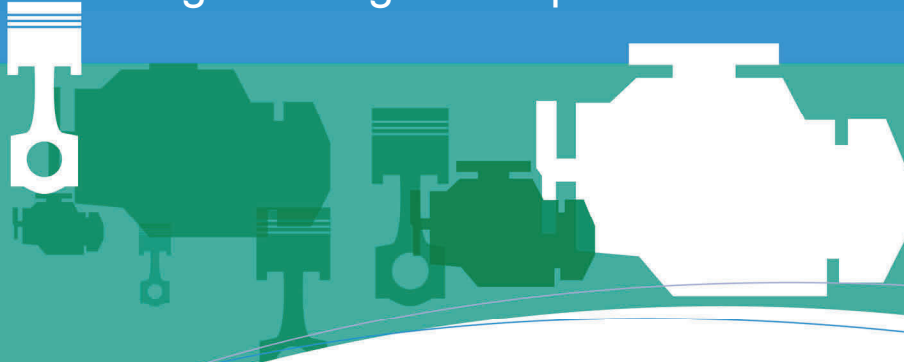


Performance you can rely on.

Engine design and operation



InfineumInsight.com/Learn

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Performance you can rely on.

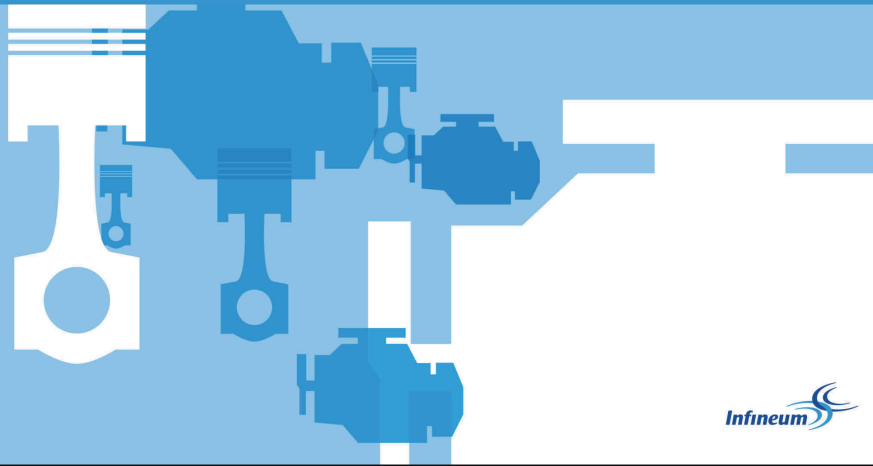
Discussion topics

- What is an internal combustion engine
- Four-stroke cycle engine - gasoline and diesel
- Engine hardware
- Engine lubrication regimes
- Heavy-duty diesel emissions
- Summary

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The internal combustion engine



What is an internal combustion engine?

The reciprocating internal combustion engine generates power by converting chemically bound energy into work by the use of reciprocating motion

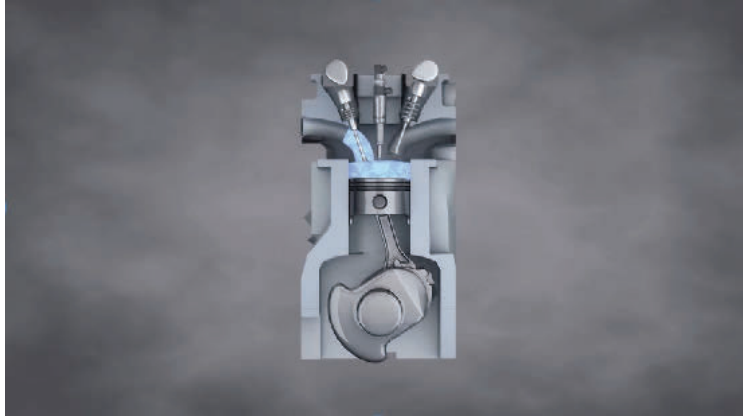
Ideal Conditions



Reality



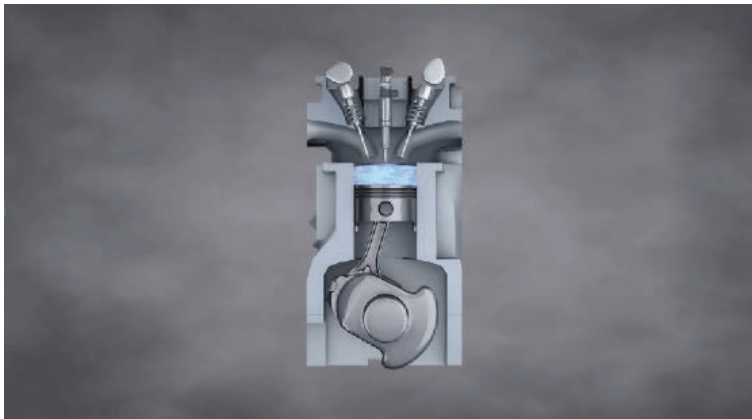
Four-stroke cycle engine



Intake

As piston moves down or toward crankcase, intake valve opens and partial vacuum is created in cylinder. Vaporized air-fuel mixture is forced into cylinder by atmospheric pressure.

