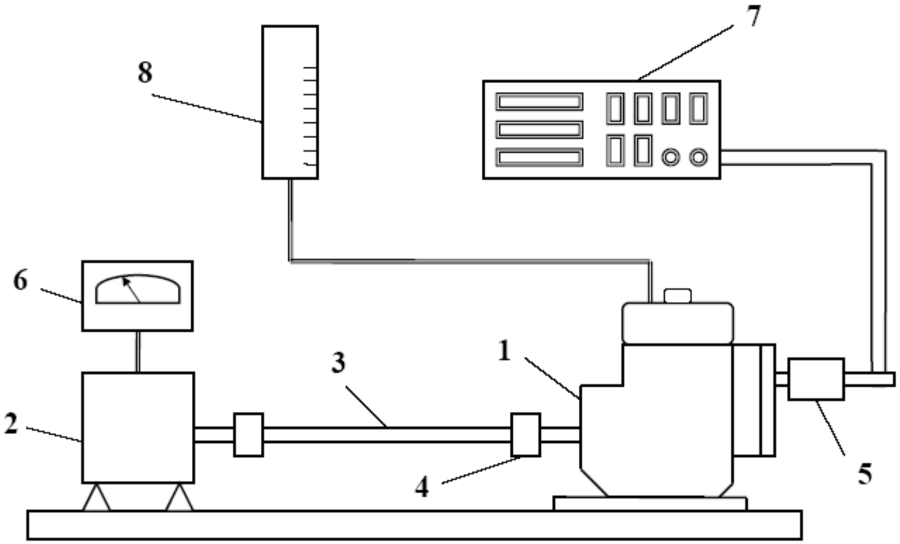
Internal combustion engine lab

Engine/dynamometer parameters



The schematic diagram of the experimental set-up. (1) Engine, (2) Dynamometer, (3) Shaft, (4) Flywheel, (5) Exhaust pipe, (6) Dynamometer control unit, (7) Gas analyzer, and (8) Fuel measurement system.

Ioannis Gravalos, Dimitrios Moshou, Theodoros Gialamas, Panagiotis Xyradakis, Dimitrios Kateris and Zisis Tsiropoulos (2011). Performance and Emission Characteristics of Spark Ignition Engine Fuelled with Ethanol and Methanol Gasoline Blended Fuels, Alternative Fuel, Dr. Maximino Manzanera (Ed.), ISBN: 978-953-307-372-9, InTech, DOI: 10.5772/23176.

Experimental tasks

- Measure fuel consumption rate as a function of engine speed
- Measure torque as a function of engine speed
- Measure power output as a function of engine speed
- Measure cylinder pressure vs. time and crank angle as a function of engine speed.

