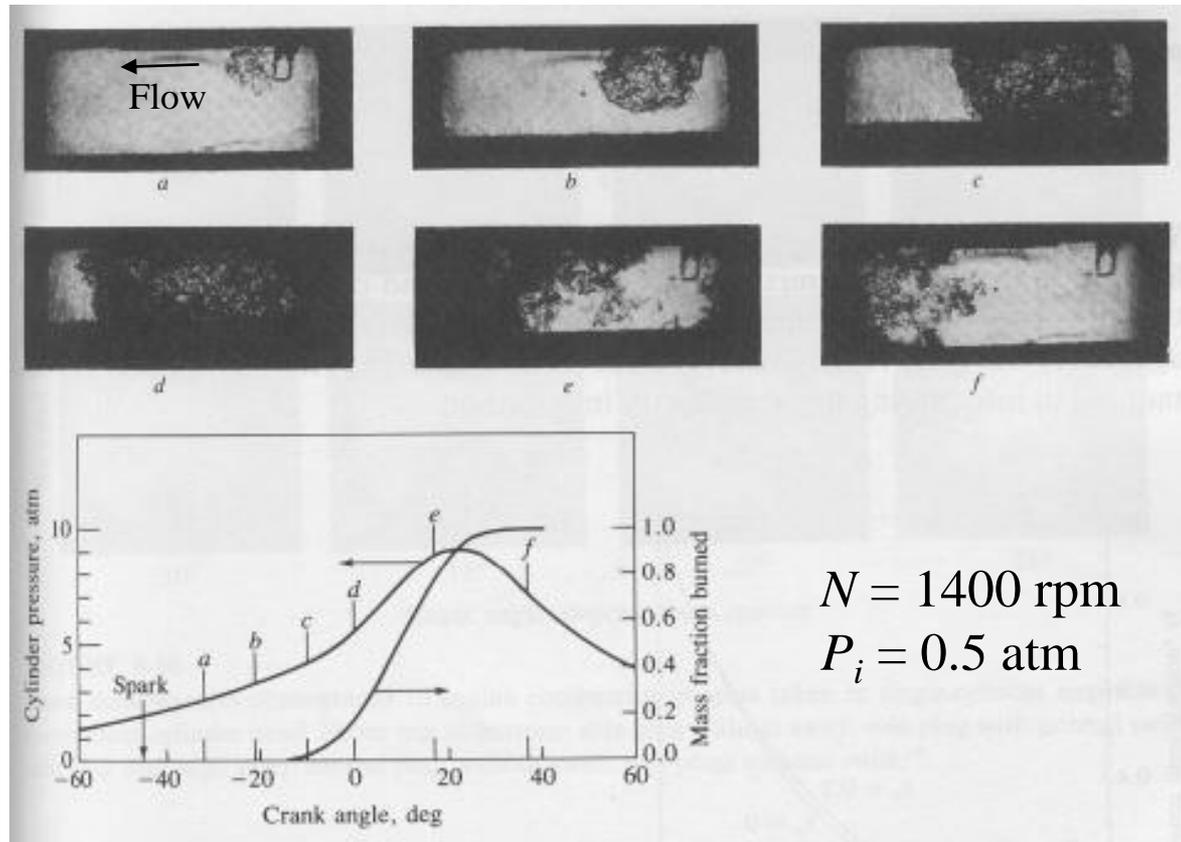


Flame Propagation in SI Engine

After intake the fuel-air mixture is compressed and then ignited by a spark plug just before the piston reaches top center

The turbulent flame spreads away from the spark discharge location.



