ME 430 Internal Combustion Engines

Engineering Fundamentals of Internal Combustion Engines

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ME 430 Internal Combustion Engines

Lecture Notes for the Undergraduate Course

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Chapter 2

Engine Characteristics and Operating Parameters

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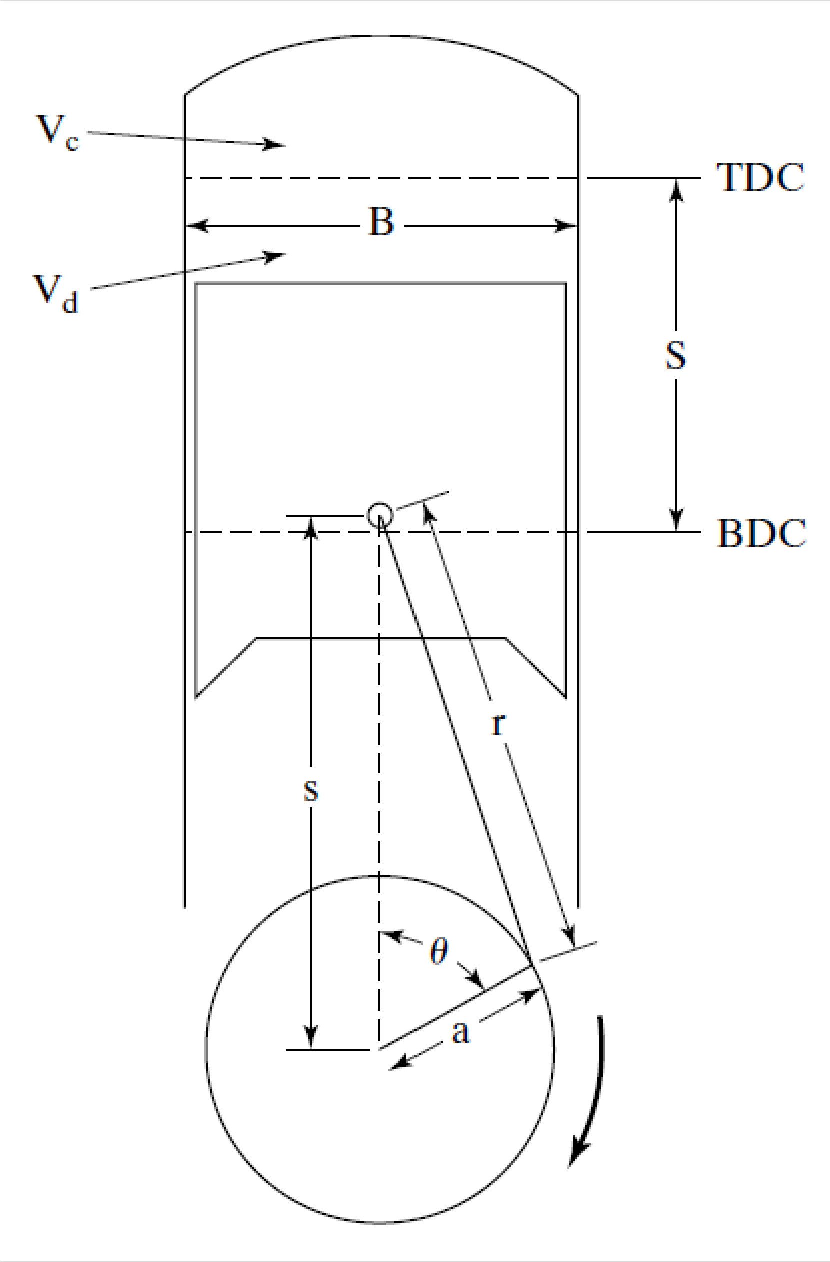
CONTENTS

- Engine Parameters
- Work
- Mean Effective Pressure
- Torque and Power / Dynamometers
- Air-Fuel Ratio and Fuel-Air Ratio
- Specific Fuel Consumption
- Engine Efficiencies and Volumetric Efficiency
- Specific Emissions