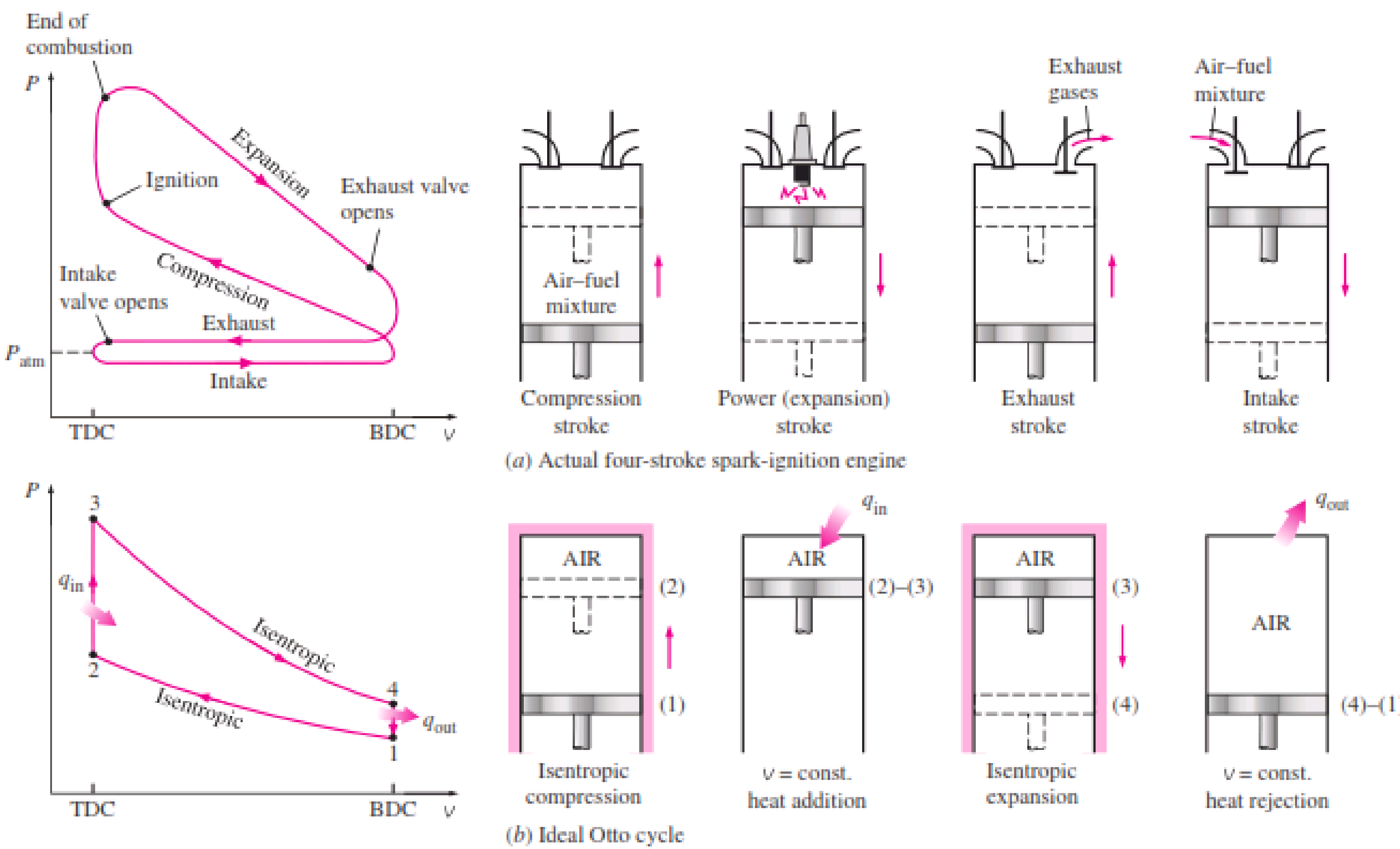
Analytical tasks

- Calculate fuel conversion efficiency as a function of engine speed by comparing heat input/time to power output.
- Plot brake torque and brake power as a function of engine speed.
- Convert crank angle to piston volume vs. time.
- Integrate p-V curve to determine the mechanical work/cycle, power/cycle, mechanical conversion efficiency

Videos of internal combustion engine operation

- Four stroke, spark ignition
  - https://www.youtube.com/watch?v=OGj8OneMjek
- Two stroke, spark ignition
  - https://www.youtube.com/watch?v=xNLE8G3pC0k
- Four stroke, compression ignition
  - https://www.youtube.com/watch?v=kcwjJKDR3yM
  - https://www.youtube.com/watch?v=fTAUq6G9apg
  - https://www.youtube.com/watch?v=HapIGjHkBHU&feature=iv&src_vid=fTAUq6G9apg&annotation_id=annotation_256661839

How engine delivers power – p-V diagram



http://sounak4u.weebly.com/gas-power-cycle.html

Geometry of cylinder, piston, connection rod, and crankshaft

V_d = displaced volume
V_c = clearance volume
R=$\ell/$a
L=2a

$$r_c = \frac{V_d + V_c}{V_c}$$

Cylinder volume

$$V = V_c + \frac{\pi B^2}{4}(\ell + a - s)$$

$$= V_c\left(1 + \frac{1}{2}(r_c - 1)\left[R + 1 - \cos\theta - \left(R^2 - \sin^2\theta\right)^{1/2}\right]\right)$$