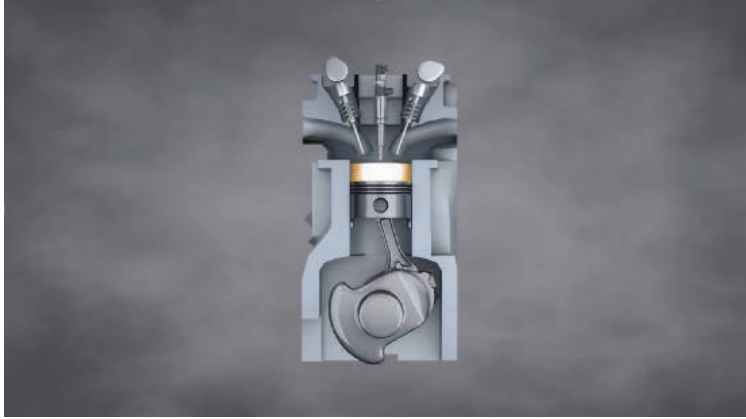
Four-stroke cycle engine



Compression

Intake valve closes. As crankshaft rotates, piston moves up and compresses air-fuel mixture.

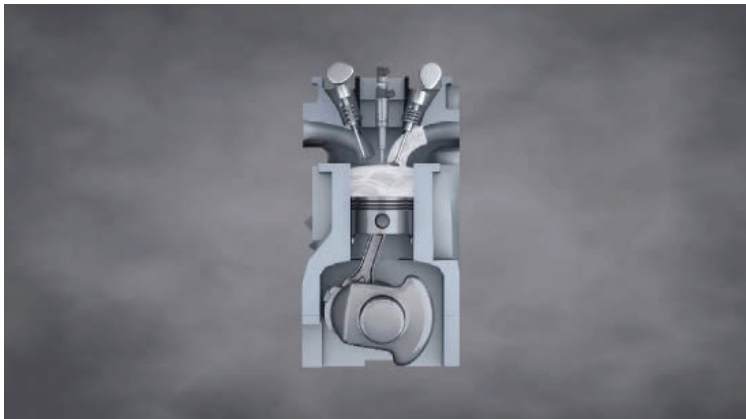
Four-stroke cycle engine



Power

Ignition system fires spark plug to ignite mixture just before piston reaches top of its travel. Expanding gases, which result from burning of fuel, force piston down to turn crankshaft.

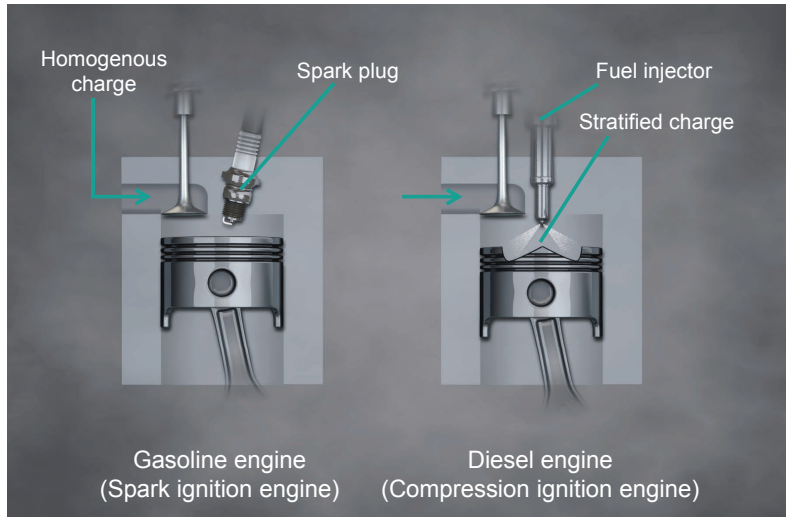
Four-stroke cycle engine



Exhaust

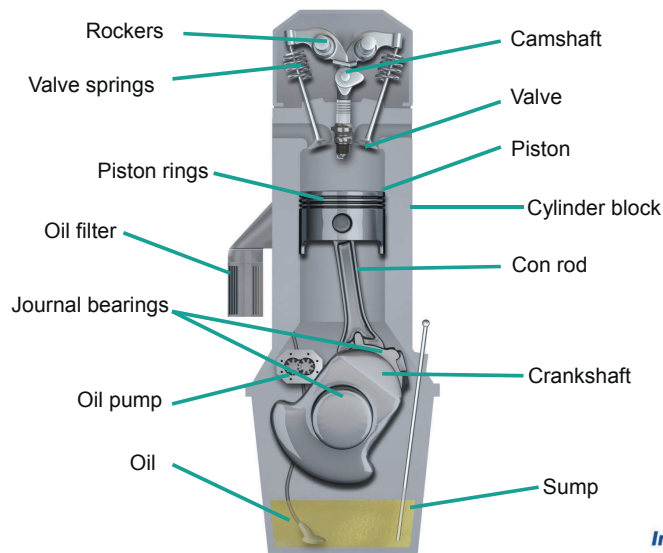
After fuel charge is burned, exhaust valve opens. Burned gases are forced out of cylinder by upward movement of piston.