ENGINE PARAMETERS



Piston and Cylinder geometry of reciprocating engine

B = Bore

S = Stroke

r = Connecting Rod Length

a = Crank Ofset

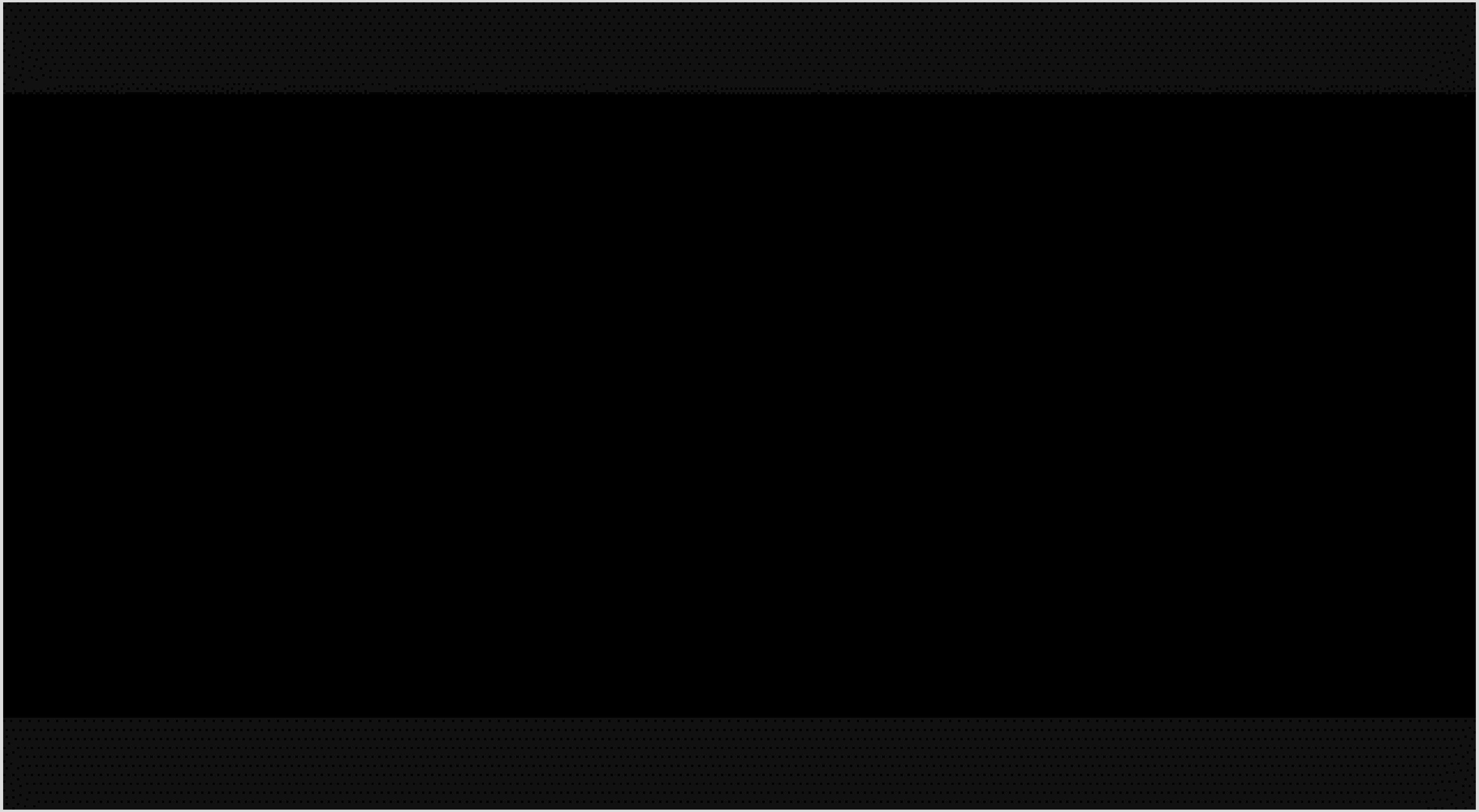
s = Piston Position

V_d = Displacement Volume

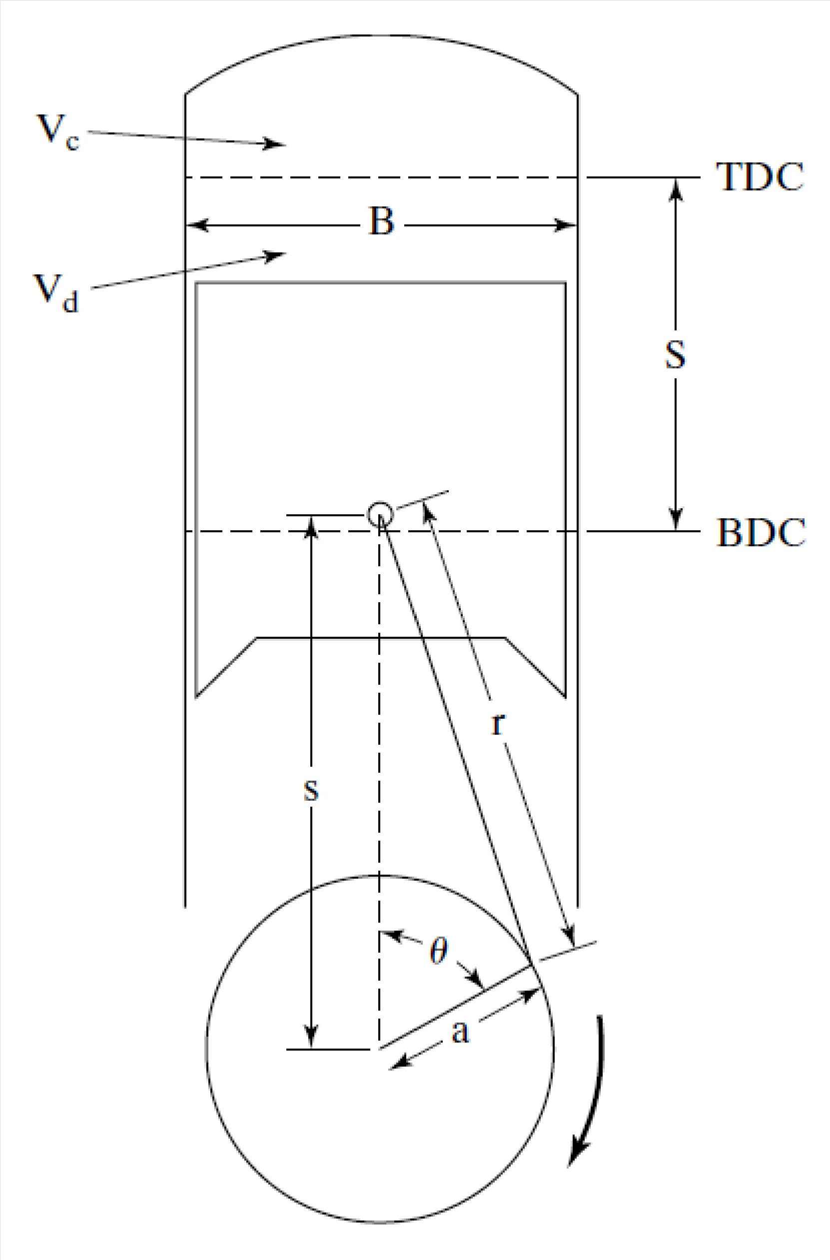
V_c =Clearance Volume

Θ = Crank Angle

ENGINE PARAMETERS



ENGINE PARAMETERS



Stroke

$$S = 2a$$

Average Piston Speed

$$\bar{U}_p = 2SN$$

__Bore Size of Engine__

0.5 m down to 0.5 cm

__B/S Ratio for small engines__

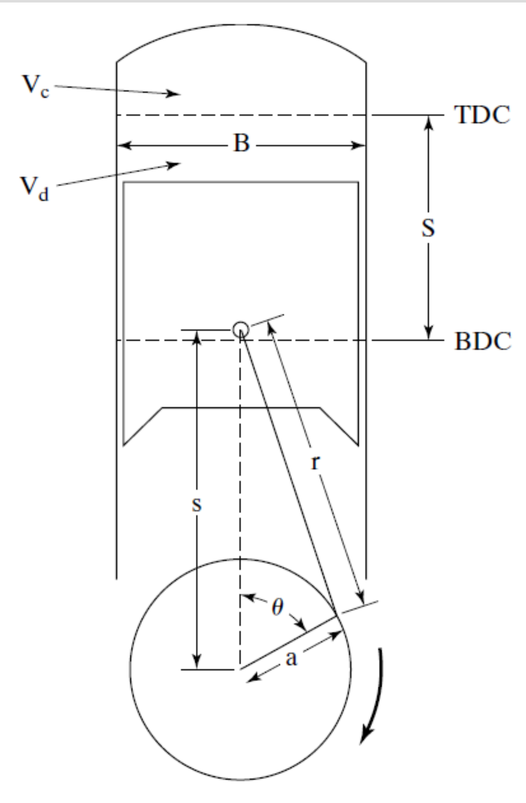
0.8 to 1.5

N is generally given in RPM (revolutions per minute), $\bar{U}_p$ in m/sec (ft/sec), and *B*, *a*, and *S* in m or cm (ft or in.).

ENGINE PARAMETERS

The distance between the crank axis and wrist pin axis is given by;

$$s = a\cos\theta + \sqrt{r^2 - a^2\sin^2\theta}$$



a = crankshaft offset
r = connecting rod length
θ = crank angle, which is measured from the cylinder centerline and is zero when the piston is at TDC

When s is differentiated with respect to time, the instantaneous piston speed;

$$U_p = ds/dt$$

The ratio of instantaneous piston speed divided by the average piston speed can then be written as;

$$U_p/\overline{U}_p = (\pi/2)\sin\theta[1 + (\cos\theta/\sqrt{R^2 - \sin^2\theta})]$$

Where;

$$R = r/a$$

R is the ratio of connecting rod length to crank offset and usually has values of 3 to 4 for small engines, increasing to 5 to 10 for the largest engines

ENGINE PARAMETERS

Displacement, or displacement volume, is the volume displaced by the piston as it travels from BDC to TDC:

$$V_d = V_{\mathrm{BDC}} - V_{\mathrm{TDC}}$$

For one cylinder,

$$V_d = (\pi/4)B^2S$$

For an engine with N cylinders,

$$V_d = N_c(\pi/4)B^2S$$

where

B = cylinder bore

S = stroke

N_c = number of engine cylinders

Typical values for engine displacement range from for small 0.1 cm^3 model airplanes, to about 8 L for large automobiles, to much larger numbers for large ship engines. The displacement of a modern average automobile engine is about 1.0 to 2.5 liters.

$$1\ \mathrm{L} = 10^{-3}\ \mathrm{m}^3 = 10^3\ \mathrm{cm}^3$$

ENGINE PARAMETERS

Minimum cylinder volume occurs when the piston is at TDC and is called the clearance volume. We have;

$$V_c = V_{\mathrm{TDC}}$$

$$V_{\mathrm{BDC}} = V_c + V_d$$

The compression ratio of an engine is defined as;

$$r_c = V_{\mathrm{BDC}}/V_{\mathrm{TDC}} = (V_c + V_d)/V_c = v_{\mathrm{BDC}}/v_{\mathrm{TDC}}$$

*Modern spark ignition (SI) engines have compression ratios of **8 to 12,** while compression ignition (CI) engines have compression ratios in the range **12 to 24**.*

ENGINE PARAMETERS

The cylinder volume at any crank angle is;

$$V = V_c + (\pi B^2/4)(r + a - s)$$

where

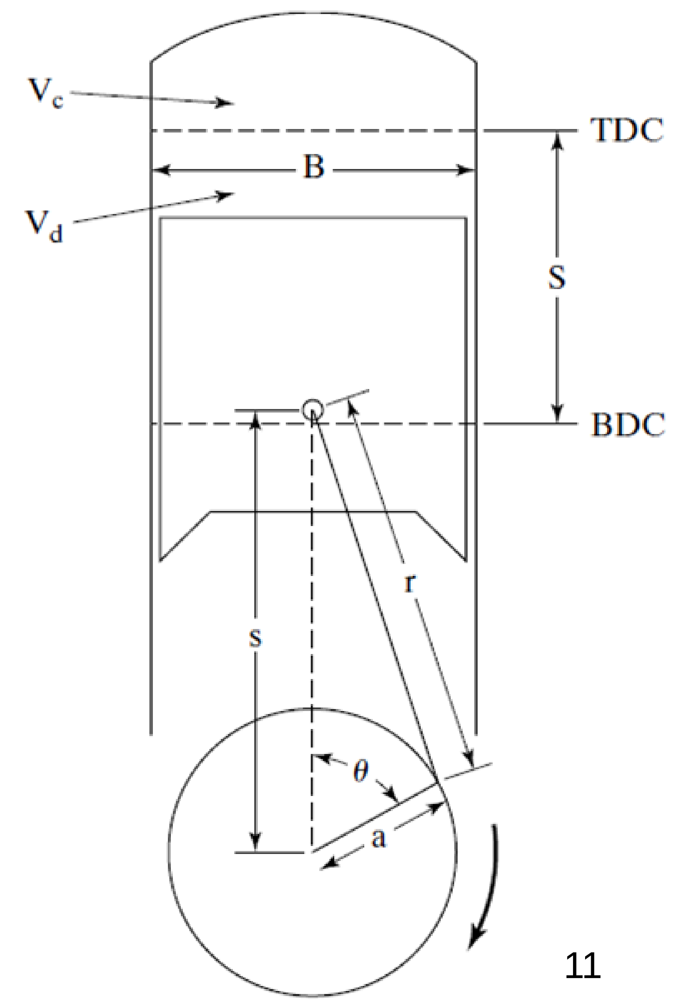
V_c = clearance volume

B = bore

r = connecting rod length

a = crank offset

s = piston position shown in Fig.