Combustion chamber surface area

$$A = A_{ch} + A_p + \pi B(\ell + a - s)$$

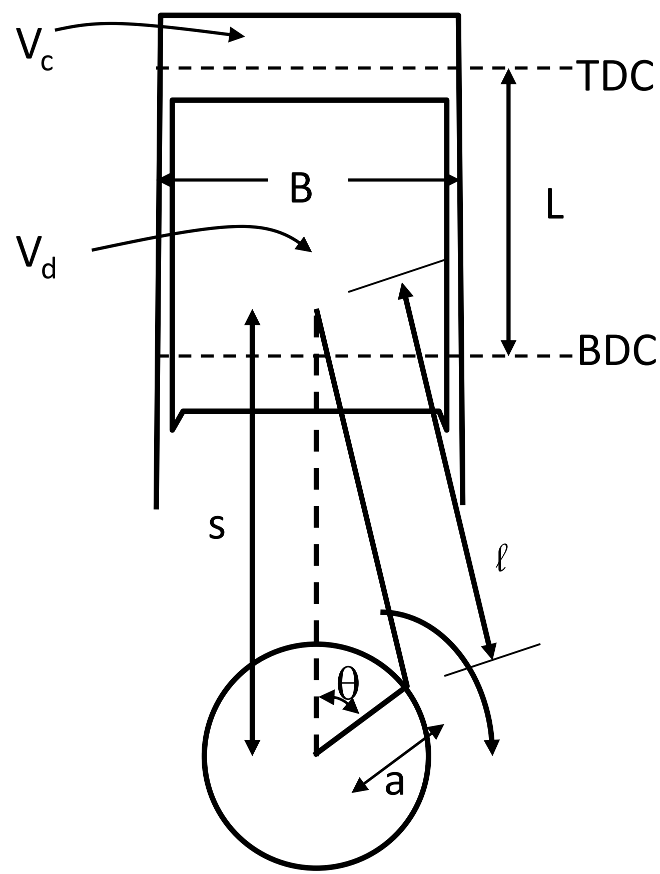
A_{ch} = cylinder head area

A_p = piston crown surface

$$s = a\cos\theta + \left(\ell^2 - a^2\sin^2\theta\right)^{1/2}$$

Mean piston speed $\quad \bar{S}_p = 2LN$

N = rotational speed



θ = crank angle degree CAD

From Internal Combustion Engine Fundamentals, John B. Heywood

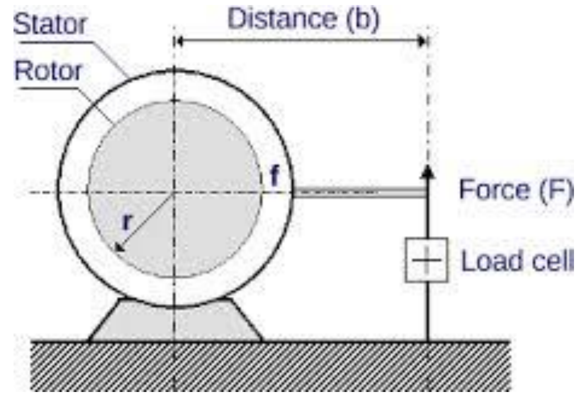
More definitions

Brake power

$$T = Fb = \text{torque}$$

$$P = 2\pi NT = \text{power}$$

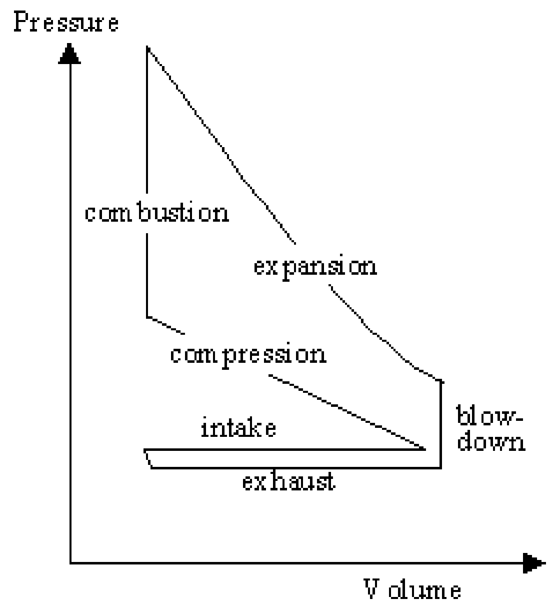
$$N = \text{rotational speed}$$



Indicated work per cycle

$$W_{c,i} = \oint p\,dV$$

Gross indicated work – delivered over compression and expansion strokes only.
Net indicated work – includes exhaust cycle