$N = 1400 \text{ rpm}$

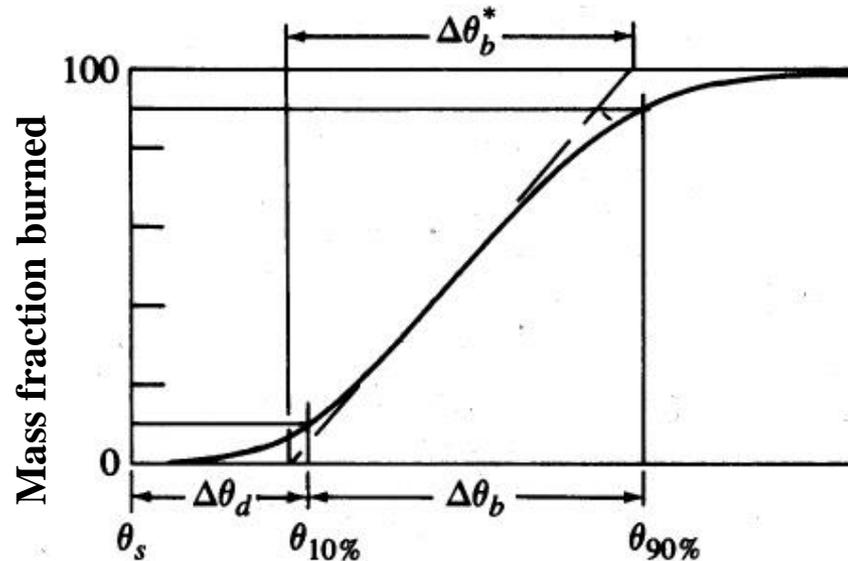
$P_i = 0.5 \text{ atm}$

Flame Development

Flame development angle $\Delta\theta_d$ – crank angle interval during which flame kernel develops after spark ignition.

Rapid burning angle $\Delta\theta_b$ – crank angle required to burn most of mixture

Overall burning angle - sum of flame development and rapid burning angles



Mixture Burn Time vs Engine Speed

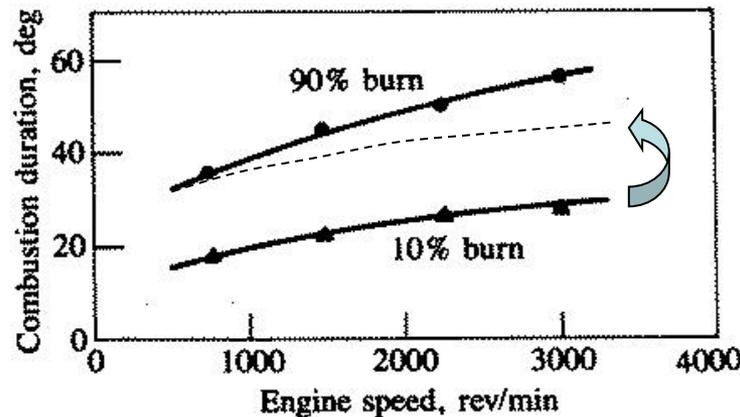
How does the flame burn all the mixture in the cylinder at high engine speeds?

The piston speed is directly proportional to the engine speed, $u_p \sim N$

Recall the turbulent intensity increases with piston speed, $u_t = \frac{1}{2} u_p$

Recall the turbulent burning velocity is proportional to the turbulent intensity $S_t \sim u_t$, so at higher engine speeds the turbulent flame velocity is also higher and as a result need less time to burn the entire mixture

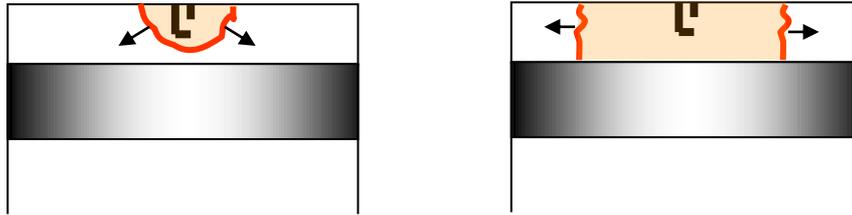
Combustion duration in crank angles (40-60 degrees) only increases a small amount with increasing engine speed.



$\phi = 1.0$
 $P_i = 0.54 \text{ atm}$
Spark 30° BTC

Heat Losses During Burn

During combustion the cylinder volume is very narrow.