In a nondimensionel form dividing by Vc;

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

where

r_c = compression ratio

$R = r/a$

ENGINE PARAMETERS

The cross-sectional area of a cylinder and the surface area of a flat-topped piston are each given by;

$$A_p = (\pi/4)B^2$$

The combustion chamber surface area is;

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

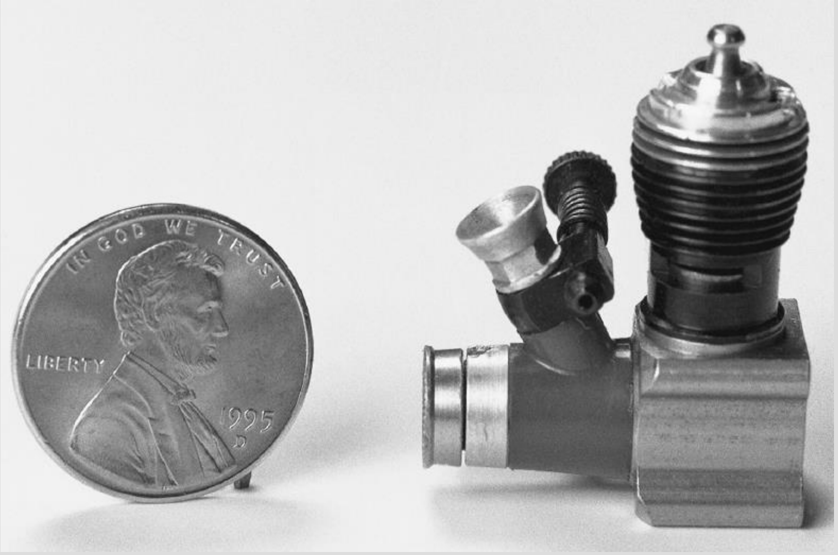
where A_{ch} is the cylinder head surface area, which will be somewhat larger than A_p Then if the definitions for r, a, s, and R are used previous Eq. can be rewritten as;

$$A = A_{ch} + A_p + (\pi BS/2)[R + 1 - \cos\theta - \sqrt{R^2 - \sin^2\theta}]$$

ENGINE PARAMETERS

TABLE ypical Engine Operating Parameters

	Model Airplane Two-Stroke Cycle	Automobile Four-Stroke Cycle	Large Stationary Two-Stroke Cycle
Bore (cm)	2.00	9.42	50.0
Stroke (cm)	2.04	9.89	161
Displacement/cyl (L)	0.0066	0.69	316
Speed (RPM)	13,000	5200	125
Power/cyl (kW)	0.72	35	311
Average Piston Speed (m/sec)	8.84	17.1	6.71
Power/Displacement (kW/L)	109	50.7	0.98
bmep (kPa)	503	1170	472



Cox air-cooled, single cylinder, two-stroke cycle model airplane engine. Engine has displacement of 0.01 cubic inches (0.164 cm^3)

ENGINE PARAMETERS

Example Problem 1

John's automobile has a three-liter SI V6 engine that operates on a four-stroke cycle at 3600 RPM. The compression ratio is 9.5, the length of the connecting rods is 16.6 cm, and the engine is square $(B = S)$. At this speed, combustion ends at 20° aTDC.
Calculate:

1. cylinder bore and stroke length
2. average piston speed
3. clearance volume of one cylinder
4. piston speed at the end of combustion
5. distance the piston has traveled from TDC at the end of combustion
6. volume in the combustion chamber at the end of combustion

WORK

Work is the output of any heat engine, and in a reciprocating IC engine this work is generated by the gases in the combustion chamber of the cylinder. Work is the result of a force acting through a distance. That is, the force due to gas pressure on the moving piston generates the work in an IC engine cycle.

$$W = \int F dx = \int P A_p dx$$

A_p = area against which the pressure acts (i.e., the piston face)
x = distance the piston moves

dV is the differential volume displaced by the piston as it travels a distance d/x, so the work done can be written;

$$W = \int P\, dV$$

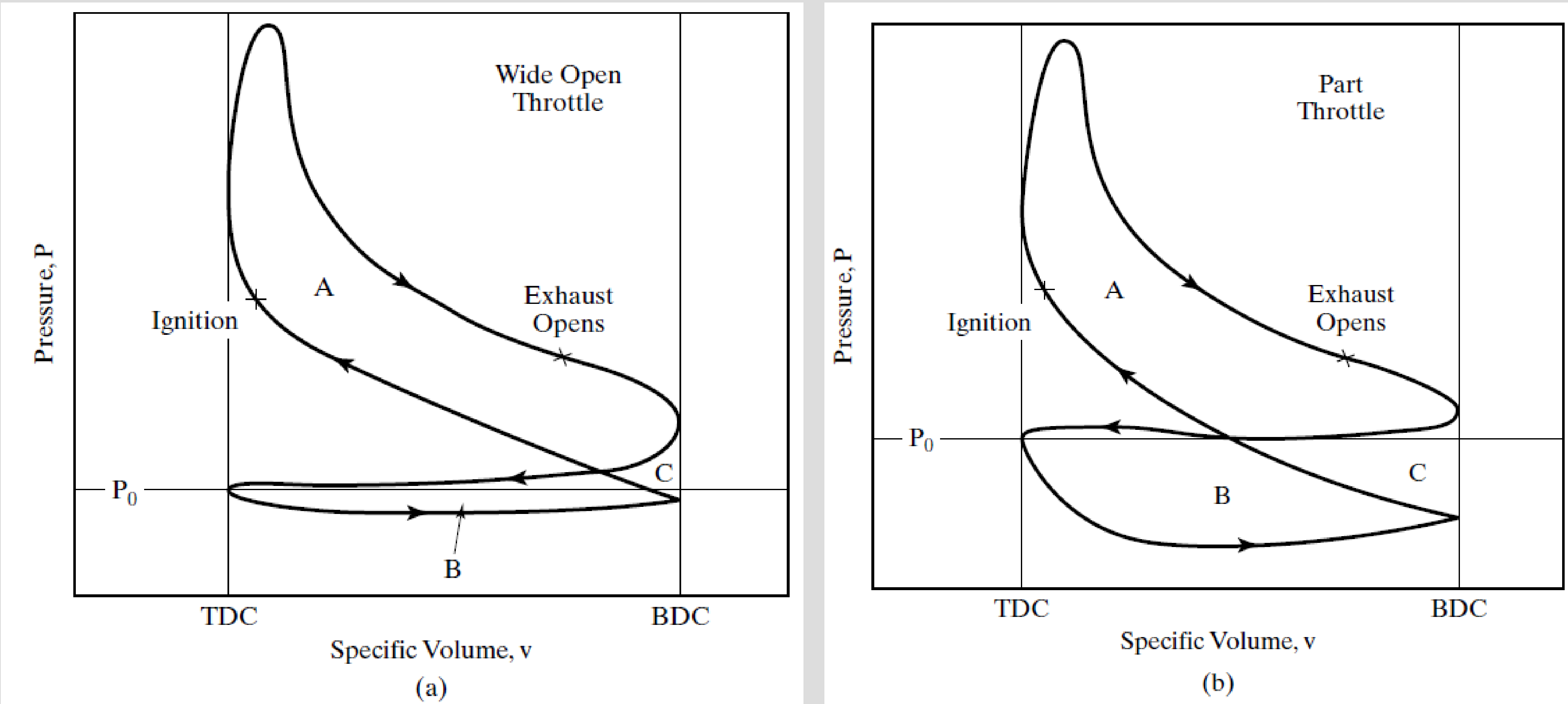
Because engines are often multicylinder, it is convenient to analyze engine cycles per unit mass of gas m within the cylinder. To do so, volume V is replaced with Specific volume and work is replaced with specific work:

$$w = W/m \qquad v = V/m$$

WORK

$$W = \int P\, dV$$

The specific work is equal to the ***area under the process lines P-v*** on the coordinates of Figure below.



TERMINOLOGY AND ABBREVIATIONS

Wide-Open Throttle (WOT) :Engine operated with throttle valve fully open when maximum power and/or speed is desired.

WORK

The work inside the combustion chamber. This is called ***indicated work***. Work delivered by the crankshaft is less than indicated work, due to mechanical friction and parasitic loads of the engine.

Parasitic loads include the oil pump, supercharger, air conditioner compressor, alternator, etc. Actual work available at the crankshaft is called **brake work**,

$$w_b = w_i - w_f$$

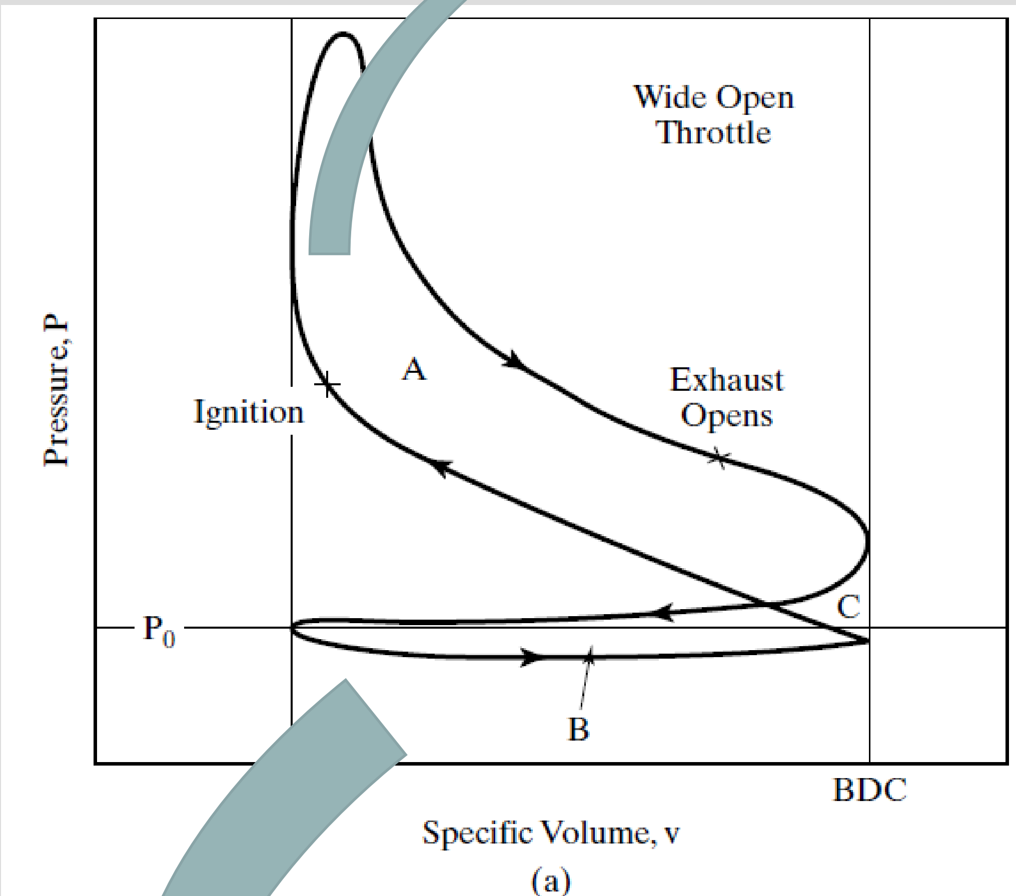
where

w_i = indicated specific work generated inside combustion chamber

w_f = specific work lost due to friction and parasitic loads

Units of specific work will be kJ/kg or BTU/lbm.