Power per cylinder

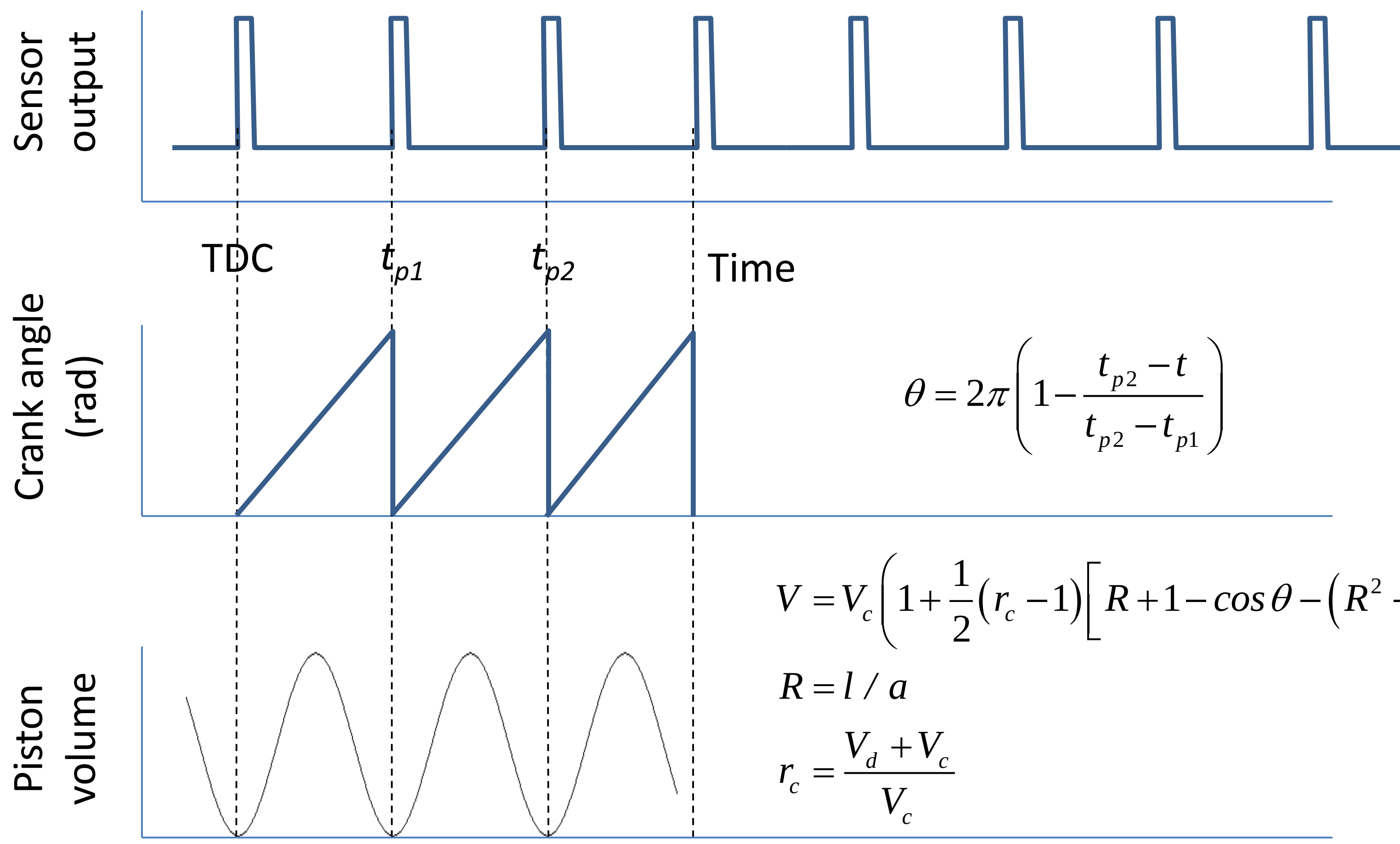
$$P_i = \frac{W_{c,i} N}{n_r}$$

$$n_r = 2 \text{ for four stroke, \# crank revolutions per stroke}$$

Fuel conversion efficiency $\eta_f = \dfrac{P}{\dot{m}_f Q_{hv}}$

Q_{hv} is heat content of fuel

Calculation of cylinder volume from crankshaft position sensor



$$\theta = 2\pi\left(1 - \frac{t_{p2} - t}{t_{p2} - t_{p1}}\right)$$

$$V = V_c\left(1 + \frac{1}{2}(r_c - 1)\left[R + 1 - \cos\theta - \left(R^2 - \sin^2\theta\right)^{1/2}\right]\right)$$

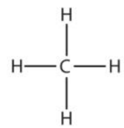
$$R = l \,/\, a$$

$$r_c = \frac{V_d + V_c}{V_c}$$

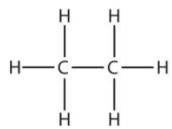
Components of petroleum

Alkanes (Paraffins)

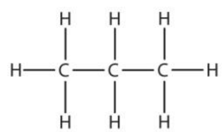
methane, CH_4