Gasoline and diesel combustion



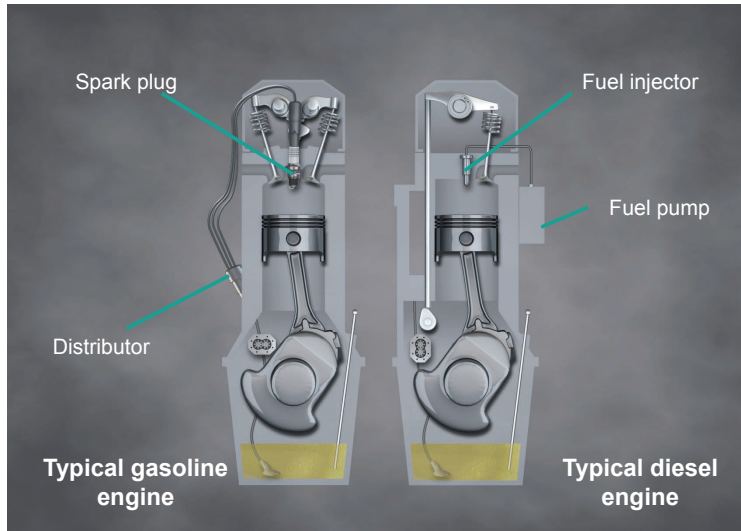
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Main components of an internal combustion engine



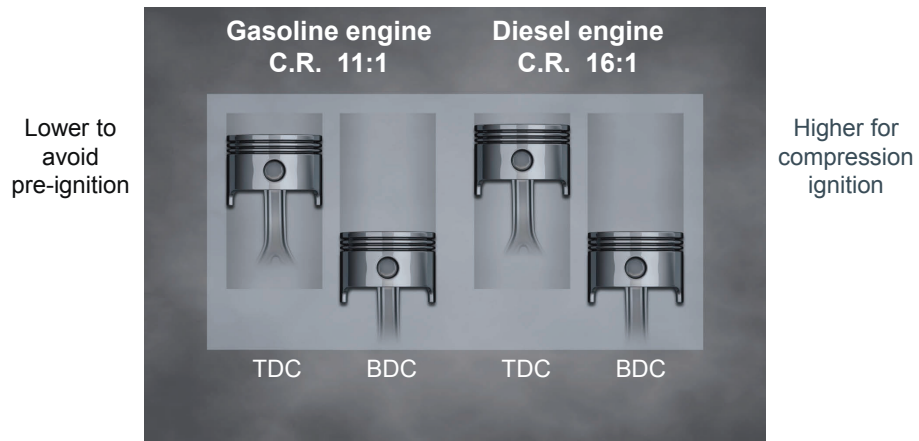
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Additional components of gasoline and diesel engines



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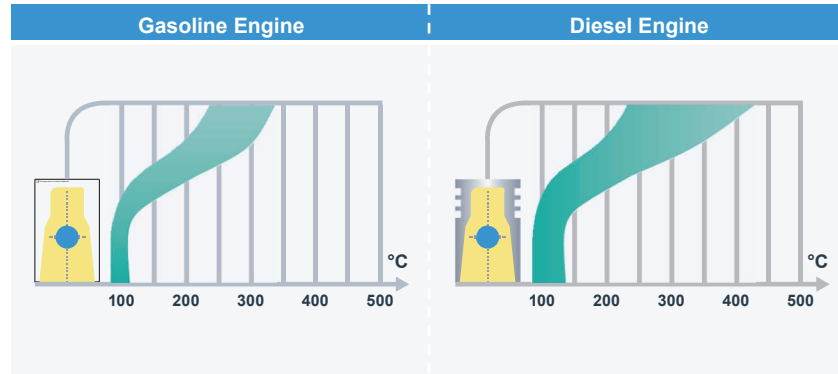
Compression ratios



Ratio of the volume of the combustion chamber and cylinder volume measured when the piston is at the bottom of its stroke to the volume when the piston is at the top of its stroke.

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Temperature distribution of diesel and gasoline engines



Median distribution temperature of light alloy pistons. Shaded portions show that structural and functional characteristics influence temperatures.

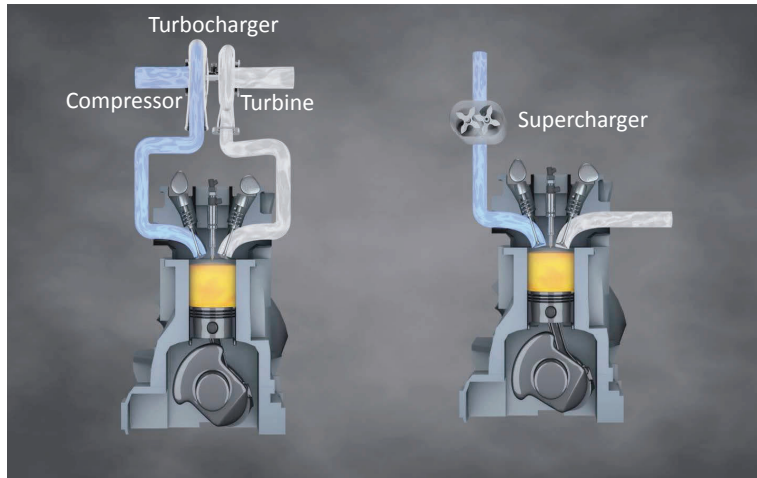


Engine breathing systems

- Two categories for engine breathing
 - **Naturally aspirated** – using suction from the engine
 - **Pressure charging** – forcing air into the cylinder
- Pressure charging is applicable to gasoline and diesel
- Power output depends on the quantity of fuel and air that can be burned
- Naturally aspirated engines are limited by atmospheric pressure
- Pressure charging means that more fuel can be added, producing more power
- Two types of pressure chargers
 - **Turbocharger** (driven by exhaust gases)
 - **Supercharger** (driven by the engine)