WORK



Definitions:

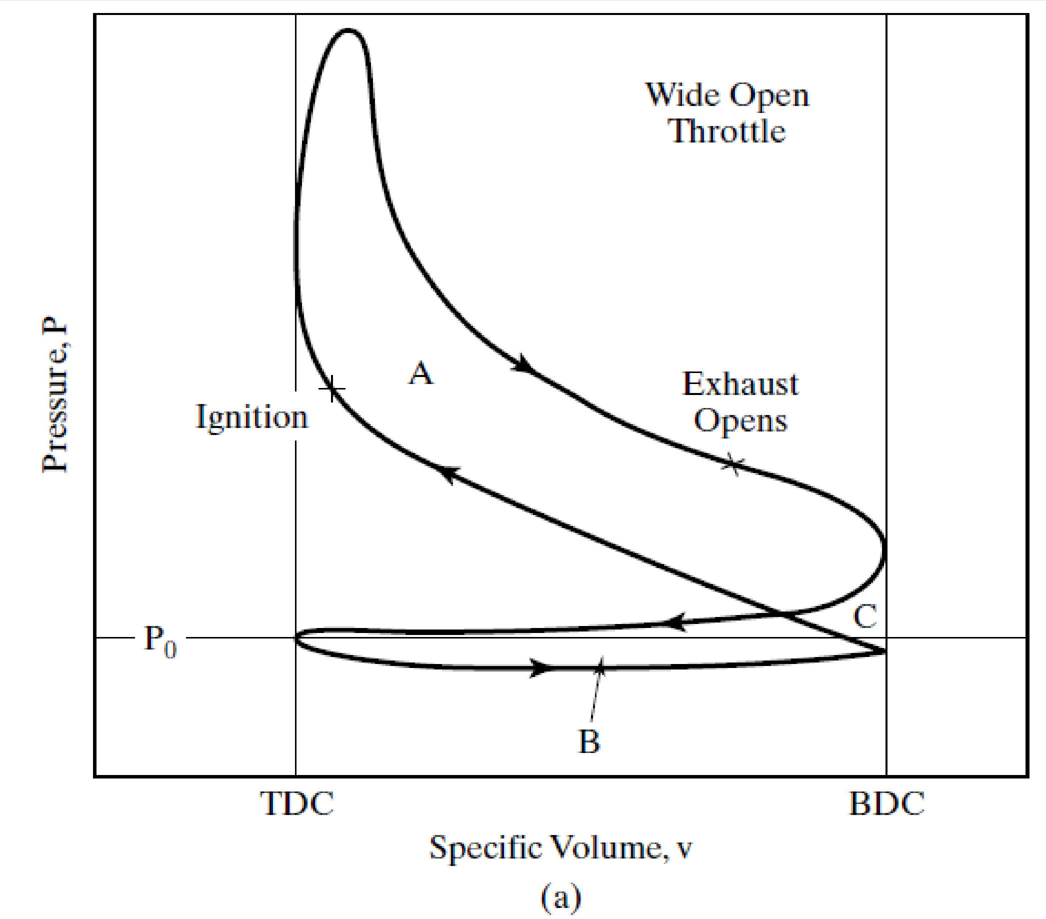
Gross Indicated Work
Net Indicated Work
Pump Work
Friction Work
Brake Work

The upper loop of the engine cycle in Fig. consists of the compression and power strokes where output work is generated and is called;

Gross indicated work :
areas A and C in Fig .

The lower loop, which includes the **intake and exhaust strokes**, is called **pump work** and absorbs work from the engine
Pump Work : areas B and C in Fig.

WORK



Four-stroke cycle of typical SI engine plotted on P-v coordinates at wide open throttle; The upper loop consists of the compression stroke and power stroke and the area represents gross indicated work. The lower loop represents negative work of the intake stroke and exhaust stroke. This is called indicated pump work.

Net indicated work is;

$$w_{net} = w_{gross} + w_{pump}$$

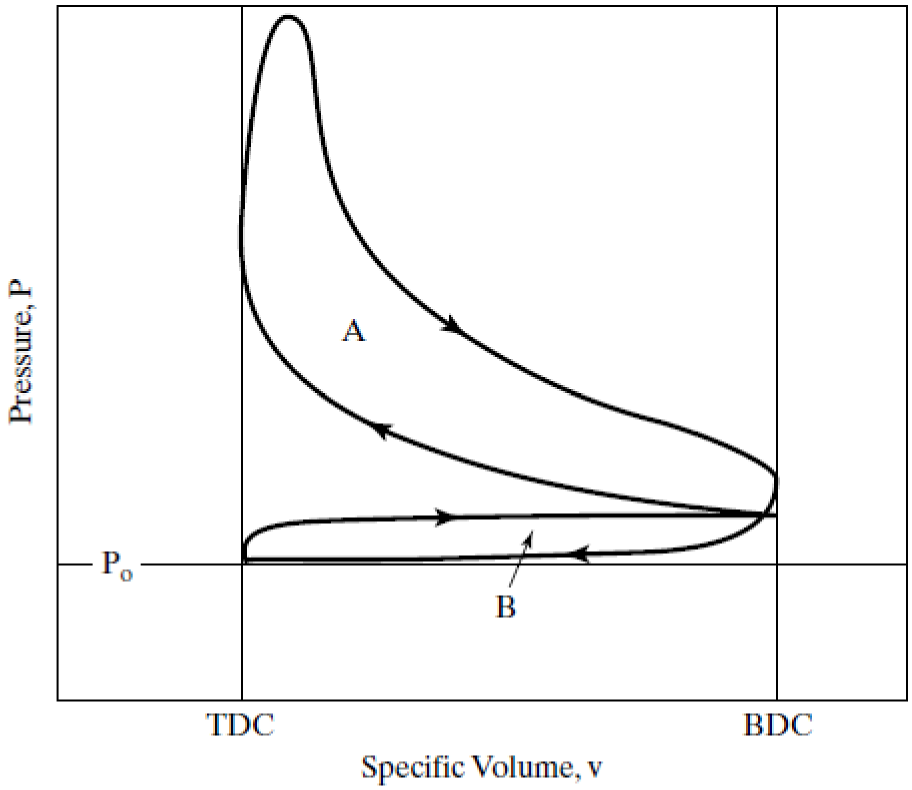
Pump work w_{pump} is negative for engines without superchargers, so

$$w_{net} = (\text{Area A}) - (\text{Area B})$$

Engines with superchargers or turbochargers can have intake pressure greater than exhaust pressure, giving a **positive pump work.**

$$w_{net} = (\text{Area A}) + (\text{Area B}) \qquad (26)$$

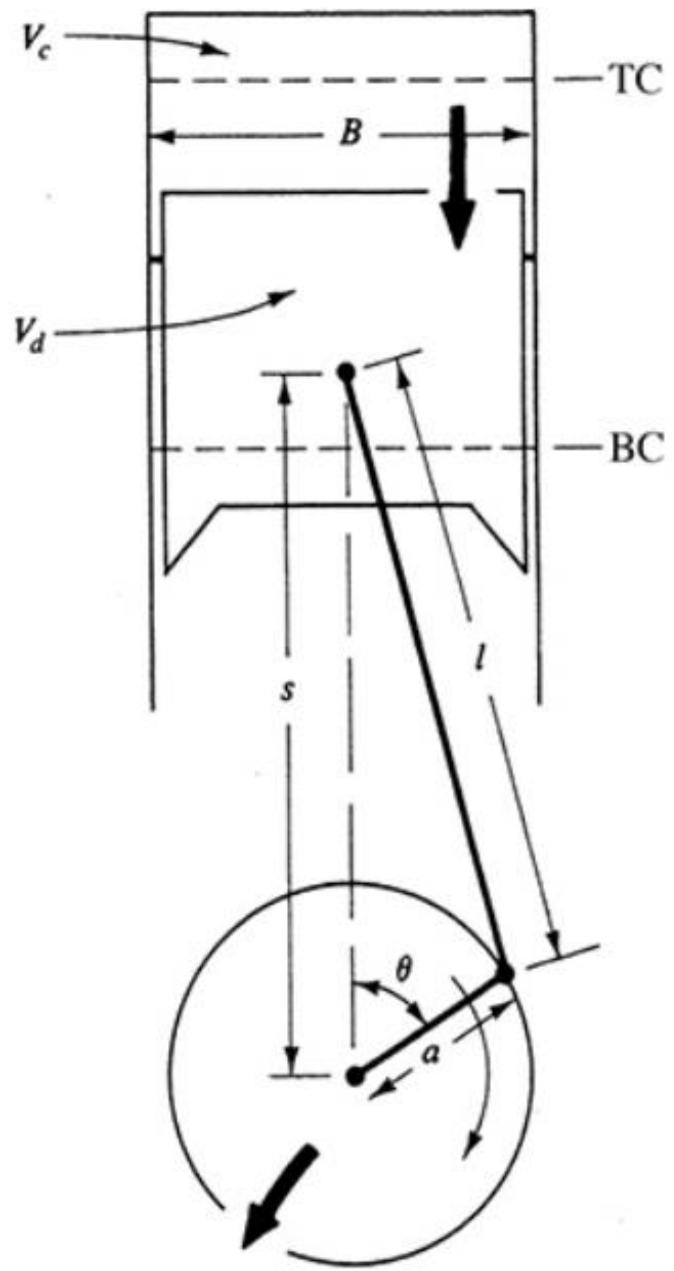
Superchargers increase net indicated work but add to the friction work of the engine since they are driven by the crankshaft.



