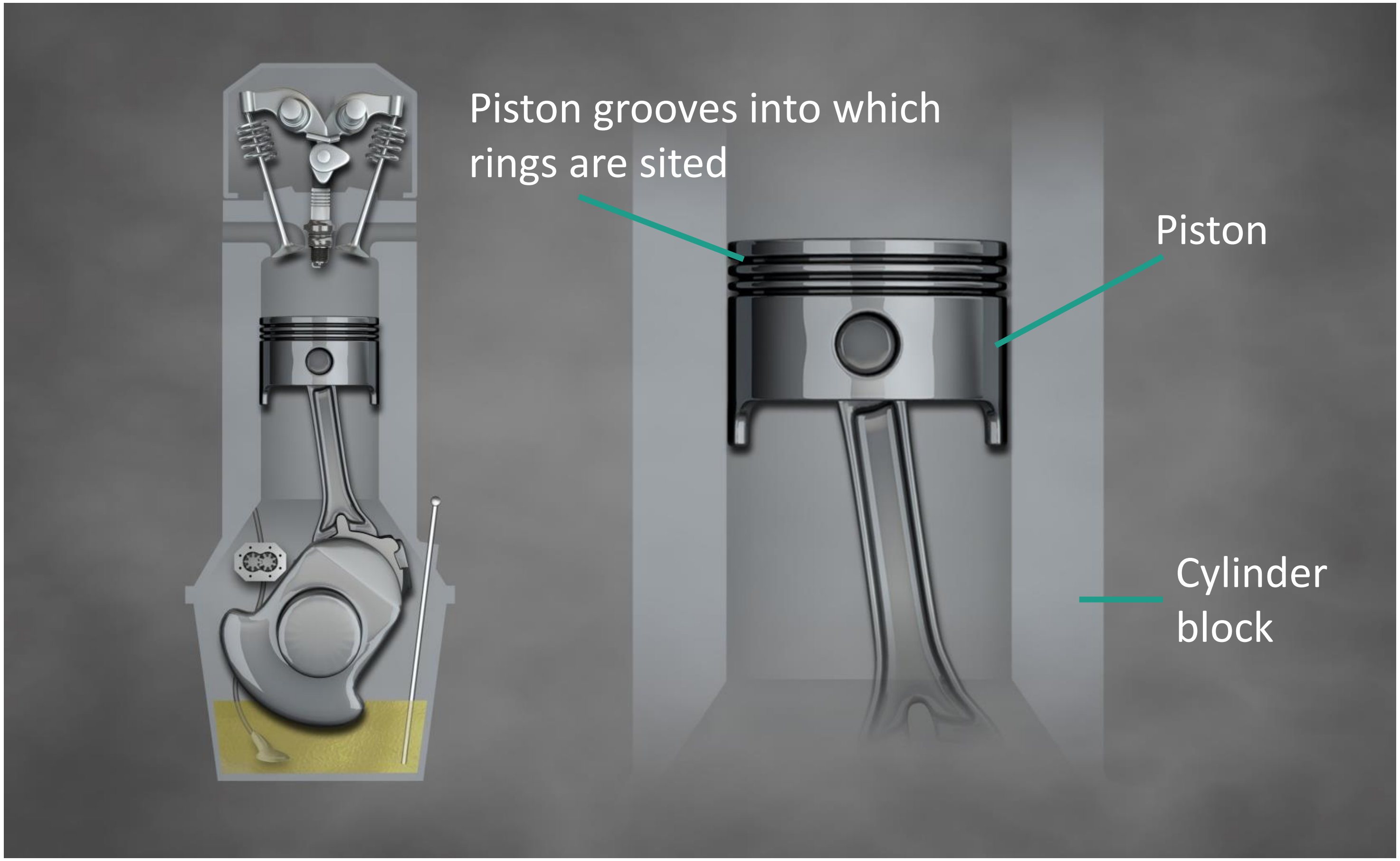
Piston and Cylinder Zone 2

Overview



Piston and Cylinder Zone 2

Background

- 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
- 50% of engine friction is between piston rings and liner
- Typical detrimental process is cracking or polymerisation of the oil and fuel residue to form deposits on surfaces