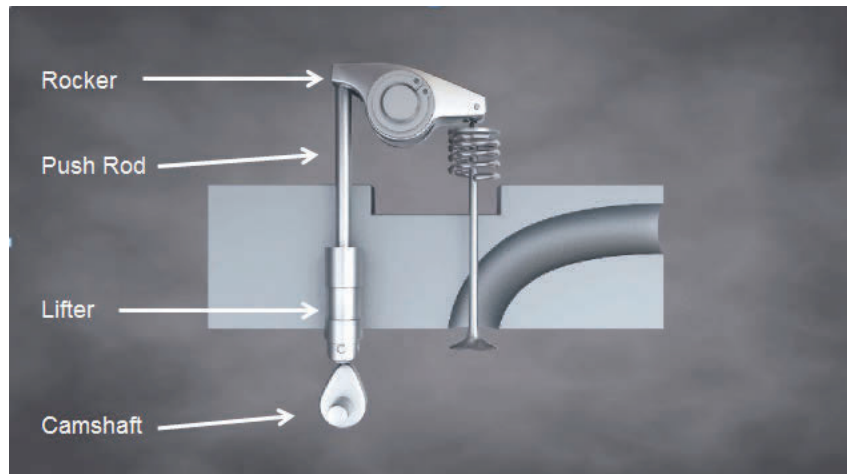


Turbocharging and supercharging



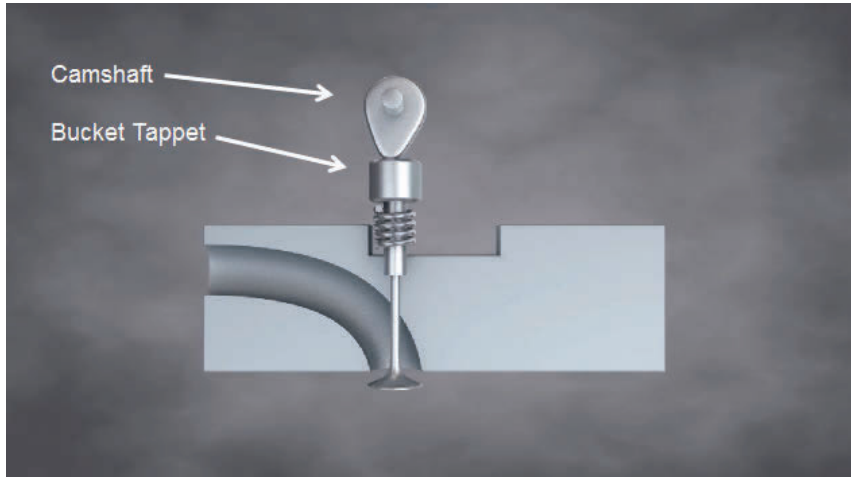
Different valve configurations

Pushrod



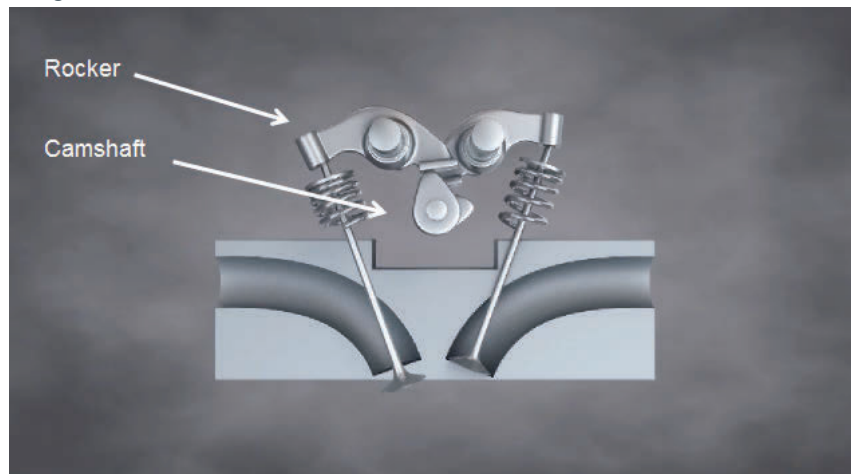
Different valve configurations

Single overhead cam (direct acting)