Four-stroke cycle of an SI engine equipped with a supercharger or turbocharger, plotted on P-v coordinates.

For this cycle, intake pressure is greater than exhaust pressure and the pump work loop represents positive work.

Summary of the work produced and consumed inside the engine;



Indicated work per cycle:
Transferred from in-cylinder gas to piston

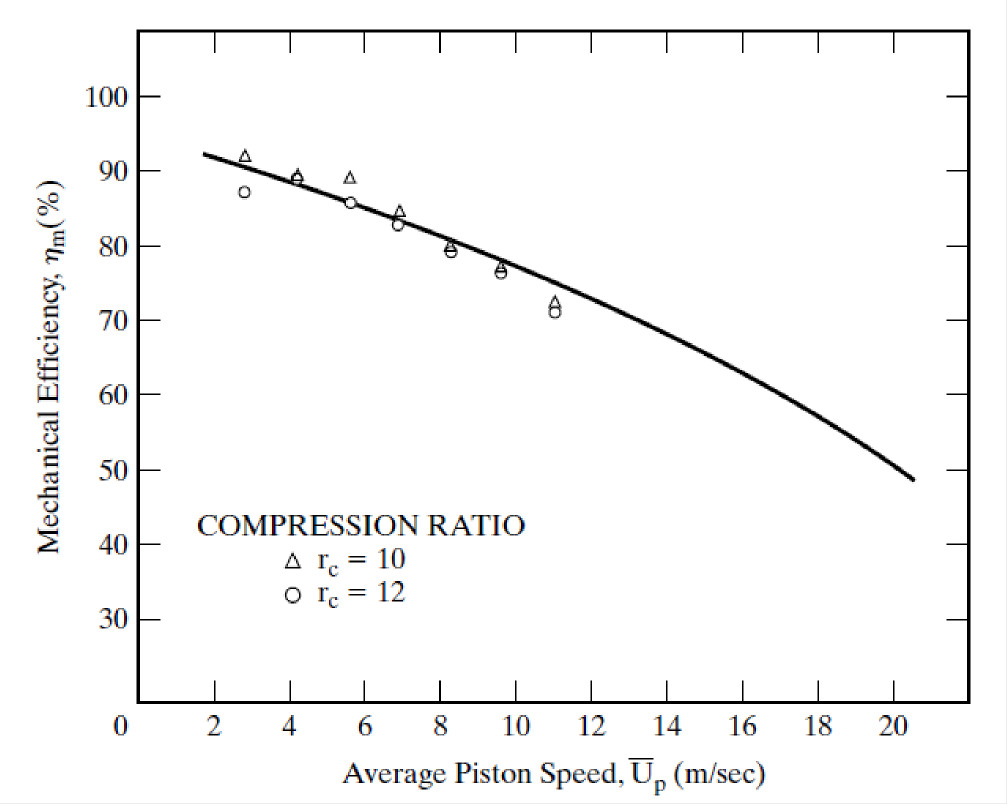
Friction work per cycle:
Mechanical/rubbing friction
Work to drive essential accessories
(Pumping work, NA engines)

Brake (useable) work per cycle:
Transferred to drive shaft

WORK

The ratio of brake work at the crankshaft to indicated work in the combustion chamber defines the ***mechanical efficiency*** of an engine:

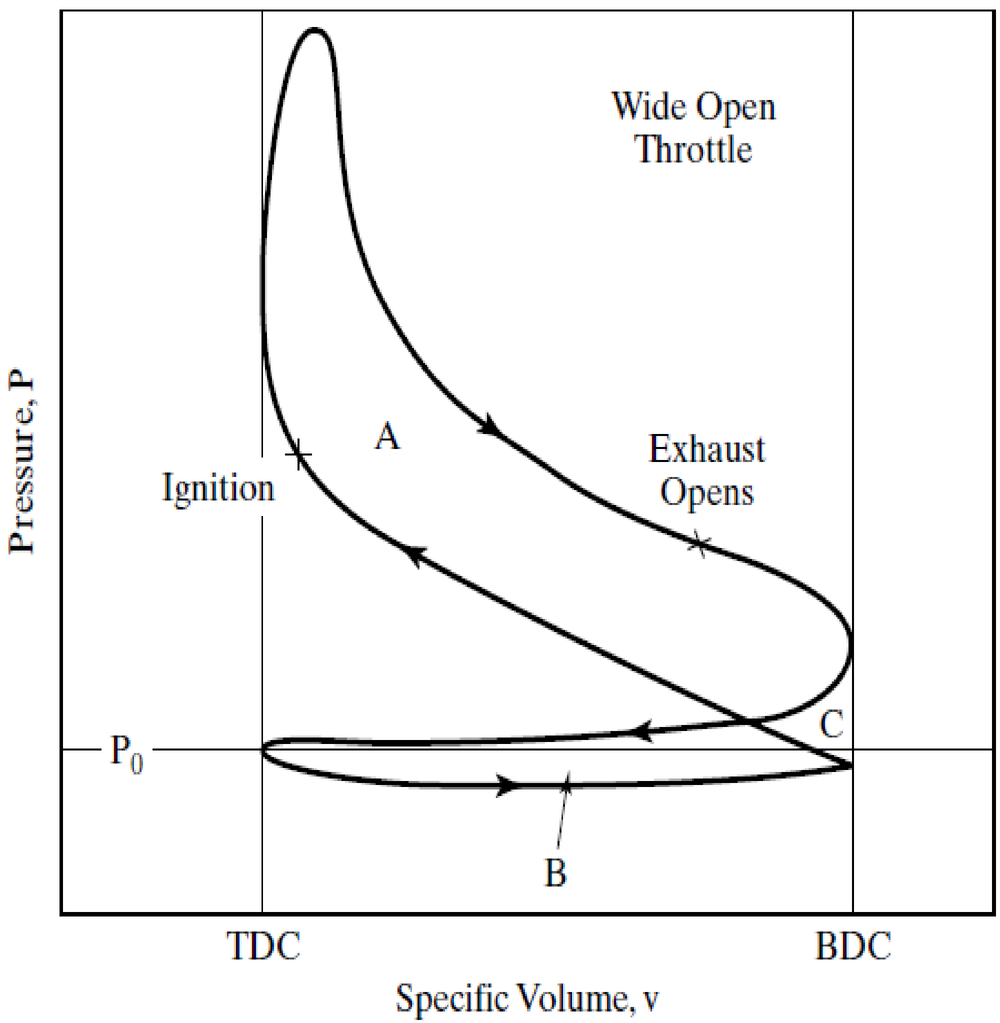
$$\eta_m = w_b/w_i = W_b/W_i$$



Mechanical and fluid friction are the greatest energy losses at high speed, while heat loss is the greatest loss at low speed.

MEAN EFFECTIVE PRESSURE

It can be seen that **pressure** in the cylinder of an engine is **continuously changing during the cycle**. An average or **mean effective pressure (mep)** is defined by;



(a)

$$w = (\text{mep})\Delta v$$

$$\text{mep} = w/\Delta v = W/V_d$$

$$\Delta v = v_{\text{BDC}} - v_{\text{TDC}}$$

where

W = work of one cycle

w = specific work of one cycle

V_d = displacement volume

Various mean effective pressures can be defined by using different work terms in Eqn.

MEAN EFFECTIVE PRESSURE

If brake work is used, **brake mean effective pressure** is obtained:

$$\text{bmep} = w_b/\Delta v$$

Indicated work gives **indicated mean effective pressure.**

$$\text{imep} = w_i/\Delta v$$

The **imep** can further be divided into **gross indicated mean effective pressure** and **net indicated mean effective pressure**:

$$(\text{imep})_{\text{gross}} = (w_i)_{\text{gross}}/\Delta v$$
$$(\text{imep})_{\text{net}} = (w_i)_{\text{net}}/\Delta v$$

Pump mean effective pressure (which can have negative values) is given by

$$\text{pmep} = w_{\text{pump}}/\Delta v$$

and **friction mean effective pressure** is given by

$$\text{fmep} = w_f/\Delta v$$

MEAN EFFECTIVE PRESSURE

Mean effective pressure is a **good parameter for comparing engines with regard to design or output because it is independent of both engine size and speed**. If torque is used for engine comparison, a larger engine will always look better. If power is used as the comparison, speed becomes very important.