ethane, C_2H_6

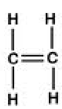


propane, C_3H_8

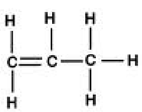


Alkenes (Olefins)

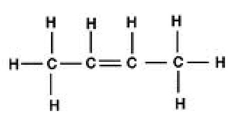
Ethene



Propene



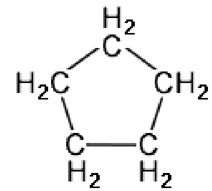
Butene



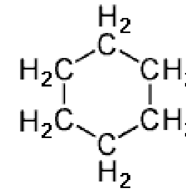
Alkynes (acetylenes)

$H-C\equiv C-H$

Cyclanes (napthenes, cycloparaffins)

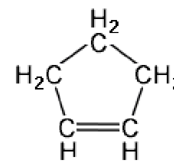


Cyclopentane

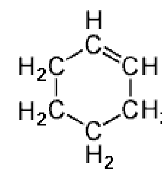


Cyclohexane

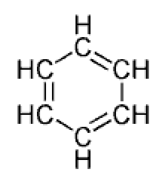
Aromatics



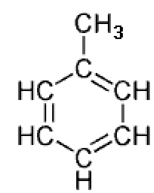
Cyclopentene



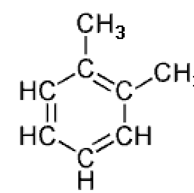
Cyclohexene



Benzene
(Phenyl hydride)

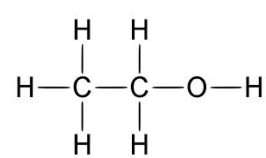


Toluene
(methylbenzene)