Piston and Cylinder Zone 2

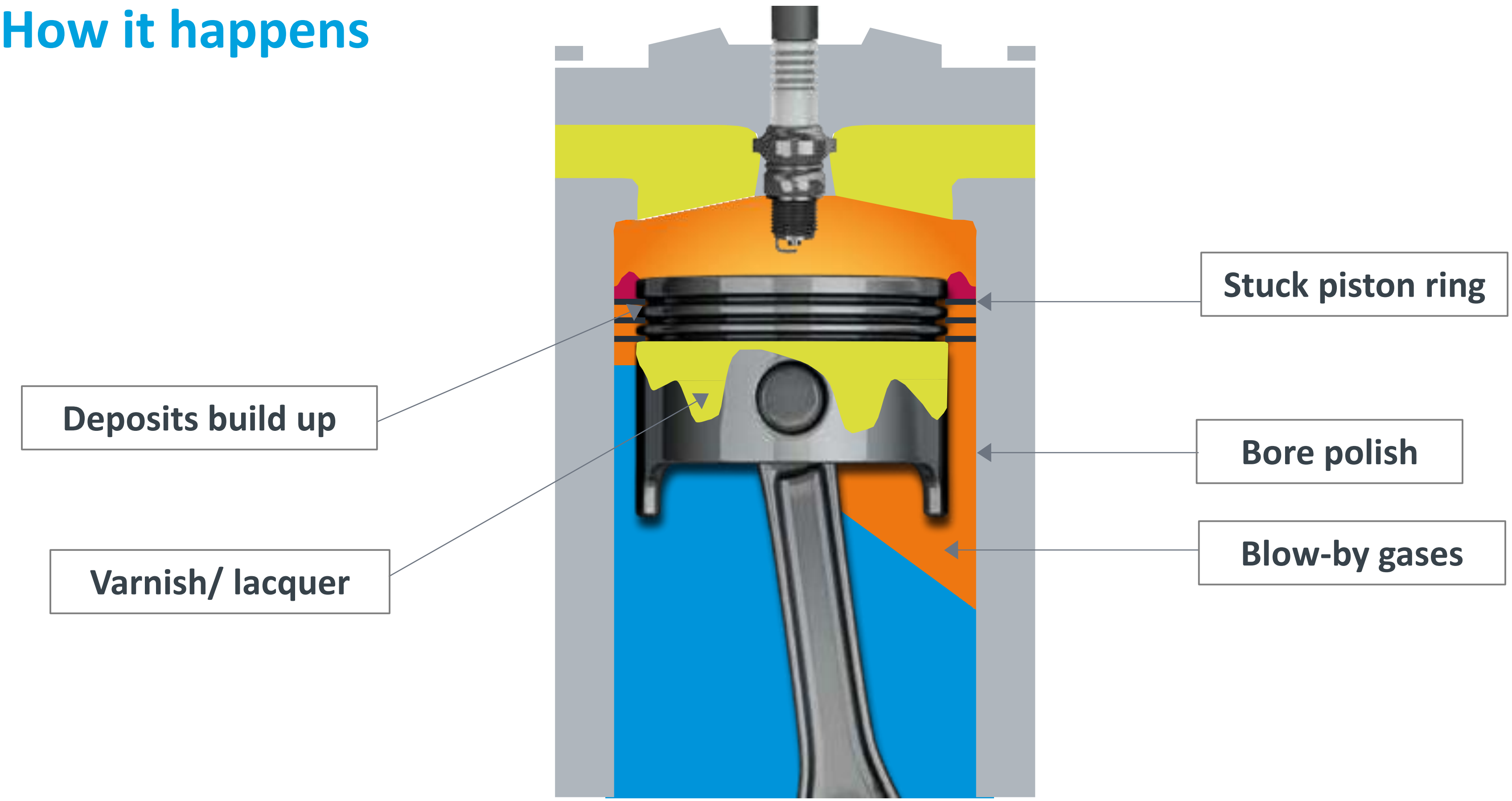
Background

- Leads to three types of phenomenon occurring
  - Ring stick
    - Deposits build-up in piston grooves surrounding 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 ring forcing it against the cylinder or "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 and increase in blow-by gases