The following equations relate some of the previous definitions:

$$\text{nmep} = \text{gmep} + \text{pmep} \qquad \text{(a)}$$

$$\text{bmep} = \text{nmep} - \text{fmep} \qquad \text{(b)}$$

$$\text{bmep} = \eta_m \, \text{imep} \qquad \text{(c)}$$

$$\text{bmep} = \text{imep} - \text{fmep} \qquad \text{(d)}$$

Typical maximum values of bmep for naturally aspirated SI engines are in the range of **850 to 1050 kPa.**

For CI engines, typical maximum values are **700 to 900 kPa** for naturally aspirated engines and **1000 to 1200 kPa** for turbocharged engines.

TORQUE AND POWER

Torque is a good indicator of an engine's ability **to do work**. It is defined as force acting at a moment distance and has units of N-m in SI Unit system. Torque is related to work by;

$$2\pi\tau = W_b = (\text{bmep})\, V_d/n$$

where

W_b = brake work of one revolution
V_d = displacement volume
n = number of revolutions per cycle

For a two-stroke cycle engine with one cycle for each revolution,

$$2\pi\tau = W_b = (\text{bmep})V_d$$

$$\tau = (\text{bmep})V_d/2\pi \qquad \text{two-stroke cycle}$$

For a four-stroke cycle engine that takes two revolutions per cycle,

$$\tau = (\text{bmep})V_d/4\pi \qquad \text{four-stroke cycle}$$

TORQUE AND POWER

Power is defined as the rate of work of the engine. If n = of revolutions per cycle and N = engine speed, then;

$$\dot{W} = WN/n$$

$$\dot{W} = 2\pi N\tau$$

$$\dot{W} = (1/2n)(\text{mep})A_p\overline{U}_p$$

$$\dot{W} = (\text{mep})A_p\overline{U}_p/4 \qquad \text{four-stroke cycle}$$

$$\dot{W} = (\text{mep})A_p\overline{U}_p/2 \qquad \text{two-stroke cycle}$$

where

W = work per cycle

A_p = piston face area of all pistons

$\overline{U}_p$ = average piston speed

Depending upon which definition of work or **mep** is used in Eqns., power can be defined as ***brake power***, ***net indicated power***, ***gross indicated power***, ***pumping power***, and even ***friction power***. Also,

$$\dot{W}_b = \eta_m \dot{W}_i$$

$$(\dot{W}_i)_{\text{net}} = (\dot{W}_i)_{\text{gross}} - (\dot{W}_i)_{\text{pump}}$$

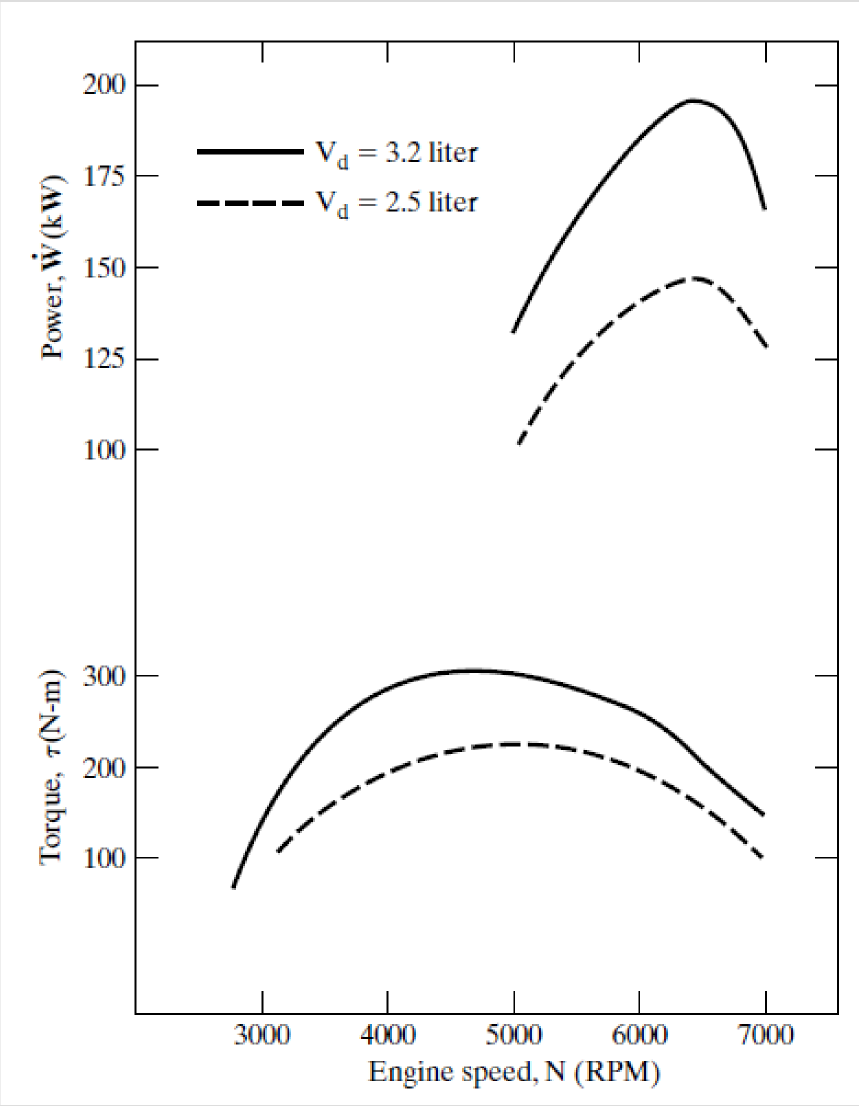
$$\dot{W}_b = \dot{W}_i - \dot{W}_f$$

$$1\ \text{hp} = 0.7457\ \text{kW}$$

$$1\text{kW} = 1.341\ \text{hp}$$

TORQUE AND POWER

The point of maximum torque is called **maximum brake torque speed** (MBT). A major goal in the design of a modern automobile engine is to flatten the torque-versus-speed curve as shown in Fig.



Brake power and torque of a typical automobile reciprocating engine as a function of engine speed and displacement.

Speed at which peak torque occurs is called **maximum brake torque (MBT) (or maximum best torque)**.

Indicated power increases with speed while brake power increases to a maximum and then decreases. This is because friction increases with engine speed to a higher power and becomes dominant at higher speeds.

TORQUE AND POWER

Other ways which are sometimes used to classify engines are as follows:

specific power	$SP = \dot{W}_b / A_p$
output per displacement	$OPD = \dot{W}_b / V_d$
specific volume	$SV = V_d / \dot{W}_b$
specific weight	$SW = (\text{engine weight}) / \dot{W}_b$

where

$\dot{W}_b$ = brake power

A_p = piston face area of all pistons

V_d = displacement volume

These parameters are important for engines used in transportation vehicles such as boats, automobiles, and especially airplanes, **where keeping weight to a minimum is necessary**. For large stationary engines, weight is not as important.

Example Problem 3

When a three-cylinder, four-stroke cycle, SI engine, operating at 4000 RPM is connected to an eddy current dynamometer, 70.4 kW of power is dissipated by the dynamometer. The engine has a total displacement volume of 2.4 liters and a mechanical efficiency of 82% at 4000 RPM. Because of heat and mechanical losses, the dynamometer has an efficiency of 93%. η_{dyno} = (power recorded by dynamometer)/(actual power from engine).
Calculate:

1. power lost to friction in engine
2. brake mean effective pressure
3. engine torque at 4000 RPM
4. engine specific volume

TORQUE AND POWER / DYNAMOMETERS

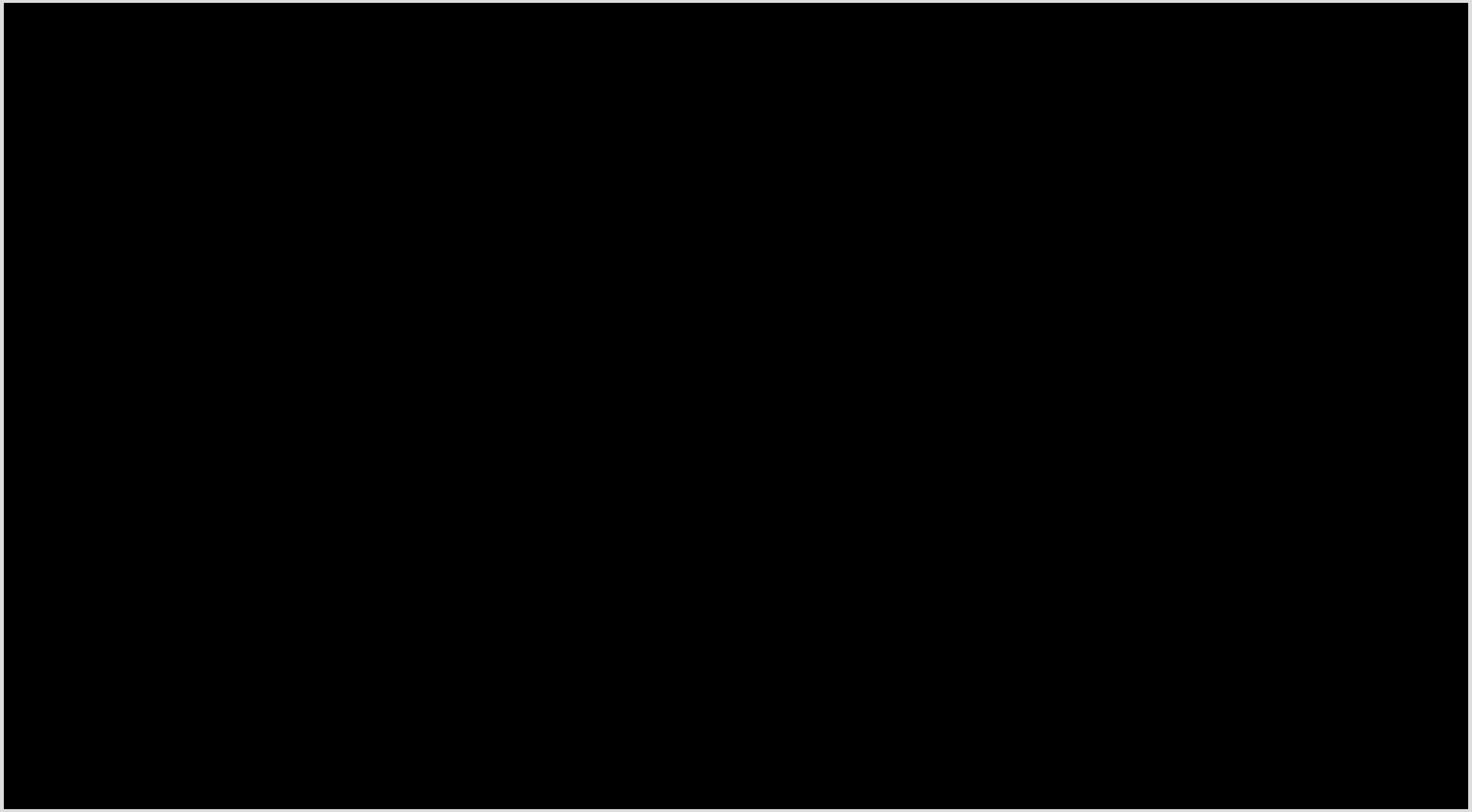
Dynamometers are used to measure **torque and power** over the engine operating ranges of speed and load. They do this by using various methods to absorb the energy output of the engine, all of which eventually ends up as heat.

