2.61 Internal Combustion Engines
Spring 2008

Auto-ignition and knock

1. Knock and surface ignition
2. Knock fundamentals
3. Fuel factor

Abnormal Combustion:
Knock and surface-Ignition

Image removed due to copyright restrictions. Please see: Fig. 9-58 in Heywood, John B. *Internal Combustion Engine Fundamentals*. New York, NY: McGraw-Hill, 1988.

SI Engine Knock

1. Knock is most critical at WOT and at low speed because of its persistence and potential for damage. Part-throttle knock is a transient phenomenon and is a nuisance to the driver.

2. Whether or not knock occurs depends on engine/fuel/vehicle factors and ambient conditions (temperature, humidity). This makes it a complex phenomenon.

3. To avoid knock with gasoline, the engine compression ratio is limited to approximately 12.5 in PFI engines and 13.5 in DISI engines. Significant efficiency gains are possible if the compression ratio could be raised. (Approximately, increasing CR by 1 increases efficiency by one percentage point.)

4. Feedback control of spark timing using a knock sensor is increasingly used so that SI engine can operate close to its knock limit.

Knock damaged pistons

Also see any other photos of knock damage to pistons, such as: http://cameronassociates.org.uk/assets/images/autogen/a_Piston_Damage.jpg

From Lichty, *Internal Combustion Engines*

From Lawrence Livermore website

Pressure oscillations observed in engine knock

Image removed due to copyright restrictions. Please see: Fig. 9-59 in Heywood, John B. *Internal Combustion Engine Fundamentals*. New York, NY: McGraw-Hill, 1988.

Single cylinder engine, 381 cc displacement; 4000 rpm, WOT

End Gas Geometry, Knock, and Pressure Signal

(SAE 960827,Stiebels, Schreiber, and Sakak)

Images (12 μs apart) of flame luminescence and pressure trace; RON= 90, 2400 rpm, ign. at 35° BTC; white circle indicating first autoignition

Knock Fundamentals

Knock originates in the extremely rapid release of much of the fuel chemical energy contained in the end-gas of the propagating turbulent flame, resulting in high local pressures. The non-uniform pressure distribution causes strong pressure waves or shock waves to propagate across and excites the acoustic modes of the combustion chamber.

When the fuel-air mixture in the end-gas region is compressed to sufficiently high pressures and temperatures, the fuel oxidation process — starting with the pre-flame chemistry and ending with rapid heat release — can occur spontaneously in parts or all of the end-gas region.

Most evidence indicates that knock originates with the auto-ignition of one or more local regions within the end-gas. Additional regions then ignite until the end-gas is essentially fully reacted. The sequence of processes occur extremely rapidly.

Knock chemical mechanism

CHAIN BRANCHING EXPLOSION

Chemical reactions lead to increasing number of radicals, which leads to rapidly increasing reaction rates

Chain Initiation

$$RH + O_2 \Rightarrow \dot{R} + H\dot{O}_2$$

Chain Propagation

$$\dot{R} + O_2 \Rightarrow R\dot{O}_2, \text{etc.}$$

Formation of Branching Agents

$$R\dot{O}_2 + RH \Rightarrow ROOH + \dot{R}$$

$$R\dot{O}_2 \Rightarrow R'CHO + R''\dot{O}$$

Degenerate Branching

$$ROOH \Rightarrow R\dot{O} + \dot{O}H$$

$$R'CHO + O_2 \Rightarrow R'\dot{C}O + H\dot{O}_2$$

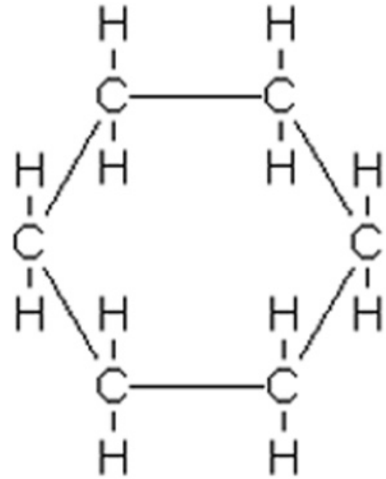
FUEL FACTORS

- The auto-ignition process depends on the fuel chemistry.
- Practical fuels are blends of a large number of individual hydrocarbon compounds, each of which has its own chemical behavior.
- A practical measure of a fuel's resistance to knock is the octane number. High octane number fuels are more resistant to knock.