Piston and Cylinder Zone 2

Piston Deposits and Ring Stick

How it happens



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Piston and Cylinder Zone 2

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

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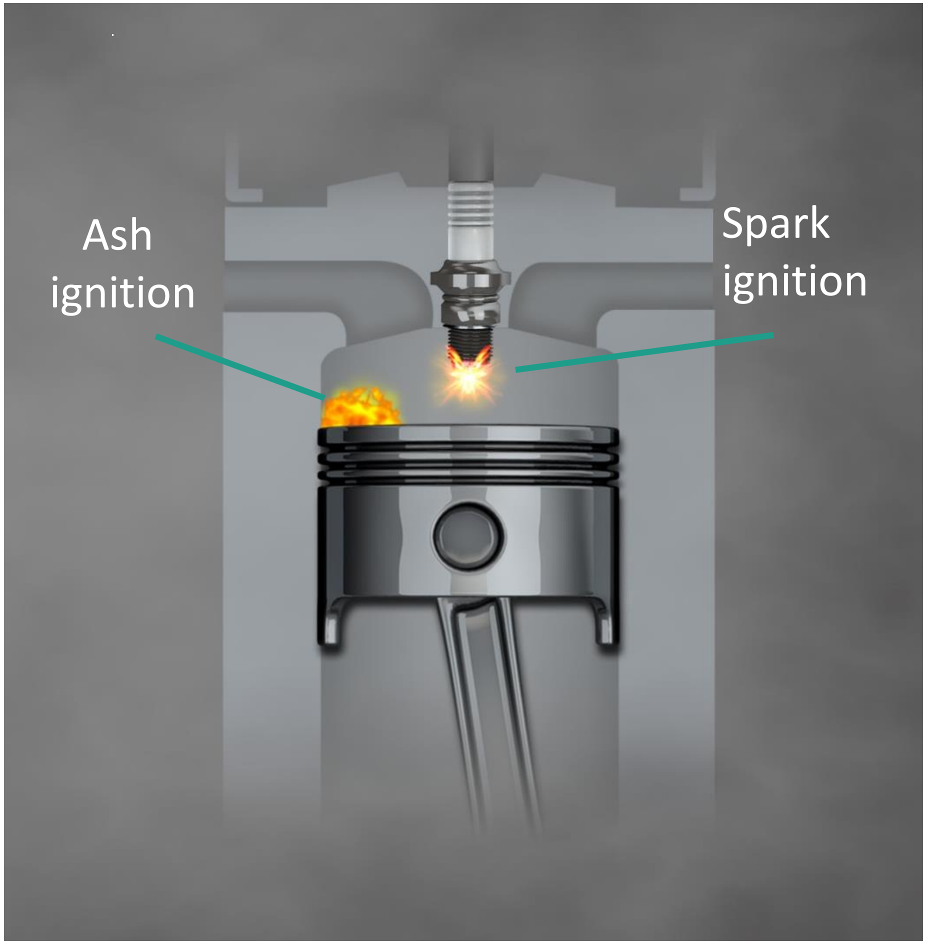
Cylinder Wear and Bore Polish Difference

Cylinder Wear and Bore Polish Difference

Ash Deposits 1
(Specific to gasoline engine)

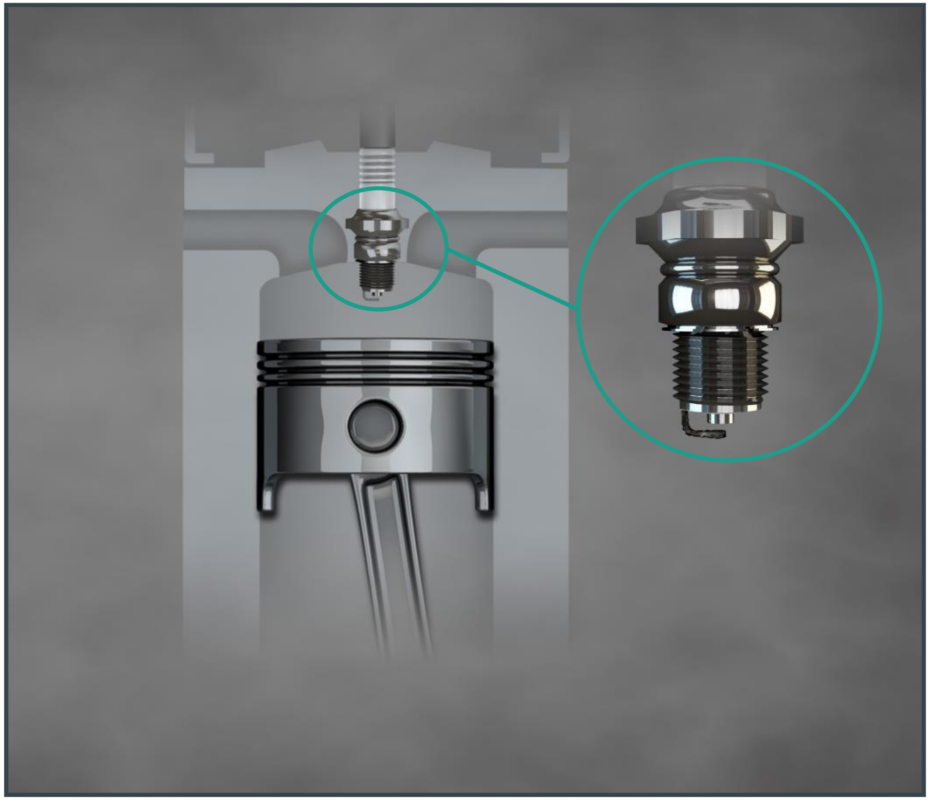
Carbon particles from poorly burnt fuel and ash from additives in the lubricant can form combustion chamber deposits

- Leads to pre-ignition in combustion chamber
  - Deposits become hot and ignite the fuel before spark occurs
  - Strains engine, particularly on bearings and crankshaft
  - Leads to uncontrolled combustion hot spots and loss of power



Ash Deposits 2
(Specific to gasoline engine)