Heat loss to the piston and cylinder head is very important

In order to reduce the heat loss want burn time to be small (high flame velocity) accomplished by either increasing

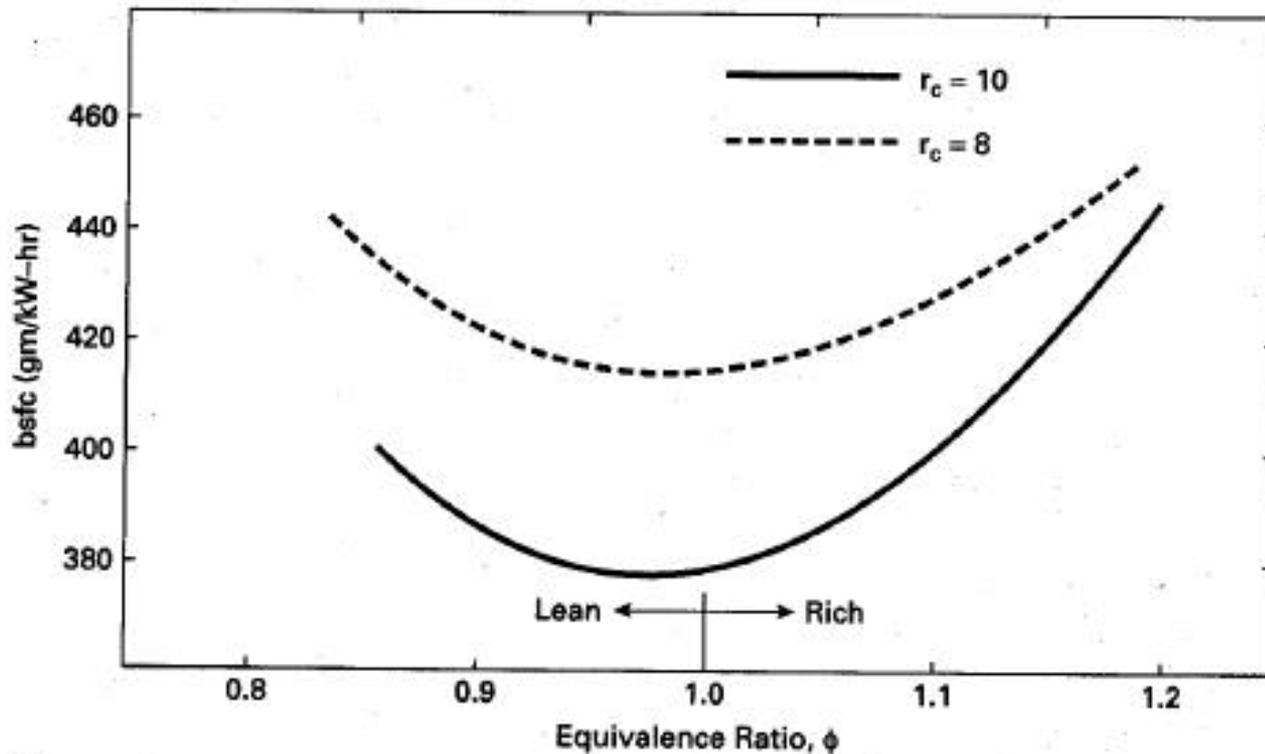
- a) laminar burning velocity, or
- b) turbulence intensity.

Highest laminar burning velocity is achieved for slightly rich mixtures (for isooctane maximum $S_l = 26.3$ cm/s at $\phi = 1.13$)

Optimum F/A Composition

Maximum power is obtained for a F/A that is about 1.1 since this gives the highest burning velocity and thus minimum heat loss.