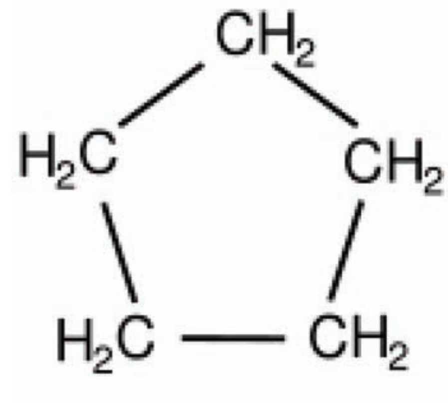
Types of hydrocarbons

(See text section 3.3)

NAPHTHENES

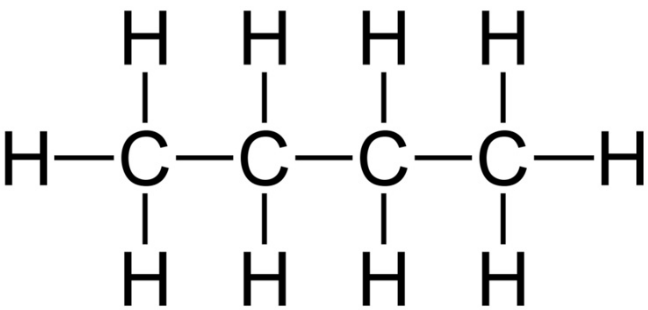


Cyclohexane



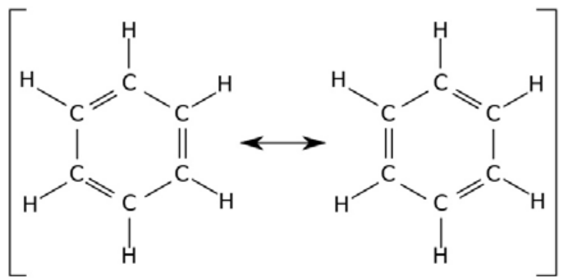
Cyclopentane

PARAFFINS



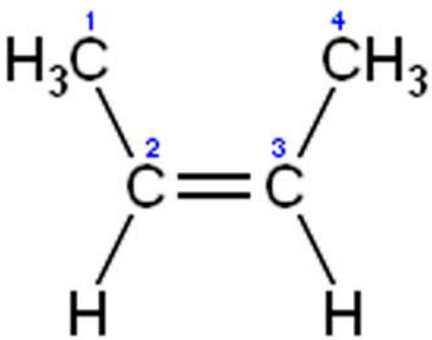
Butane

AROMATICS



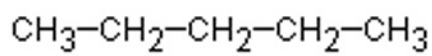
Benzene

OLEFINS

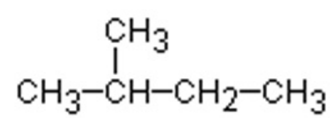


Cis-2-Butane

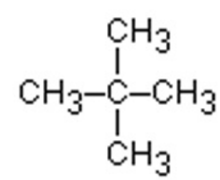
ISOMERS



n-pentan



isopentan
2-methylbutan



neopentan
2,2-dimethylpropan

Knock tendency of individual hydrocarbons

Image removed due to copyright restrictions. Please see: Fig. 9-69 in Heywood, John B. *Internal Combustion Engine Fundamentals*. New York, NY: McGraw-Hill, 1988.