Fluid or hydraulic dynamometers absorb engine energy in water or oil pumped through orifices or dissipated with viscous losses in a rotor–stator combination.

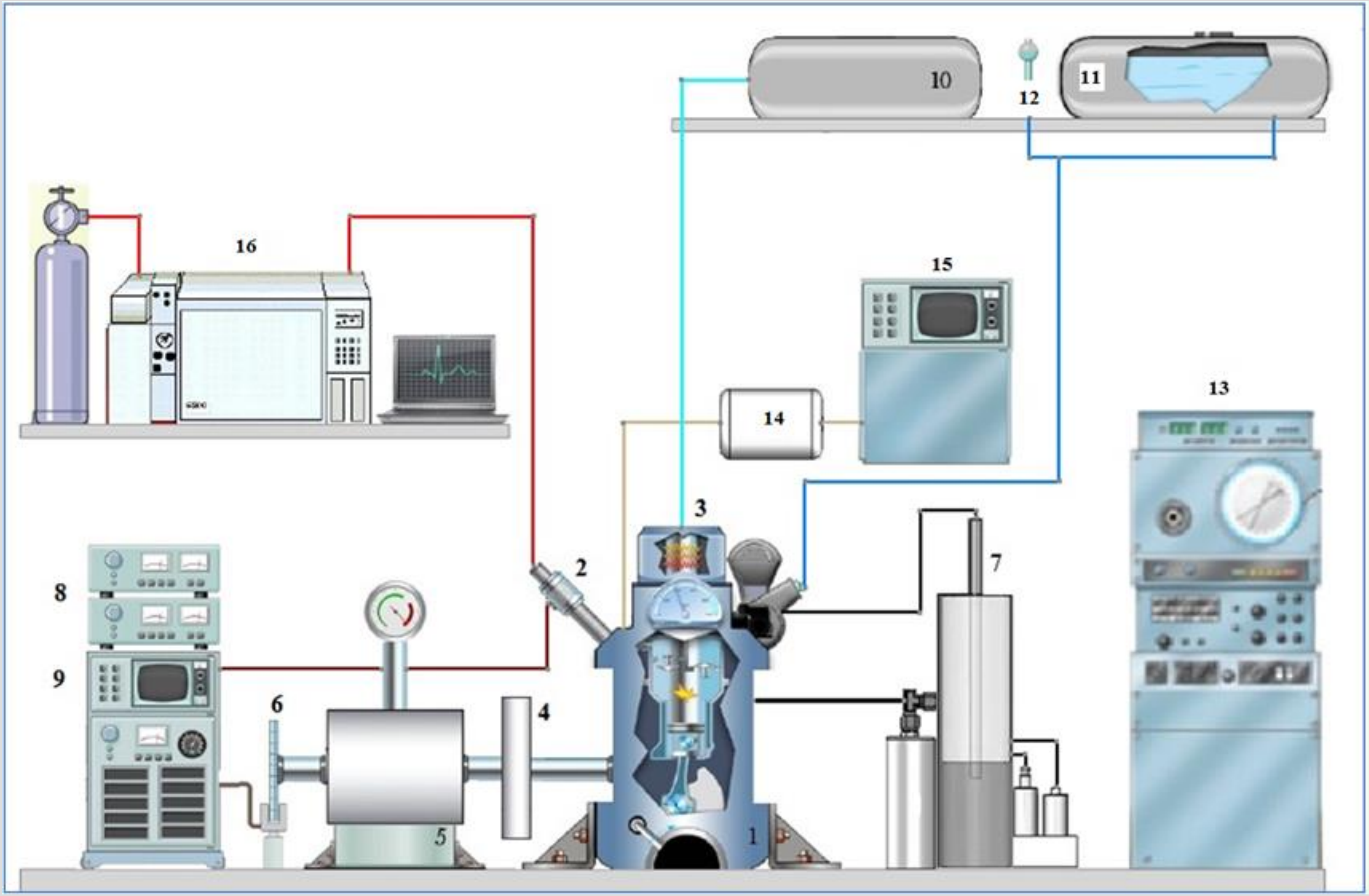
Eddy current dynamometers use a disk, driven by the engine being tested, rotating in a magnetic field of controlled strength. The rotating disk acts as an electrical conductor cutting the lines of magnetic flux and producing eddy currents in the disk.

One of the best types of dynamometer is the **electric dynamometer**, which absorbs energy with electrical output from a connected generator. Many electric dynamometers can also be operated in reverse, with the generator used as a motor to drive (or motor) an unfired engine.

This allows the engine to **be tested for mechanical friction losses and air pumping losses**, quantities that are hard to measure on a running fired engine.