Best fuel economy is obtained for a F/A that is less than 1.0

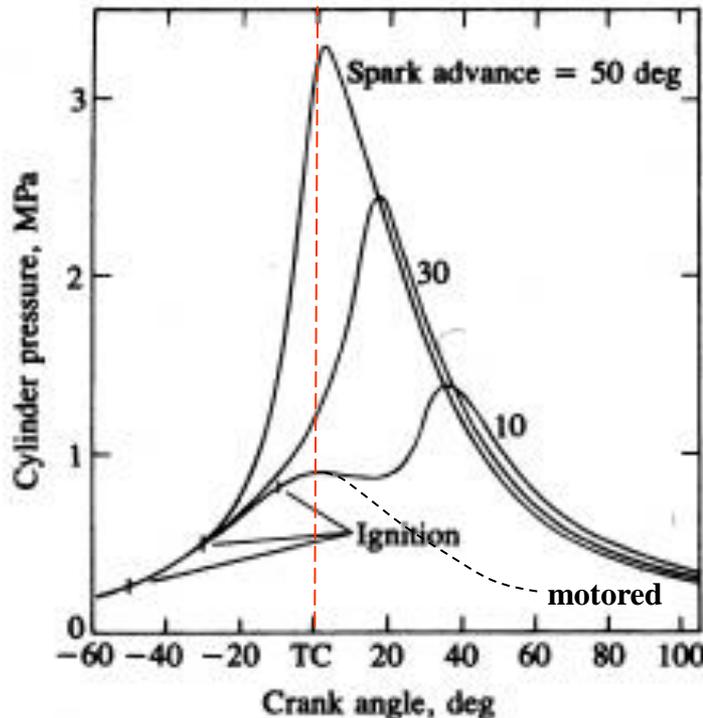


Spark Timing

Spark timing relative to TC affects the pressure development and thus the *imep* and power of the engine.

Want to ignite the gas before TC so as to center the combustion around TC.

The overall burning angle is typically between 40 to 60°, depending on engine speed.



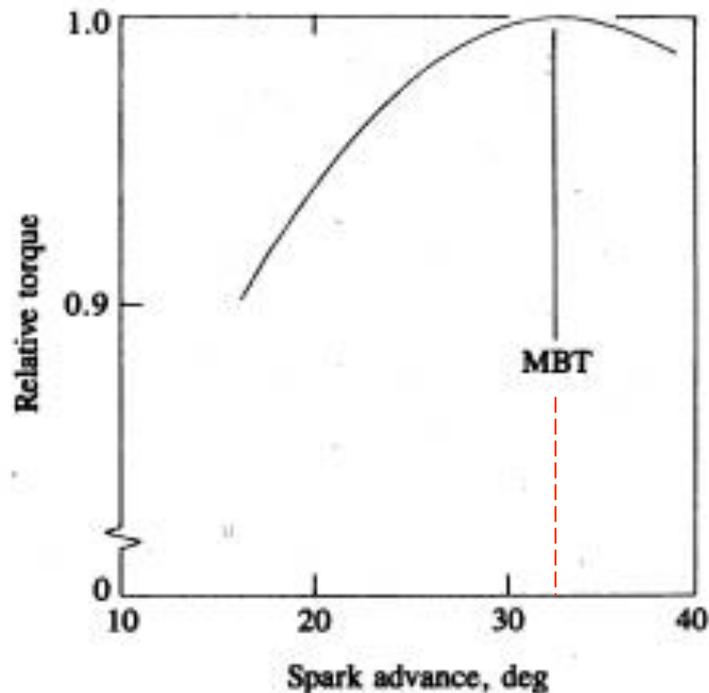
Engine at WOT, constant engine speed and A/F

Maximum Brake Torque Timing

If start of combustion is too early work is done against piston and if too late then peak pressure is reduced.