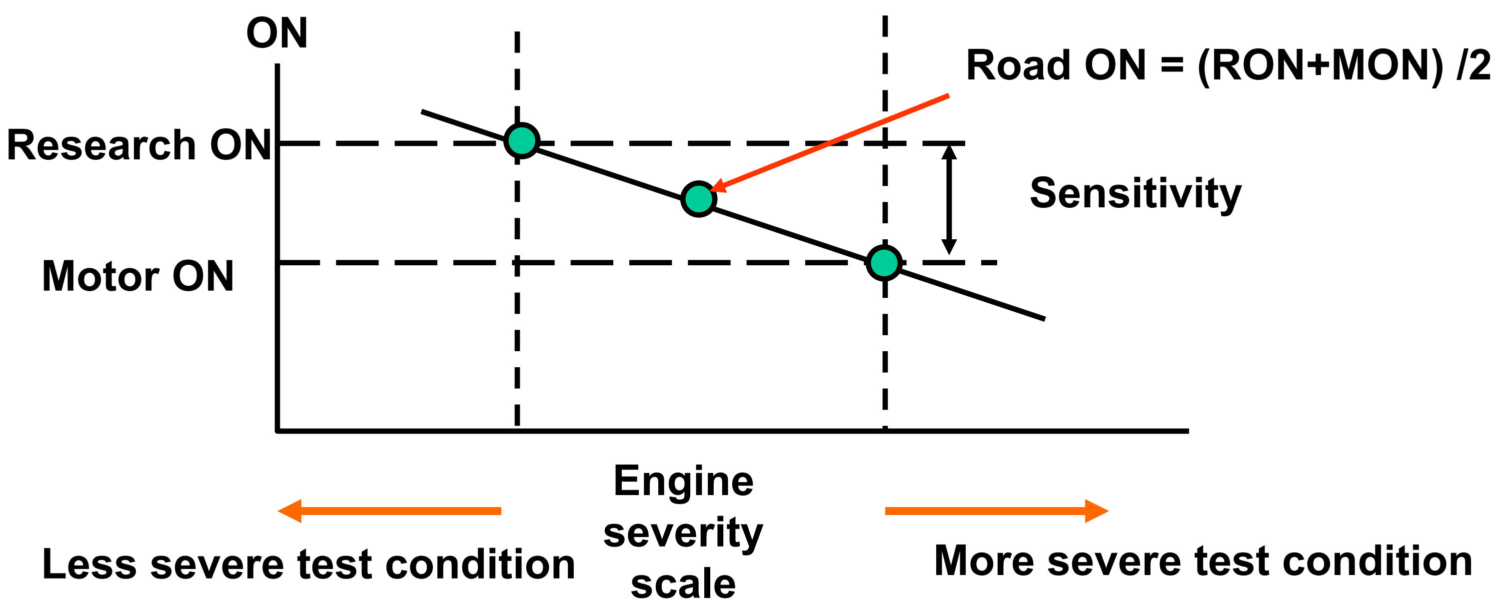
Fig 9-69

Critical compression ratio for incipient knock at 600 rpm and 450 K coolant temperature for hydrocarbons

Fuel anti-knock rating

(See table 9.6 for details)

- Blend primary reference fuels (iso-octane and normal heptane) so its knock characteristics matches those of the actual fuel.
- Octane no. = % by vol. of iso-octane
- Two different test conditions:
  - Research method: 52°C (125°F) inlet temperature, 600 rpm
  - Motor method: 149°C (300°F) inlet temperature, 900 rpm