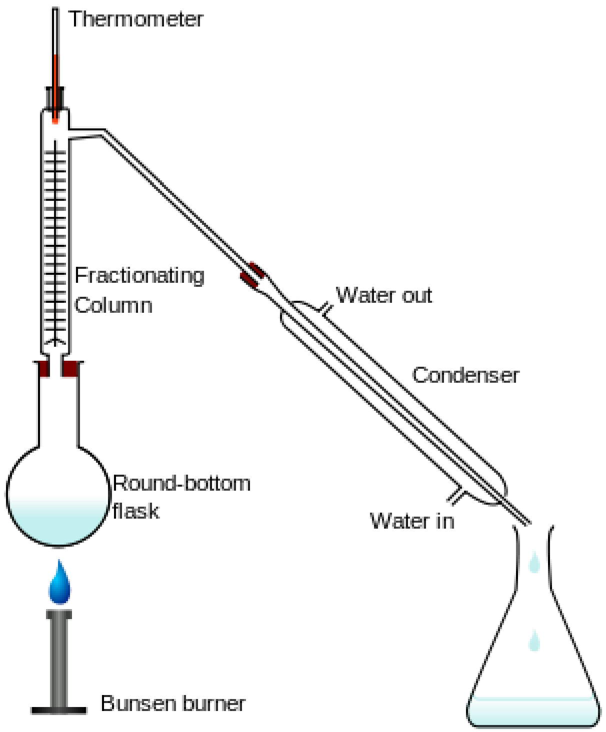


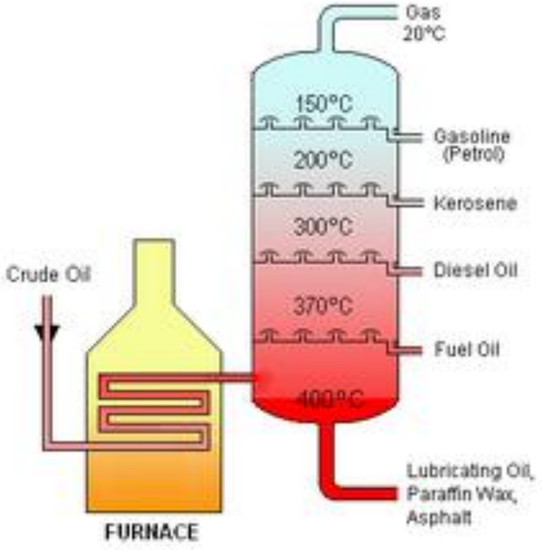
o-Xylene
(1,2-dimethylbenzene)

Alcohols



Fractional distillation to create different fuel grades





http://en.wikipedia.org/wiki/Fractional_distillation

Composition by weight		
Hydrocarbon	Average	Range
Alkanes (paraffins)	30%	15 to 60%
Naphthenes	49%	30 to 60%
Aromatics	15%	3 to 30%
Asphaltics	6%	remainder

Common fractions of petroleum as fuels	
Fraction	Boiling range ^{o}C
Liquefied petroleum gas (LPG)	−40
Butane	−12 to −1
Petrol	−1 to 110
Jet fuel	150 to 205
Kerosene	205 to 260
Fuel oil	205 to 290
Diesel fuel	260 to 315

http://en.wikipedia.org/wiki/Petroleum

Air composition

- Air is mostly nitrogen and oxygen 20.95% oxygen by volume and 78.09% nitrogen
- 3.773 moles of nitrogen per mole of oxygen
- MW of air is 28.962 g/mole ~29 g/mole

Combustion thermochemistry
Stoichiometry considerations

$$2H_2 + O_2 \rightarrow 2H_2O$$

$$C_3H_8 + aO_2 \rightarrow bCO_2 + cH_2O$$
$$C_3H_8 + aO_2 \rightarrow 3CO_2 + 4H_2O$$

$$C_aH_b + \left(a + \frac{b}{4}\right)\left(O_2 + 3.773N_2\right) \rightarrow aCO_2 + \frac{b}{2}H_2O + 3.773\left(a + \frac{b}{4}\right)N_2$$
$$C_8H_{18} + 12.5\left(O_2 + 3.773N_2\right) \rightarrow 8CO_2 + 9H_2O + 3.773\left(12.5\right)N_2$$

C_8H_{18} Is the “standard” for gasoline

Need 12.5 moles of air to completely combust iso-octane
This is a mass ratio of 15.1:1. The mass ratio for gasoline is 14.7