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



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

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

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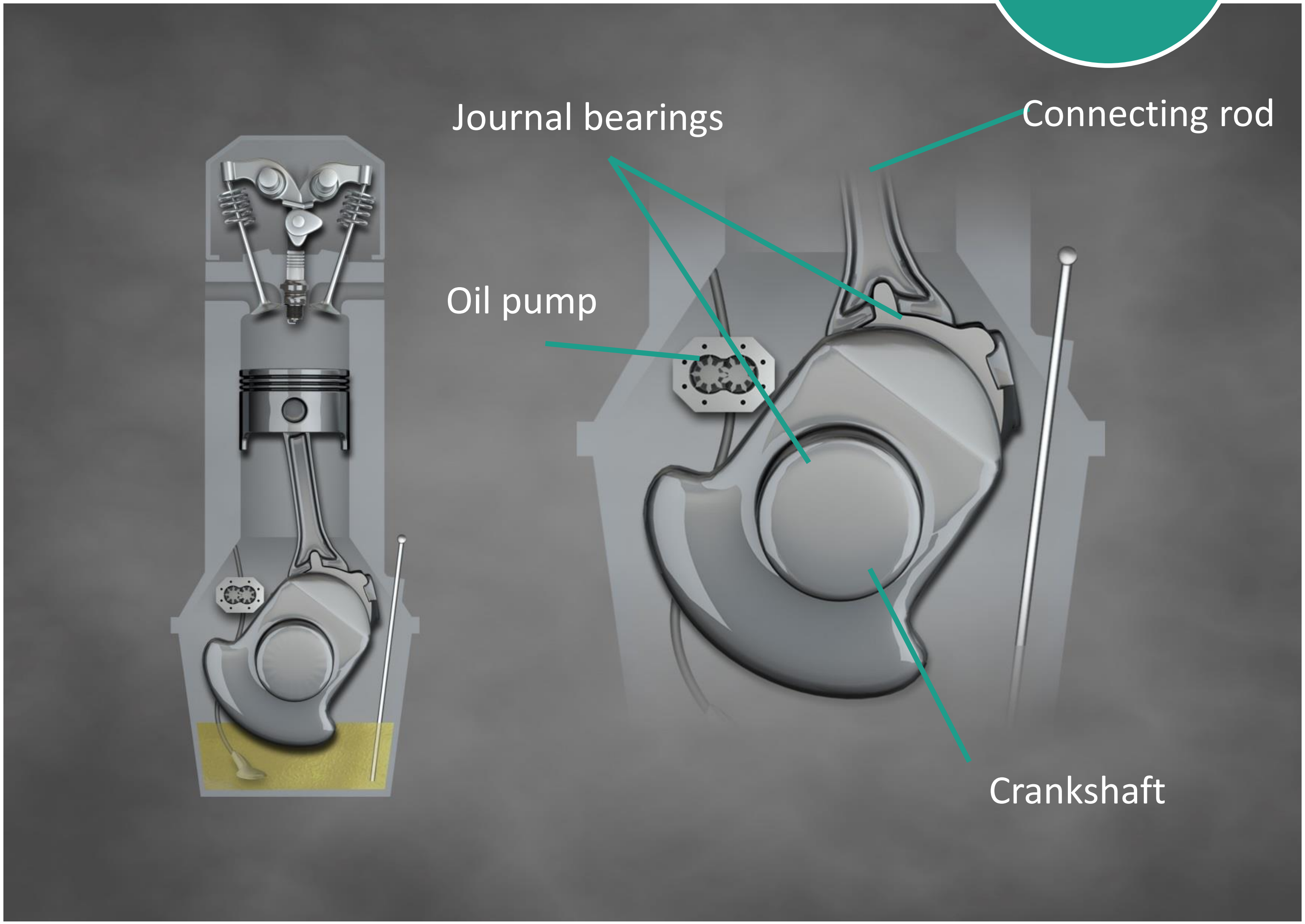
Overview

Bearings
Zone 3



Primary Issues - Wear

Bearings Zone 3

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

Lubricant Impact

Bearings
Zone 3

Types of wear which can occur

- Abrasive wear wear metals / dust / sand etc. can get lodged between or embedded in 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