Octane requirement

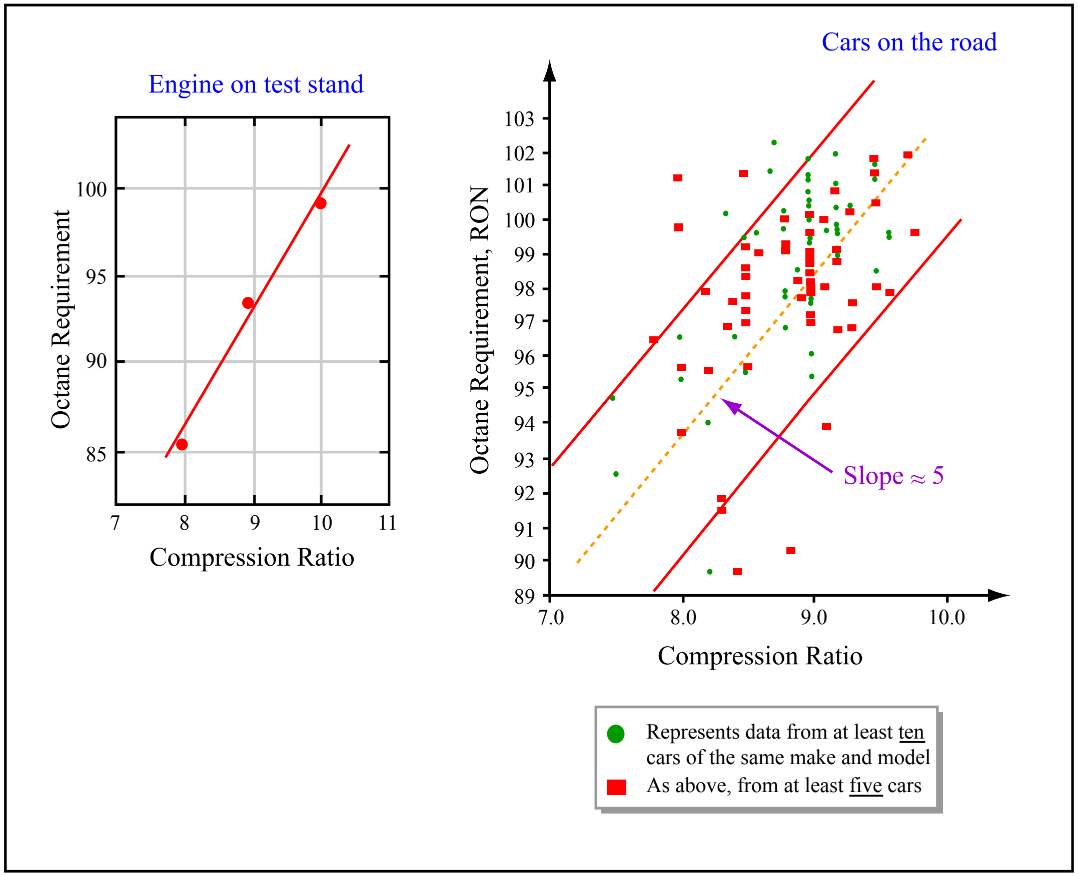


Figure by MIT OpenCourseWare. Adapted from Blackmore, D. R., and Thomas, A. Fuel Economy of the Gasoline Engine: Fuel, Lubricant, and Other Effects. London, England: Macmillan, 1977.

From Balckmore and Thomas, *Fuel Economy of the Gasoline Engine*, Wiley 1977.