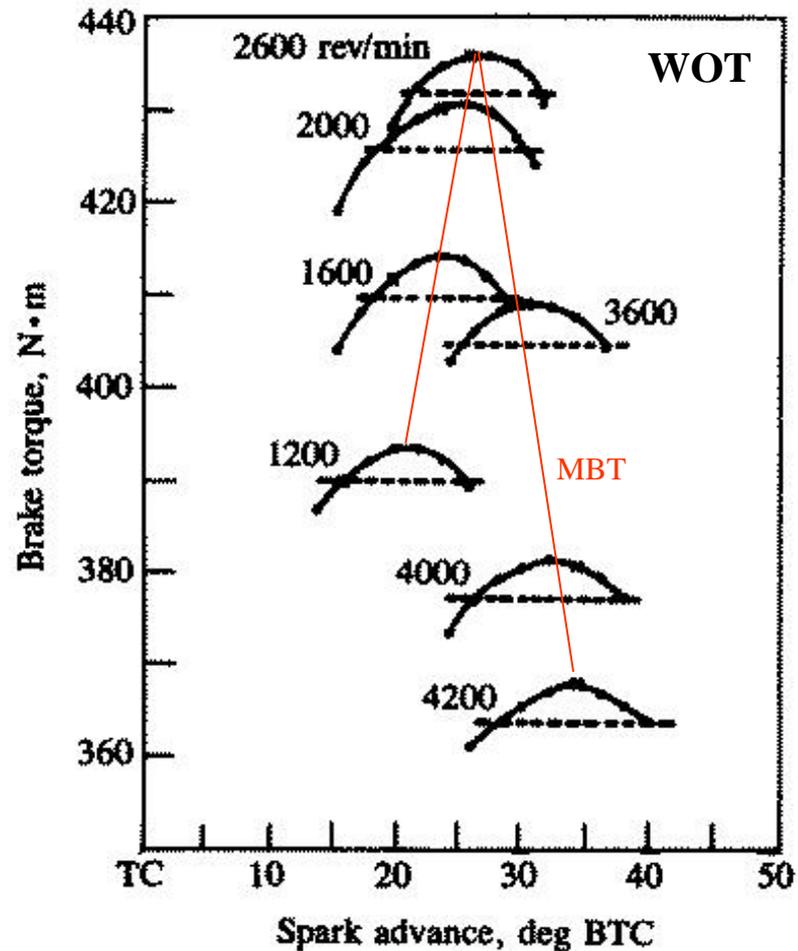
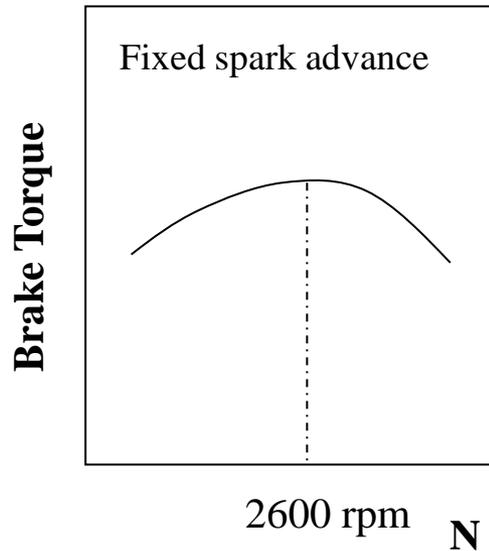
The optimum spark timing which gives the maximum brake torque, called **MBT timing** occurs when these two opposite factors cancel.