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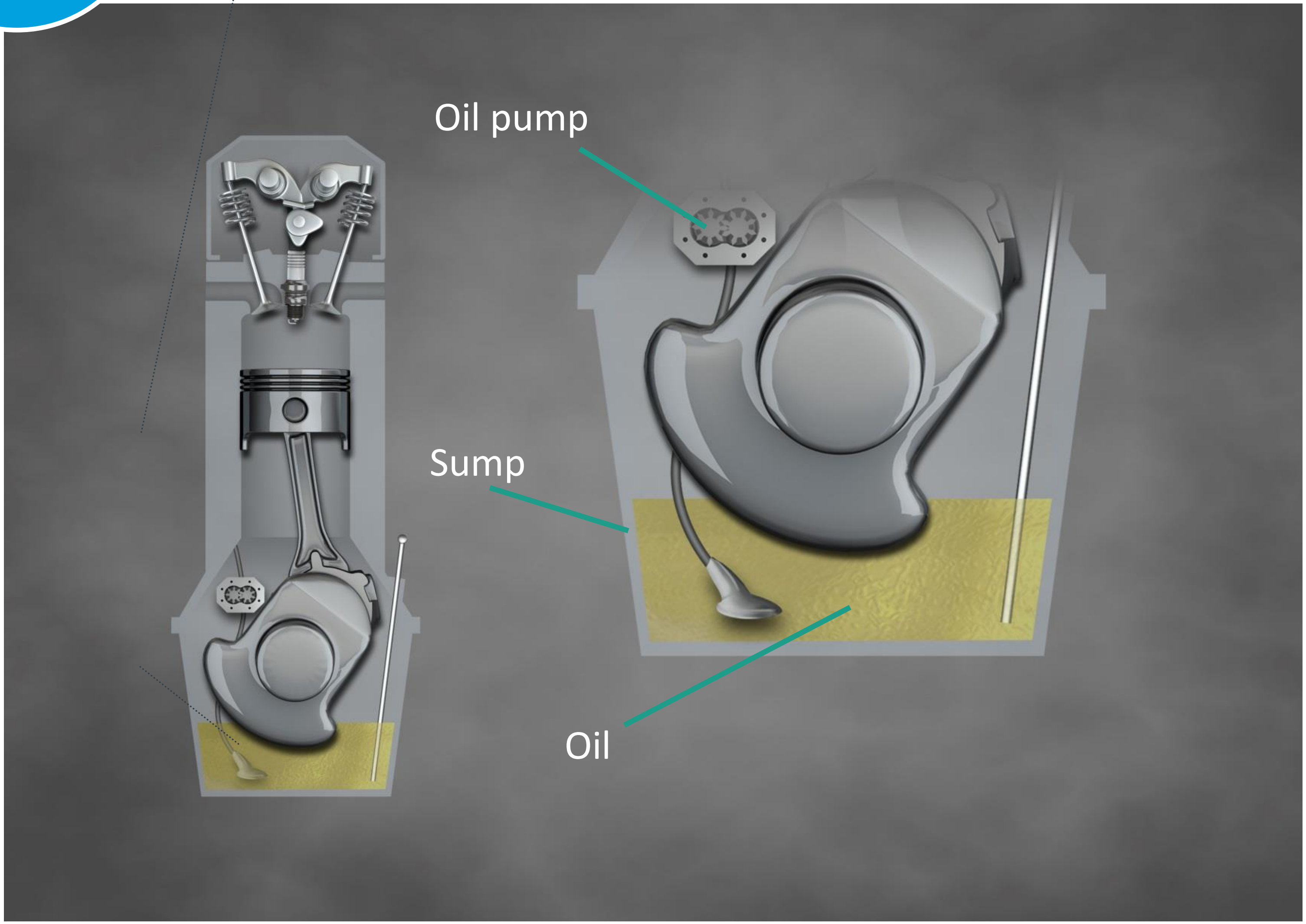
Sump and Oil Zone 4