Remark: these are old data; modern engine octane requirement relates more to MON

Octane Requirement Increase

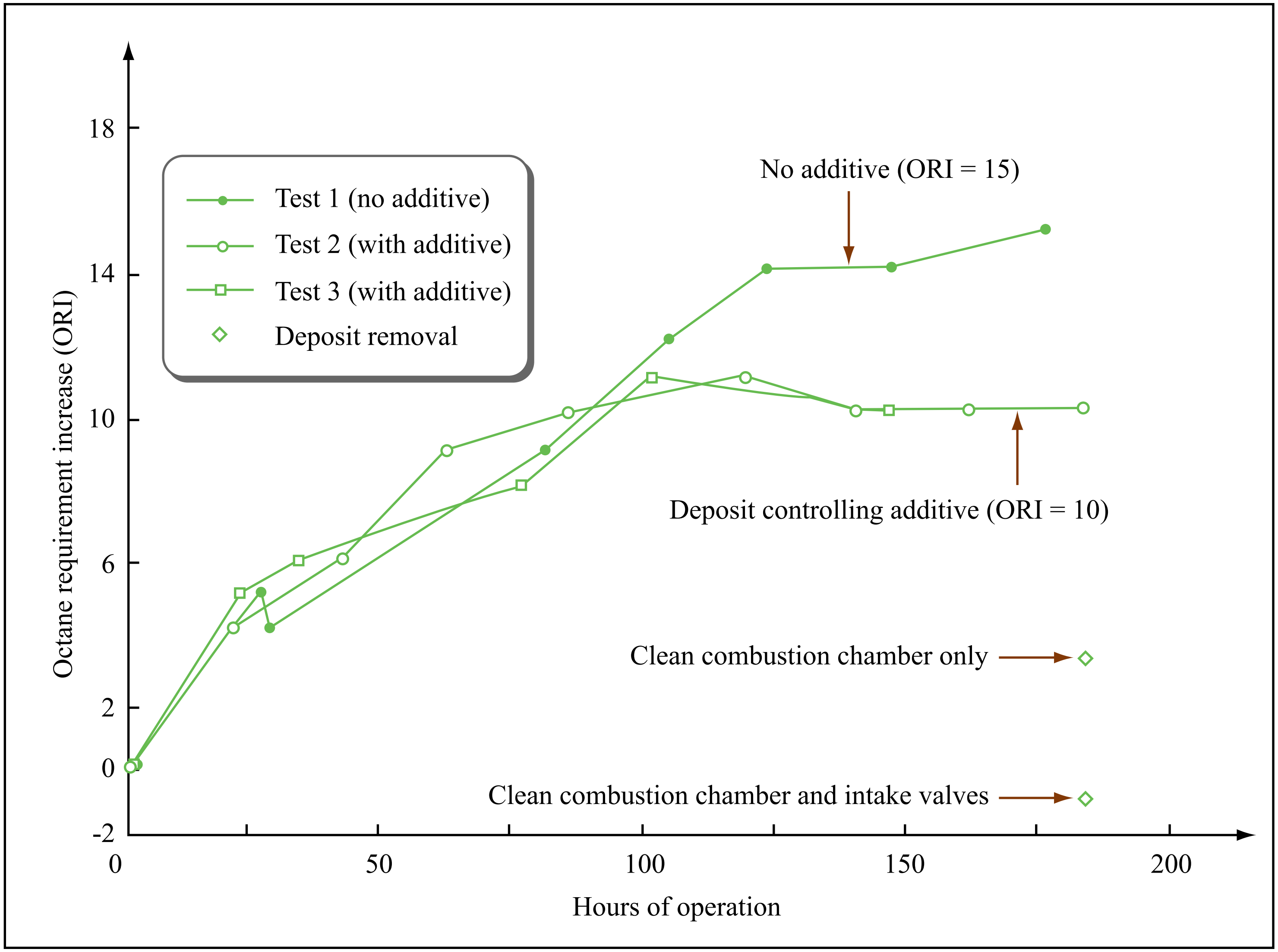


Figure by MIT OpenCourseWare.

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Knock control strategies

1. Provide adequate cooling to the engine
2. Use intercooler on turbo-charged engines
3. Use high octane gasoline
4. Anti-knock gasoline additives
5. Fuel enrichment under severe condition
6. Use knock sensor to control spark retard so as to operate close to engine knock limit
7. Fast burn system
8. Gasoline direct injection

Anti-knock Agents

Alcohols

Methanol	CH_3OH
Ethanol	C_2H_5OH
TBA (Tertiary Butyl Alcohol)	$(CH_3)_3COH$

Ethers

MTBE (Methyl Tertiary Butyl Ether)	$(CH_3)_3COCH_3$
ETBE (Ethyl Tertiary Butyl Ether)	$(CH_3)_3COC_2H_5$
TAME (Tertiary Amyl Methyl Ether)	$(CH_3)_2(C_2H_5)COCH_3$