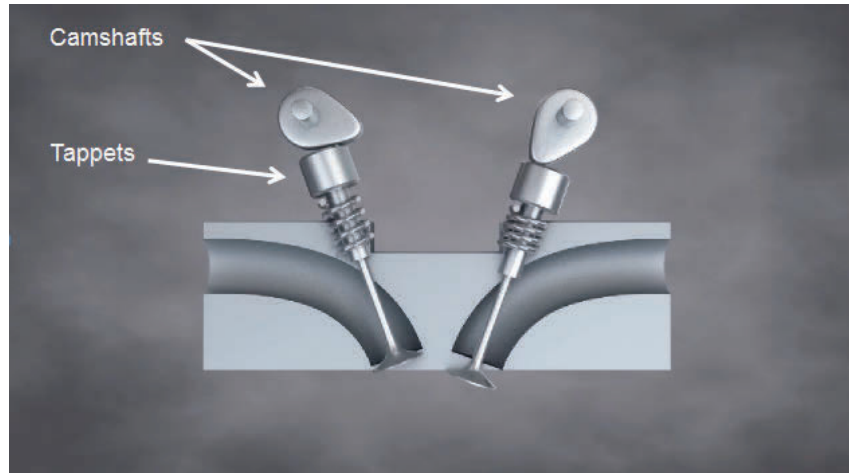
Different valve configurations

Single overhead cam



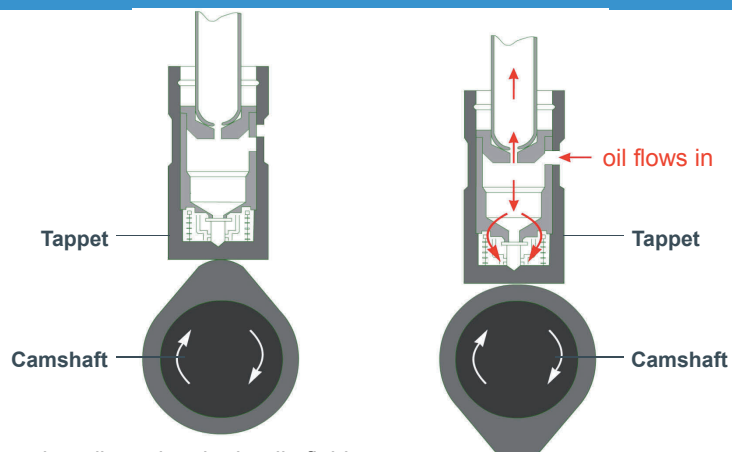
Different valve configurations

Double overhead cam



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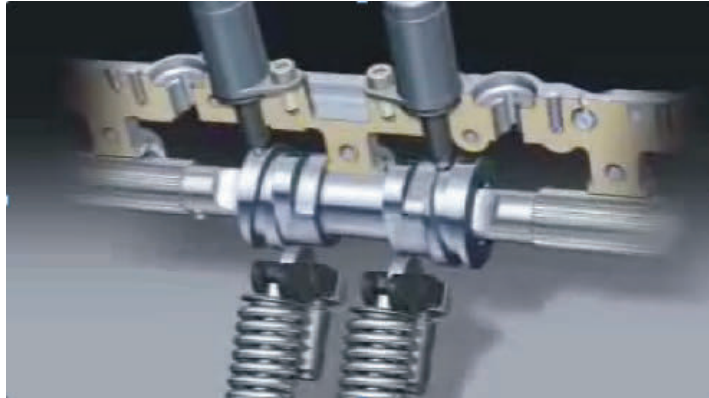
Hydraulic valve lifter



- The engine oil used as hydraulic fluid
- Ensures that the cam lobes is in constant contact with the tappet
 - Less wear and less noise while the engine is running

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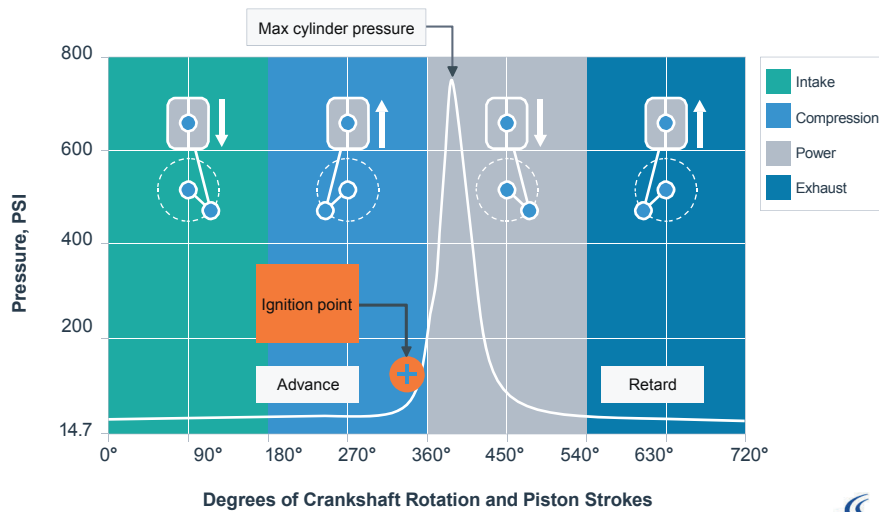
Variable valve timing (VVT)



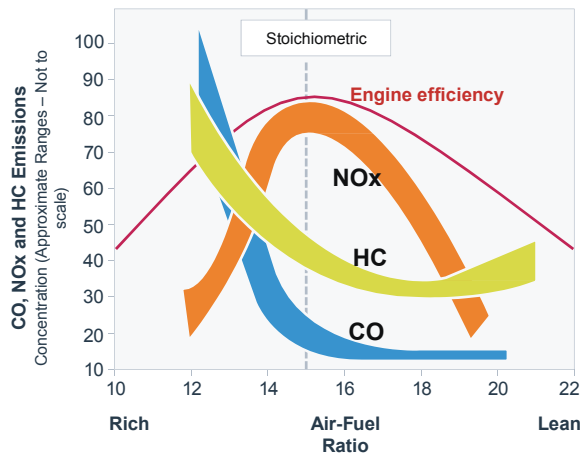
- Valves open and close at different times in the cycle and to varying amounts of lift depending on the engine speed and load
- Engines perform well across wide range of engine speeds and loads
- Less compromise between efficiency and performance
- Many different mechanical, hydraulic, and electronic options have been developed for VVT



Pressures in an engine cylinder



Effect of air/fuel ratio on combustion gas composition



Stoichiometric = 14.7 parts air to 1 part fuel

NO_x – caused by high in-cylinder temperatures experienced under moderate to heavy load

HC – unburned hydrocarbons (fuel)