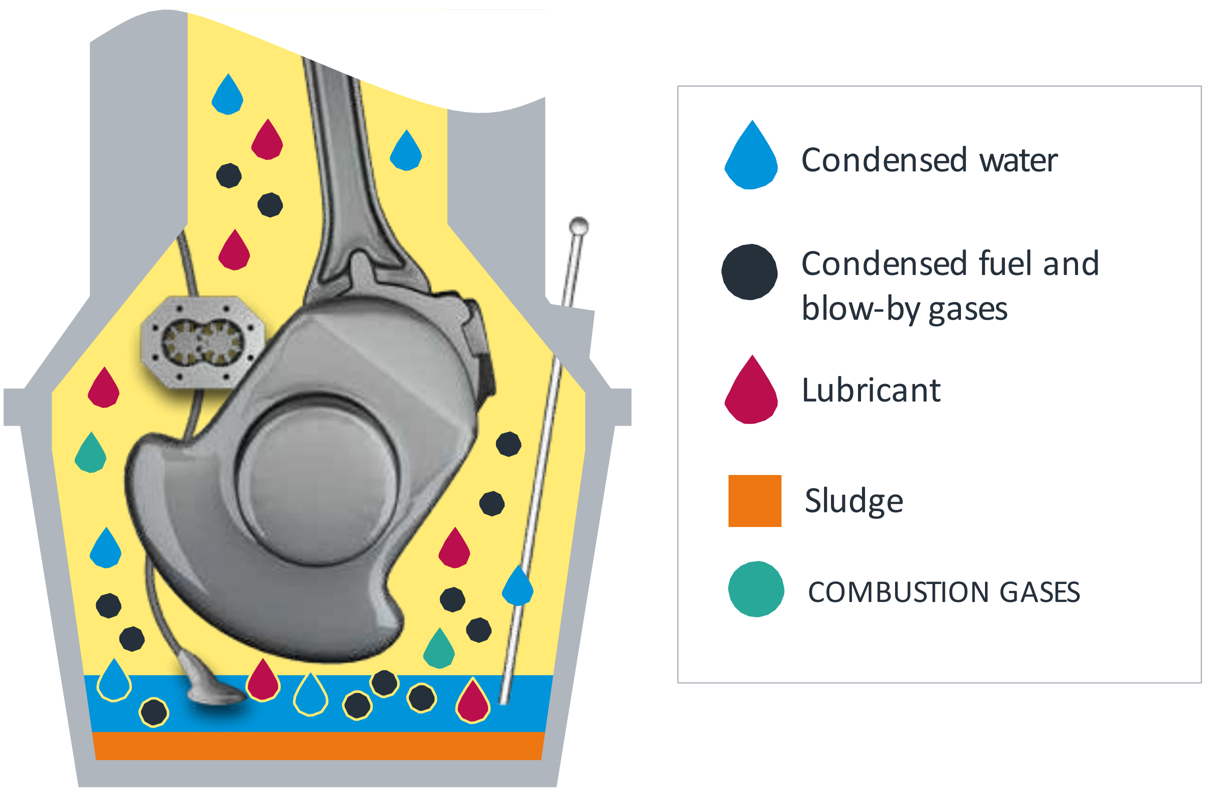
Pathways



Sump and Oil Zone 4

Sump Sludge Formation

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



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Sump and Oil Zone 4

Sump Viscosity Increase

- High temperature oxidation
  - Oil, additive package and viscosity modifier components can oxidise and then add together at high temperatures to form large molecules that thicken the oil
- Soot loading (diesel and 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 and wear

Key requirements for lubricant

- Good oxidation stability to prevent oxidation and large molecules forming
- Good dispersant components to prevent soot aggregation