Engine at WOT, constant engine speed and A/F



Effect of Engine Speed on Spark Timing

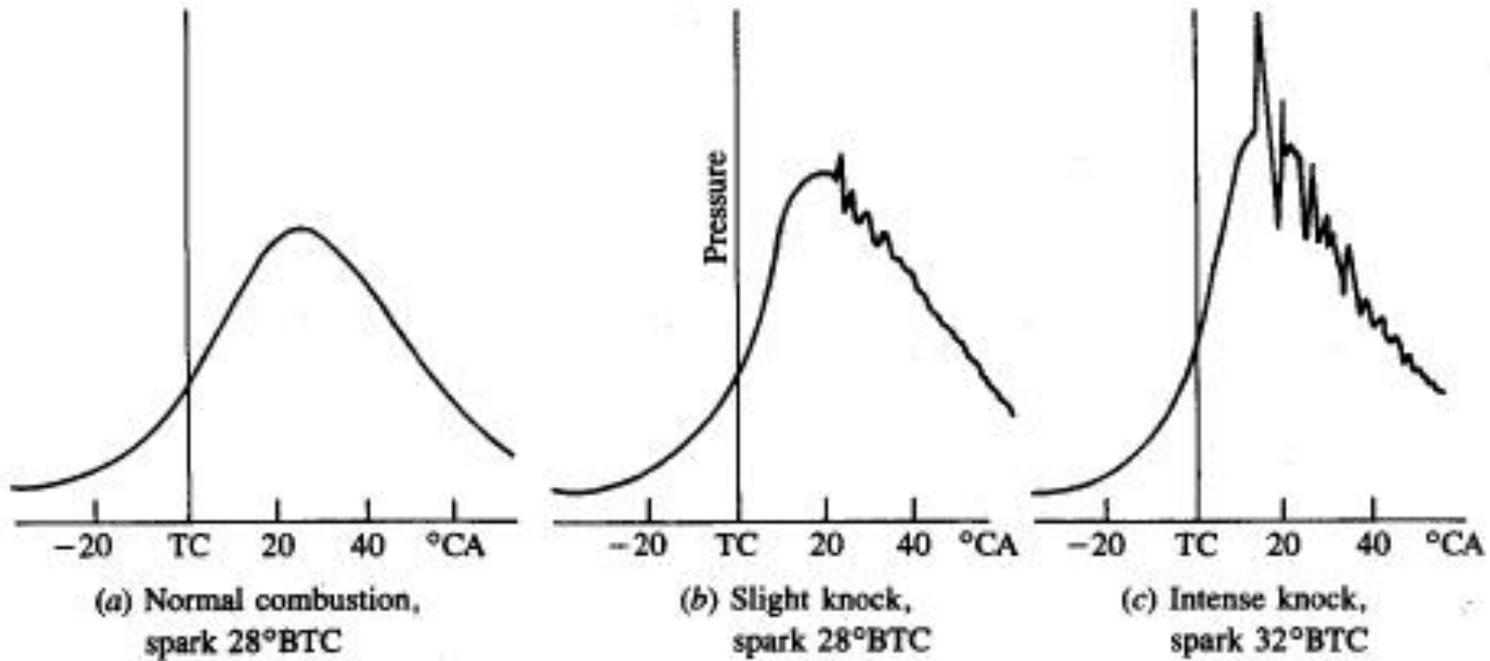
Recall the overall burn angle (90% burn) increases with engine speed, to accommodate this you need a larger spark advance.



Abnormal Combustion in SI Engine

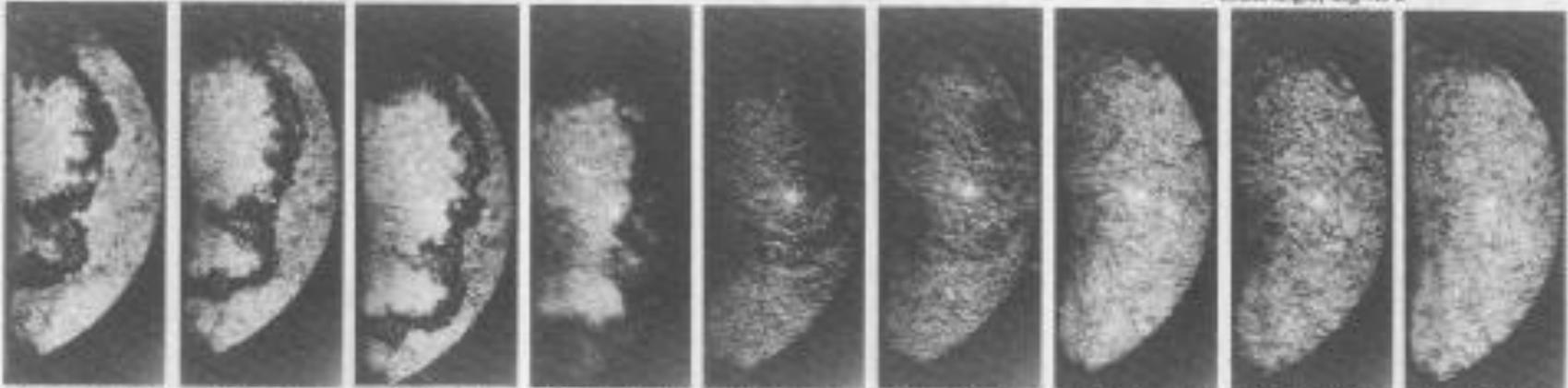
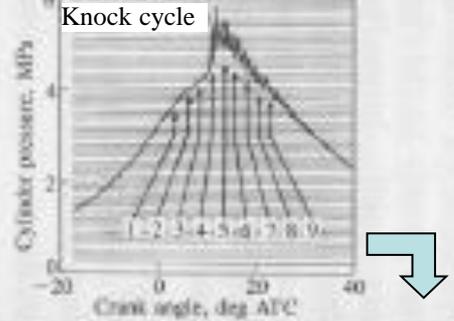
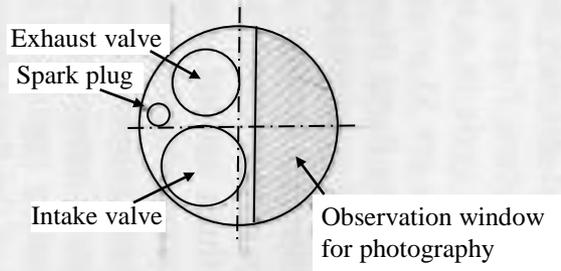
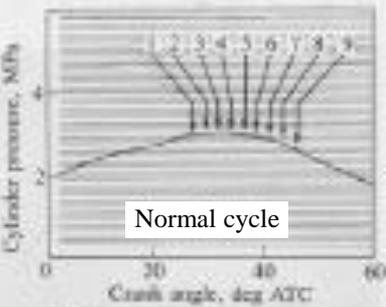
Knock is the term used to describe a pinging noise emitted from a SI engine undergoing abnormal combustion.