CO – carbon monoxide results from incomplete combustion of fuel in a low oxygen environment



Engine lubrication regimes

CONFORMING SURFACES

- **Hydrodynamic** – moving surfaces completely separated by a film of lubricant
 - Piston rings, bearings
- **Mixed** – surfaces are still separated but asperities occasionally interact
 - Piston rings, gears
- **Boundary** – surfaces come into closer contact, asperities start to break off, intense localized heat begins to activate anti-wear additives in the lubricant to form protective films
 - Piston rings, gears



NON-CONFORMING SURFACES

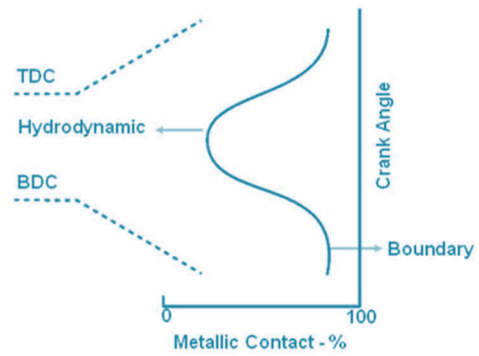
- **Elasto-hydrodynamic** – rolling contact surfaces are separated but undergo elastic deformation
 - Valve train, cam and followers



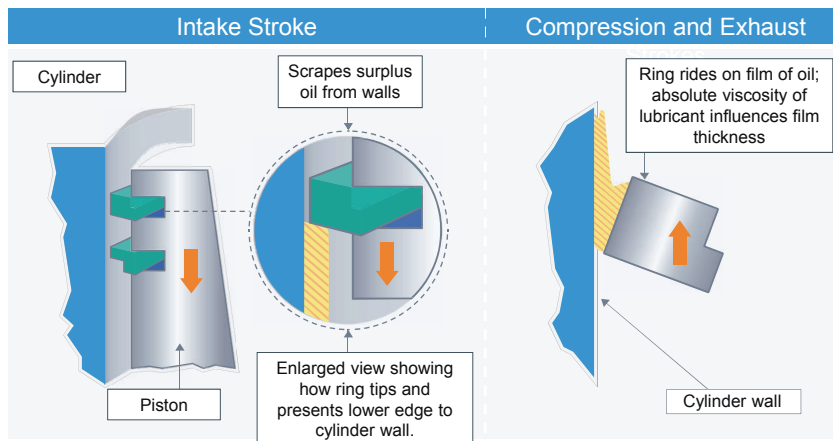
Piston ring and cylinder lubrication mode



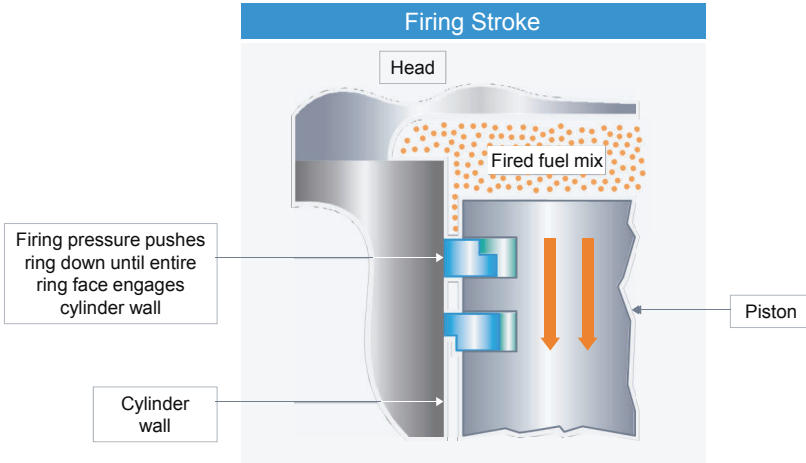
50% of engine friction is between piston rings and liner



Piston ring action



Piston ring action

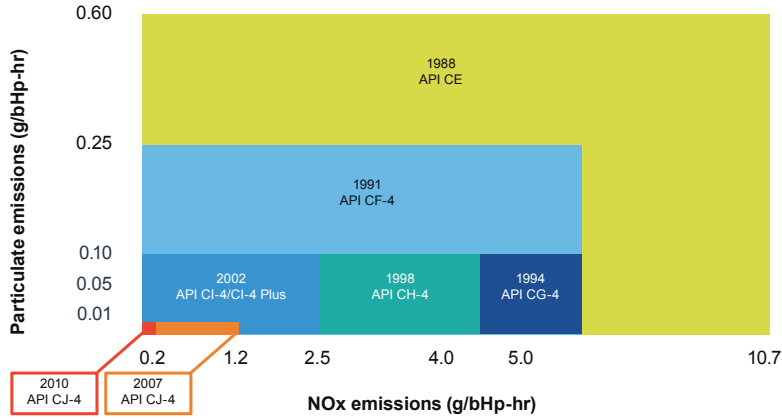


Emissions



Emissions drives changes in diesel engine hardware and oil quality

Federal On-Highway Emissions Legislation



- Ever tightening emissions regulations drives evolution of engine hardware
- Have achieved near zero exhaust emissions for Class 8 On-Highway vehicles