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Sump Viscosity Decrease

- 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

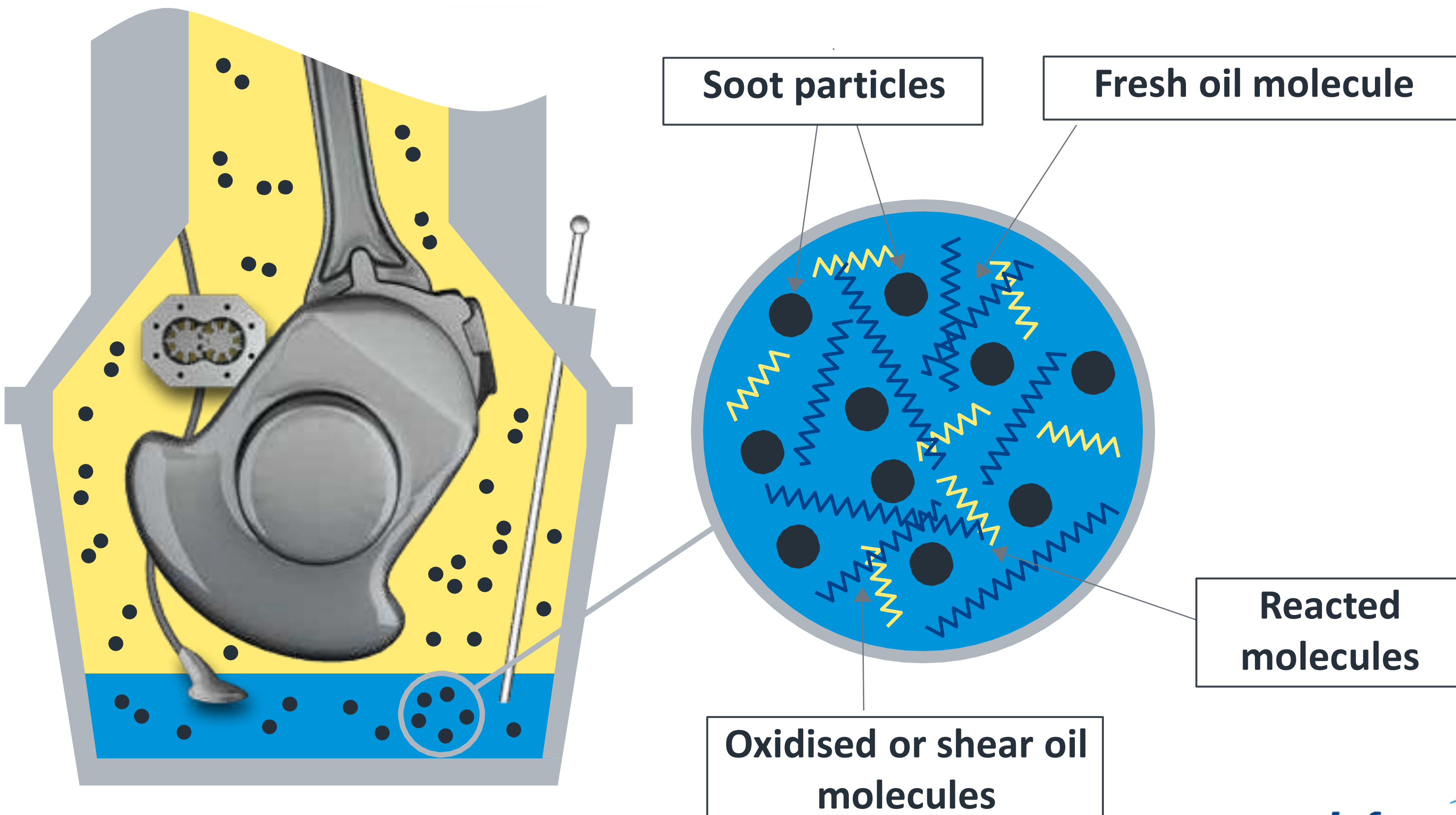
Key requirements for lubricant

- Careful choice of viscosity modifier with the right level of shear stability
- Correct fuel management

Sump and Oil Zone 4

Oil Thickening and Thinning

Viscosity modifier and polymeric components undergo similar reactions to thin or thicken the lubricant



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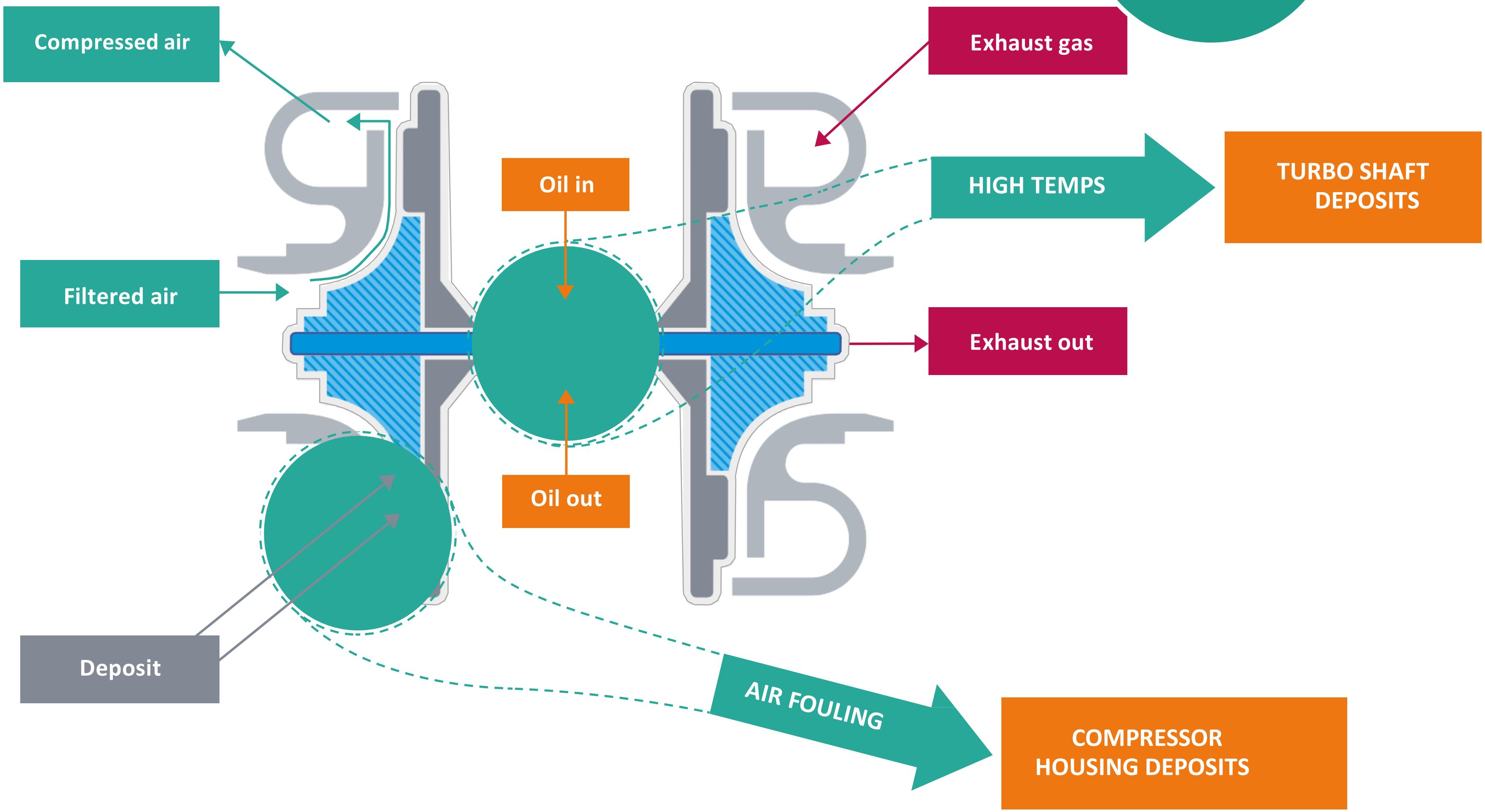
Overview