The noise is generated by shock waves produced in the cylinder when unburned gas ahead of the flame auto-ignites.





No. 1 (26.8° ATC) No. 2 (29.2°) No. 3 (31.6°) No. 4 (34.0°) No. 5 (36.4°) No. 6 (38.8°) No. 7 (41.2°) No. 8 (43.6°) No. 9 (46.0°)

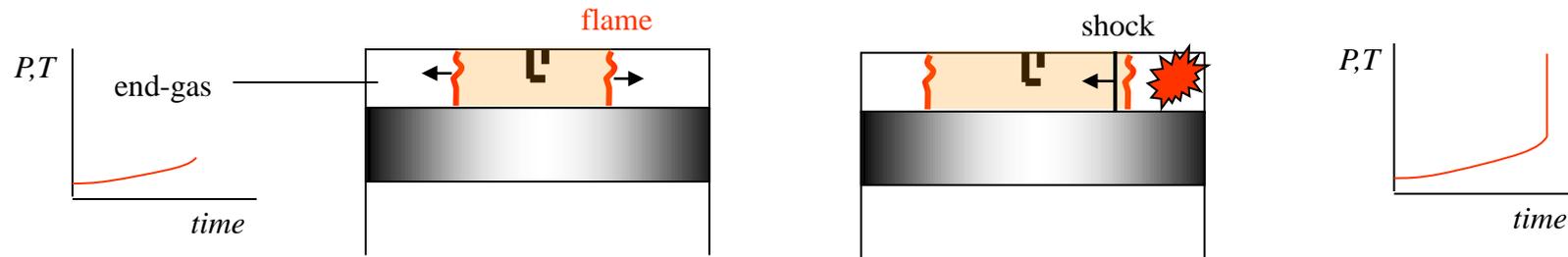


No. 1 (3.7° ATC) No. 2 (6.1°) No. 3 (8.5°) No. 4 (10.9°) No. 5 (13.3°) No. 6 (15.7°) No. 7 (18.1°) No. 8 (20.5°) No. 9 (22.9°)

Knock

As the flame propagates away from the spark plug the pressure and temperature of the unburned gas increases.

Under certain conditions the end-gas can autoignite and burn very rapidly producing a shock wave



The end-gas autoignites after a certain *induction time* which is dictated by the chemical kinetics of the fuel-air mixture.