Off-Highway legislation trails on-highway by a few years

Federal Off-Highway Emissions Regulations

HP	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
0-10					(7.8) / 0.75					(5.6) / 0.60			(5.6) / 0.30									
11-24					(7.1) / 0.60					(5.6) / 0.60			(5.6) / 0.30									
15-48					(7.1) / 0.60					(5.6) / 0.45			(5.6) / 0.22				(3.5) / 0.02					
49-74					6.9 / ---							(5.6) / 0.30		(3.5) / 0.22			(3.5) / 0.02					
75-99					6.9 / ---							(5.6) / 0.30		(3.5) / 0.30			(2.5) / 0.01		(0.30) / 0.01			
100-173					6.9 / ---						(4.9) / 0.22		(3.0) / 0.22			(2.5) / 0.01		(0.30) / 0.01				
174-301					6.9 / 0.40						(4.9) / 0.15		(3.0) / 0.15			(1.5) / 0.01		(0.30) / 0.01				
301-602					6.9 / 0.40				(4.8) / 0.15		(3.0) / 0.15			(1.5) / 0.01		(0.30) / 0.01						
603-751					6.9 / 0.40				(4.8) / 0.15		(3.0) / 0.15			(1.5) / 0.01		(0.30) / 0.01						
>751					6.9 / 0.40							4.8 / 0.15			(2.6) / 0.07 (0.50) / 0.07*		(2.6) / 0.03 (0.50) / 0.02**					

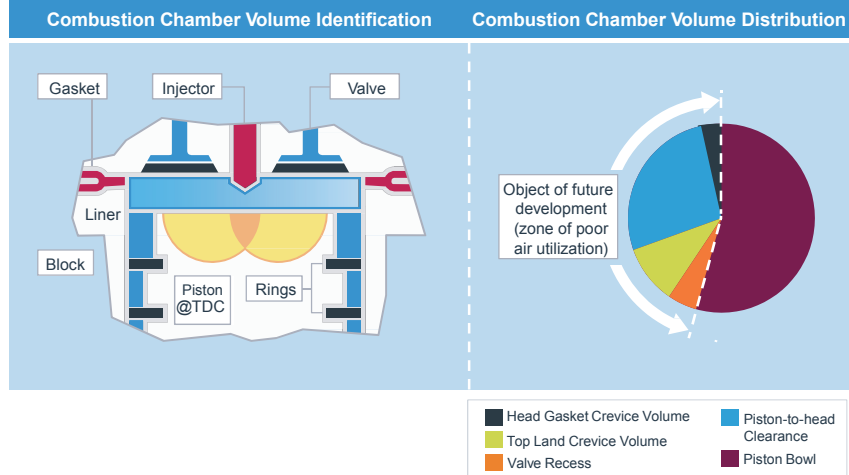
■ Tier 1
 ■ Tier 2
 ■ Tier 3
 ■ Tier 4 Interim
 ■ Tier 4 Final

NOx / PM, g/HP-hr (NOx + HC) / PM, g/HP-hr

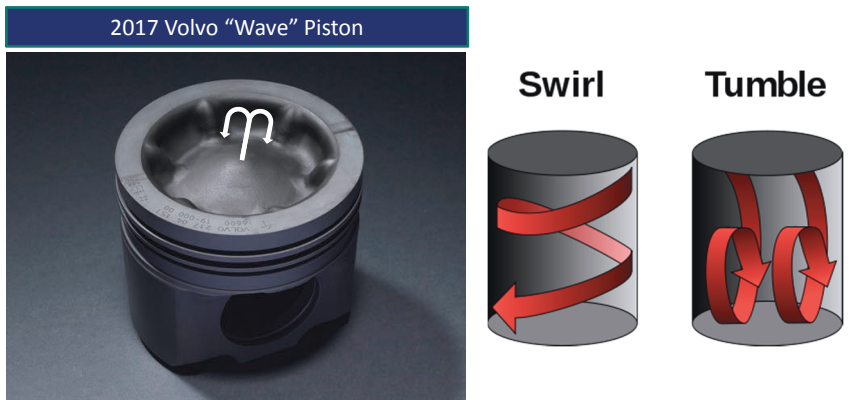
*Applies to portable power generation > 1200hp **Applies to portable power generation > 751hp



Diesel combustion zones



Diesel combustion zones

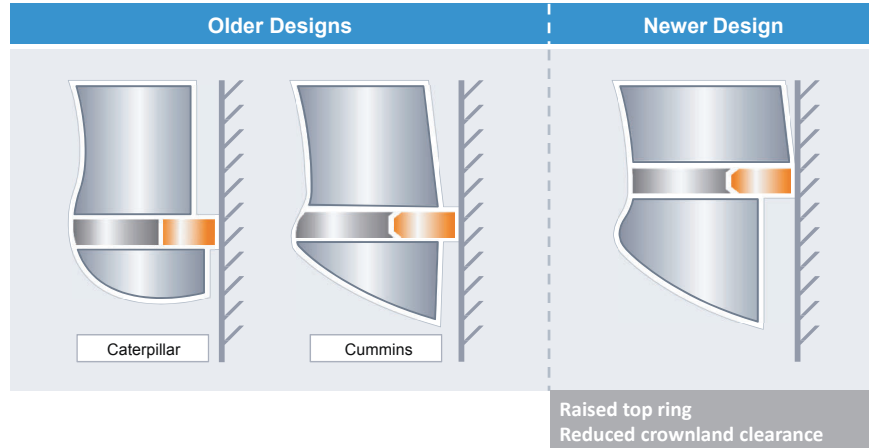


- Higher compression ratio 16:1 → 17:1
- More complete fuel burn
- Flame propagation control
- Makes better use of Oxygen at center of combustion chamber