Turbocharger Zone 5



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Lubricant Effects

Turbocharger
Zone 5

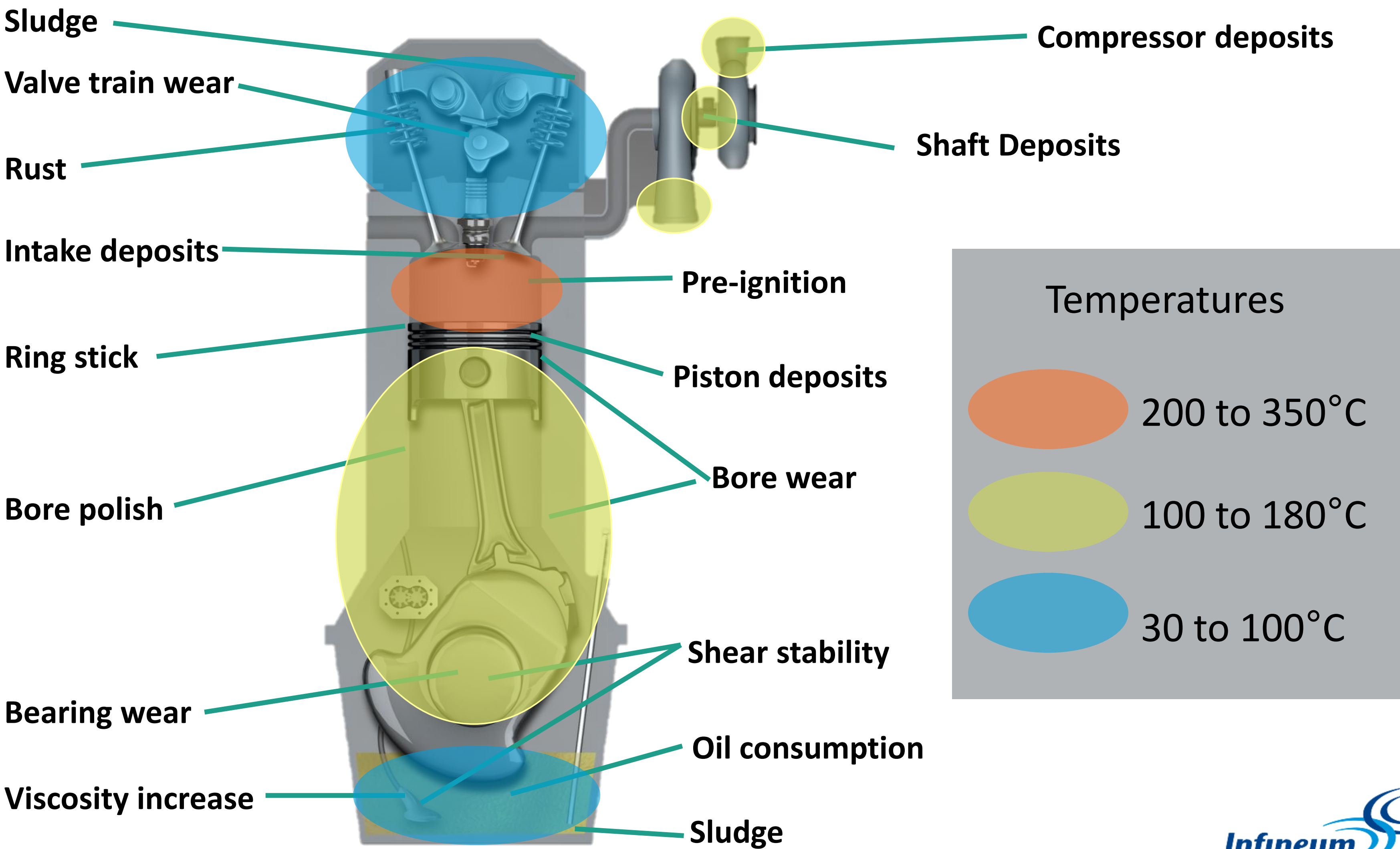
- Primary need is for cooling and turbo shaft bearing lubrication
  - High oil flow requirement at high temperature
  - Can lead to deposits on the shaft which connects turbine and compressor, especially if engine is stopped at high temperature
    - Has been successfully prevented with engine-off pumps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

The Critical Areas of Lubrication

Summary



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