If the flame burns all the fresh gas before autoignition in the end-gas can occur then knock is avoided.

Therefore knock is a potential problem when the burn time is long!

Parameters Influencing Knock

i) *Compression ratio* – at high compression ratios, even before spark ignition, the fuel-air mixture is compressed to a high pressure and temperature which promotes autoignition

ii) *Engine speed* – At low engine speeds the flame velocity is slow and thus the burn time is long, this results in more time for autoignition

However at high engine speeds there is less heat loss so the unburned gas temperature is higher which promotes autoignition

These are competing effects, some engines show an increase in propensity to knock at high speeds while others don't.

iii) *Spark timing* – maximum compression from the piston advance occurs at TC, increasing the spark advance makes the end of combustion crank angle approach TC and thus get higher pressure and temperature in the unburned gas just before burnout.

Fuel Knock Scale

To provide a standard measure of a fuel's ability to resist knock, a scale has been devised in which fuels are assigned an **octane number ON**.

The octane number determines whether or not a fuel will knock in a given engine under given operating conditions.

By definition, normal heptane ($n\text{-C}_7\text{H}_{16}$) has an octane value of zero and isooctane (C_8H_{18}) has a value of 100.

The higher the octane number, the higher the resistance to knock.

Blends of these two hydrocarbons define the knock resistance of intermediate octane numbers: e.g., a blend of 10% n-heptane and 90% isooctane has an octane number of 90.

A fuel's octane number is determined by measuring what blend of these two hydrocarbons matches the test fuel's knock resistance.

Octane Number Measurement

Two methods have been developed to measure ON using a standardized single-cylinder engine developed under the auspices of the Cooperative Fuel Research Committee in 1931.

The CFR engine is 4-stroke with 3.25" bore and 4.5" stroke, compression ratio can be varied from 3 to 30.

	Research	Motor
Inlet temperature (°C)	52	149
Speed (rpm)	600	900
Spark advance (°BTC)	13	19-26 (varies with r)
Coolant temperature (°C)		100
Inlet pressure (atm)		1.0
Humidity (kg water/kg dry air)	0.0036 - 0.0072	

Note: In 1931 iso-octane was the most knock resistant HC, now there are fuels that are more knock resistant than isooctane.

Octane Number Measurement

Testing procedure:

- Run the CFR engine on the test fuel at both research and motor conditions.
- Slowly increase the compression ratio until a standard amount of knock occurs as measured by a magnetostriction knock detector.
- At that compression ratio run the engines on blends of n-heptane and isooctane.
- ON is the % by volume of octane in the blend that produces the stand.

The antiknock index which is displayed at the fuel pump :

$$\textit{Antiknock index} = \frac{RON + MON}{2}$$

Note the motor octane number is always higher because it uses more severe operating conditions: higher inlet temperature and more spark advance.

The automobile manufacturer will specify the minimum fuel ON that will resist knock throughout the engine's operating speed and load range.

Fuel Additives

Chemical additives are used to raise the octane number of gasoline.

The most effective antiknock agents are lead alkyls;

- (i) Tetraethyl lead (TEL), $(C_2H_5)_4Pb$ was introduced in 1923
- (ii) Tetramethyl lead (TML), $(CH_3)_4Pb$ was introduced in 1960

In 1959 a manganese antiknock compound known as MMT was introduced to supplement TEL (used in Canada since 1978).

About 1970 low-lead and unleaded gasoline were introduced over toxicological concerns with lead alkyls (TEL contains 64% by weight lead).

Alcohols such as ethanol and methanol have high knock resistance.

Since 1970 another alcohol methyl tertiary butyl ether (MTBE) has been added to gasoline to increase octane number. MTBE is formed by reacting methanol and isobutylene (not used in Canada).

Effect of Fuel-air Dilution

Set spark timing for maximum brake torque (MBT), leaner mixture needs more spark advance since burn time longer.

Along MBT curve as you increase excess air reach partial burn limit (not all cycles result in complete burn) and then ignition limit (misfires start to occur).