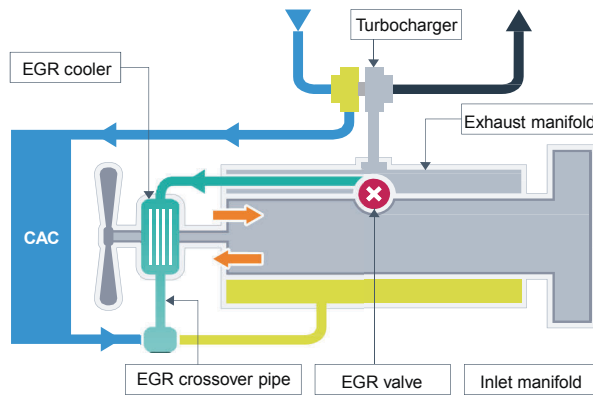
Piston design changes to reduce emissions

Reduced Crevice Volume



Exhaust Gas Recirculation (EGR) for NOx control

- NOx are formed at high combustion temperatures
- Exhaust gas has a high heat capacity
- EGR consequences
 - reduces engine efficiency
 - increases soot production
- EGR used to meet NOx emission limits
 - 2002 Light EGR (10-20%)
 - 2007 Heavy EGR (20-35%)

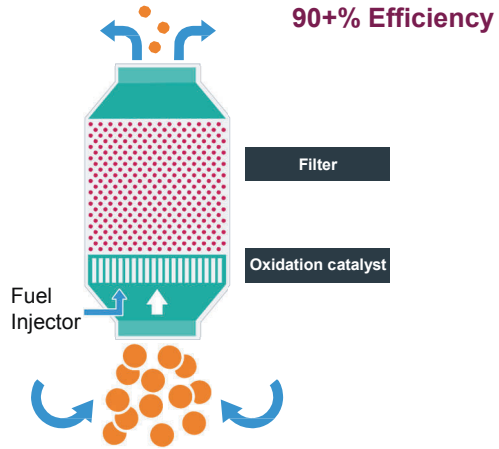


EGR routed from exhaust manifold to intake manifold



Diesel particulate filter (DPF) reduces exhaust soot

- **Filter service** is required to remove ash build-up
- **Filter Regeneration**
 - **Passive**
 - **Active**
 - Organic matter is burned off leaving small amount of incombustible **ash**
- As filter fills with soot **back pressure** builds
- Particulate matter '**soot**' enters the filter

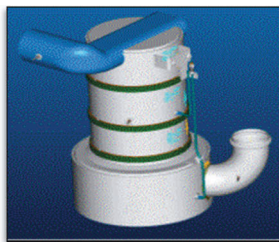


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NOTE: In use since 2007



Volvo compact DPF packaging on Volvo truck



2007-2016



Without chasis fairing option
Shown with steps & shield removed

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Selective catalytic reduction (SCR) for NOx control

- Key Components
 - Hot Exhaust gas
 - Diesel Exhaust Fluid
 - Catalyst
- DEF injected after DPF
 - DEF vaporizes and decomposes into Ammonia
- Ammonia + NOx pass over catalyst and form N₂ and water vapor
- SCR - key advantage OEMs could re-advance injection timing

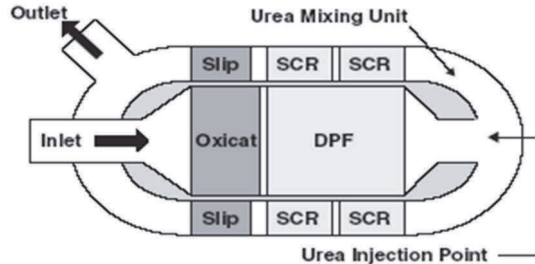


Figure 2 - Schematic representation of compact DPF-SCR system.

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NOTE: In use since 2010



SCR unit and DEF TANK packaging on Volvo truck



2010-2016

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Next Generation Exhaust After treatment



Mack Cleartech™ one 2017+

- First major redesign of emission after treatment system
- 1 box solution weighs significantly less and takes up less space
- New copper-zeolite coating improves low temperature NOx conversion for improved emissions control
- Mack – Cleartech™ one
- Cummins – Single Module™

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Continuing hardware changes will affect future formulations

Design change	Resulted in change
Higher top rings	Higher upper piston temperatures
Exhaust gas recirculation	Higher oil temperatures
Increased BMEP	Need for better oxidation stability
Higher fuel injector pressures	Greater stress on oil in crankcase
Retarded timing	Increased soot loading of oil
Lower oil consumption	Less fresh make-up oil
Exhaust after treatment devices	Chemical limits on oil formulation
Engine downsizing + Turbocharging + GDI	Higher Oxidation, LSPI

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Summary

- Internal combustion engines convert **chemical energy into work**
 - 4 stroke process: **Intake, Compression, Power, Exhaust**
- Modern gasoline and diesel engines have **many common parts** but differ in **ignition** source, engine **temperatures** and **pressures**, plus **combustion chemistry**, making the diesel lubricating environment more severe
- Heavy-duty diesel **emissions requirements** are having a significant impact on engine design and lubricant formulation
- Engine oil has many **responsibilities** (bearings, ring & liner, valvetrain, turbo, etc.) a balance of **viscometric properties and additive chemistry** is required to provide satisfactory lubrication in all phases of engine operation
- Engine design and operating conditions are **constantly evolving**, placing ever more stringent demands on the crankcase lubricant



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