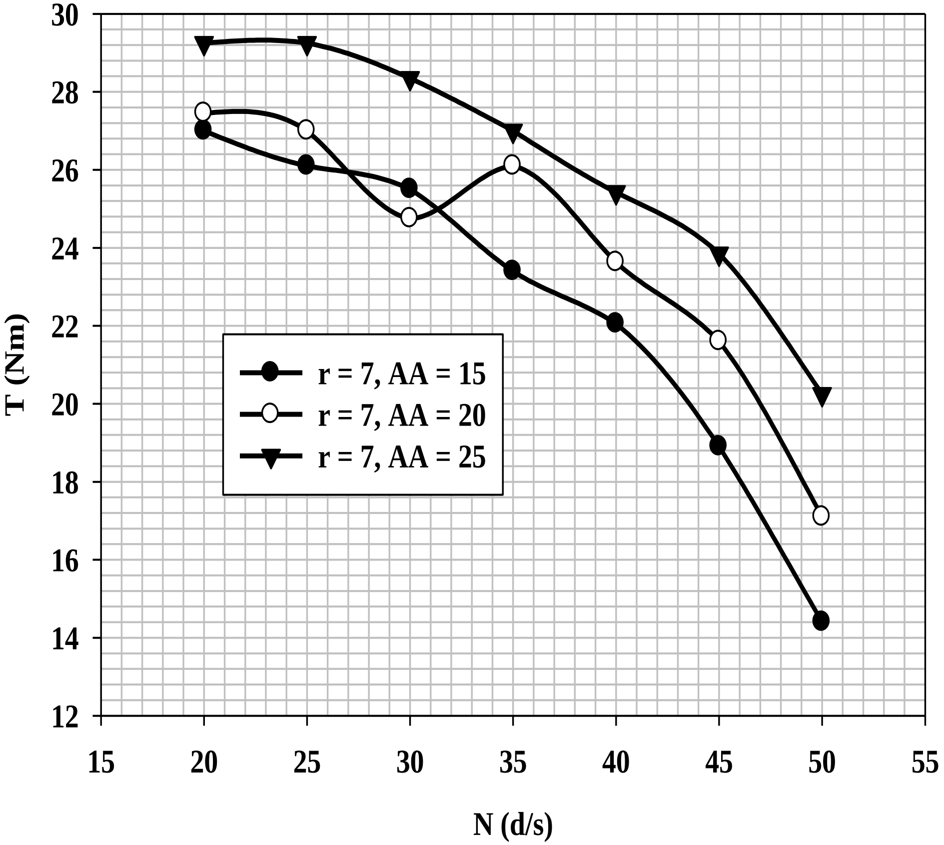


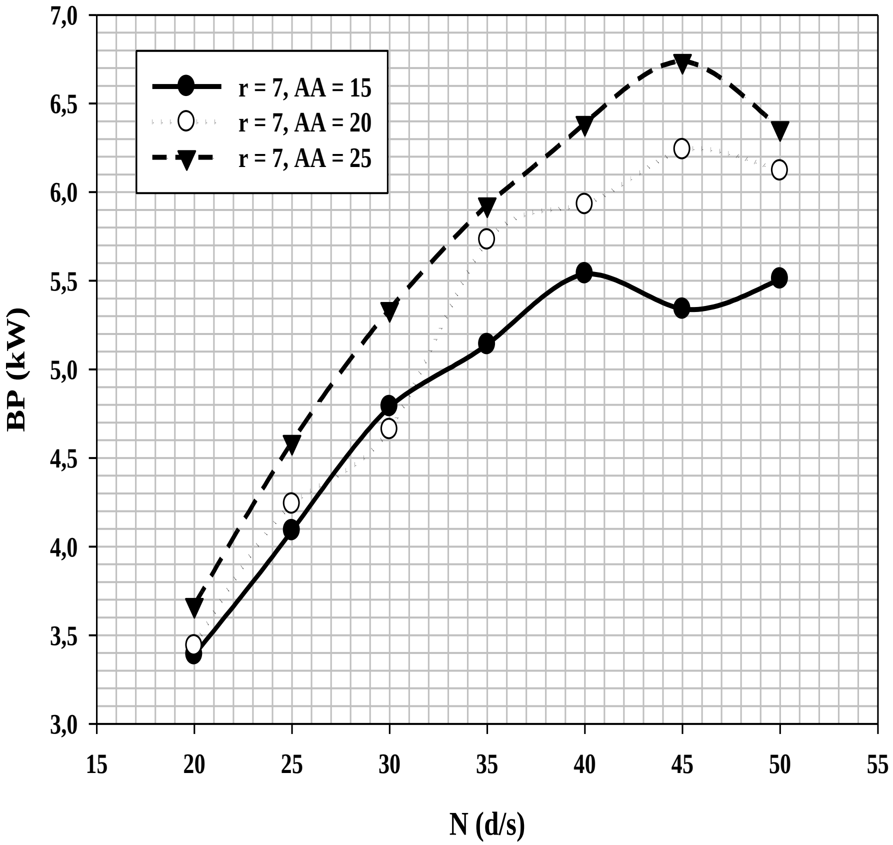
TORQUE AND POWER / DYNAMOMETERS



Schematic view of experimental set-up
Part of the Phd. Thesis of S. Karaaslan

TORQUE AND POWER / DYNAMOMETERS





General engine performance results measuring the engine Torque and Power with respect to different engine speed by using electrical dynamometer

Part of the Phd. Thesis of S. Karaaslan

AIR - FUEL RATIO AND FUEL - AIR RATIO

Energy input to an engine Q_{in} comes from the combustion of a hydrocarbon fuel. Air is used to supply the oxygen needed for this chemical reaction. For combustion reaction to occur, the proper relative amounts of air (oxygen) and fuel must be present. **Air–fuel ratio (AF) and fuel–air ratio (FA)** are parameters used to describe the mixture ratio. We have;

$$AF = m_a/m_f = \dot{m}_a/\dot{m}_f$$
$$FA = m_f/m_a = \dot{m}_f/\dot{m}_a = 1/AF$$

m_a = mass of air
$\dot{m}_a$ = mass flow rate of air
m_f = mass of fuel
$\dot{m}_f$ = mass flow rate of fuel

The ideal or stoichiometric AF for many **gasoline-type hydrocarbon fuels** is very close to 15:1, with combustion possible for values in the range of 6 to 25

AF less than 6 is ***too rich*** to sustain combustion and AF greater than 25 is ***too lean***.

Equivalence ratio is defined as the actual ratio of fuel–air to ideal or stoichiometric fuel–air:

$$\phi = (FA)_{act}/(FA)_{stoich} = (AF)_{stoich}/(AF)_{act}$$

$$\lambda = 1/\phi = (FA)_{stoich}/(FA)_{act} = (AF)_{act}/(AF)_{stoich}$$

AIR - FUEL RATIO AND FUEL - AIR RATIO

- CI engines typically have AF input in the range of **18 to 70**, which appears to be outside the limits within which combustion is possible.
- Combustion occurs because the cylinder of a CI engine, unlike an SI engine, has a very nonhomogeneous air–fuel mixture, with reaction occurring only in those regions in which a combustible mixture exists, other regions being too rich or too lean.

SPECIFIC FUEL CONSUMPTION

Specific fuel consumption is defined as

$$\text{sfc} = \dot{m}_f / \dot{W}$$

where

$$\dot{m}_f = \text{rate of fuel flow into engine}$$
$$\dot{W} = \text{engine power}$$

Brake power gives the **brake specific fuel consumption**:

$$\text{bsfc} = \dot{m}_f / \dot{W}_b$$

Indicated power gives **indicated specific fuel consumption**:

$$\text{isfc} = \dot{m}_f / \dot{W}_i$$

SPECIFIC FUEL CONSUMPTION

Other examples of specific fuel consumption parameters can be defined as follows:

$$\begin{aligned} \text{fsfc} &= \text{friction specific fuel consumption} \\ \text{igsfc} &= \text{indicated gross specific fuel consumption} \\ \text{insfc} &= \text{indicated net specific fuel consumption} \\ \text{psfc} &= \text{pumping specific fuel consumption} \end{aligned}$$

It also follows that

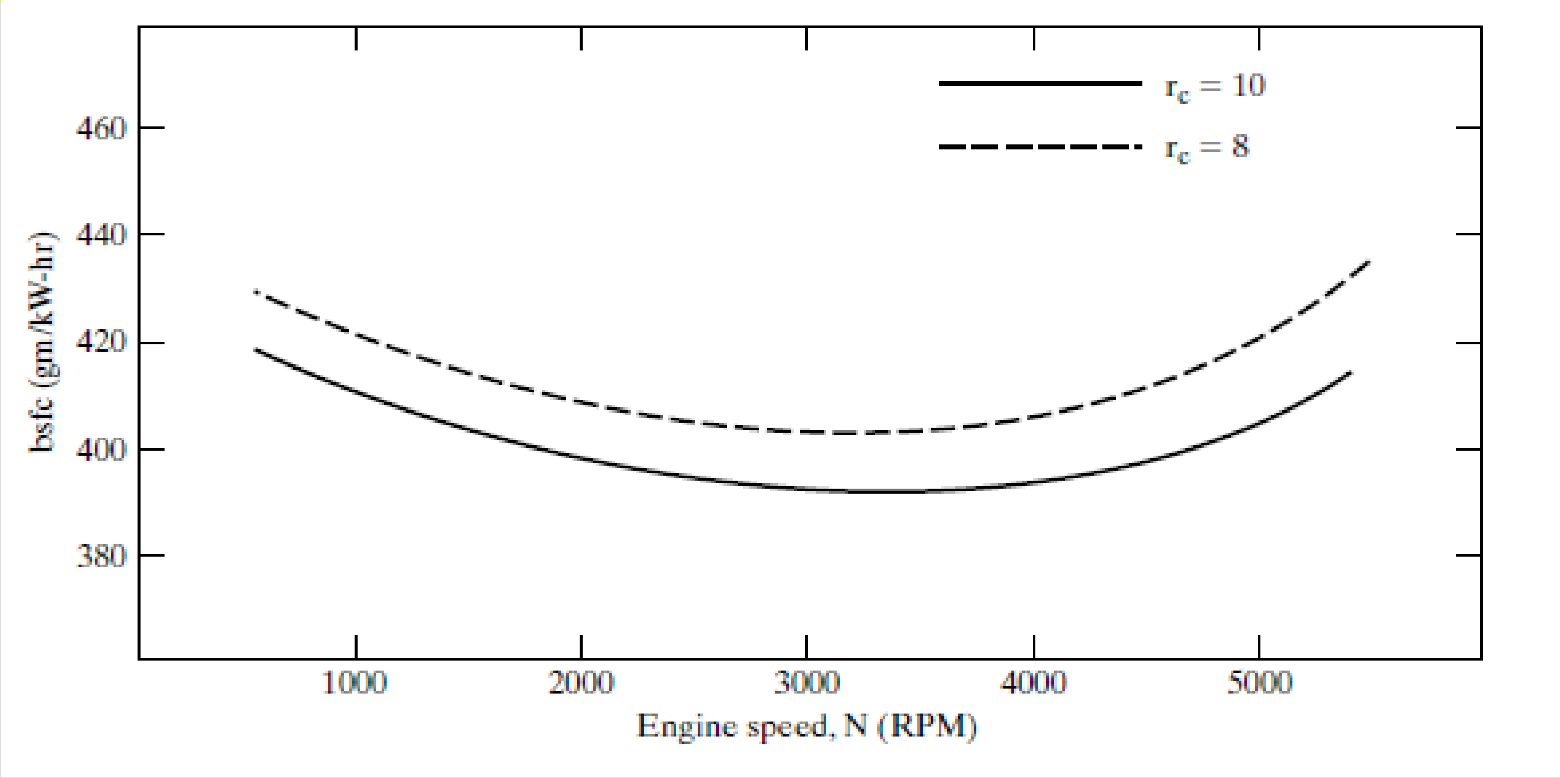
$$\eta_m = \dot{W}_b/\dot{W}_i = (\dot{m}_f/\dot{W}_i)/(\dot{m}_f/\dot{W}_b) = (\text{isfc})/(\text{bsfc})$$

where

$$\eta_m = \text{mechanical efficiency of the engine}$$

SPECIFIC FUEL CONSUMPTION

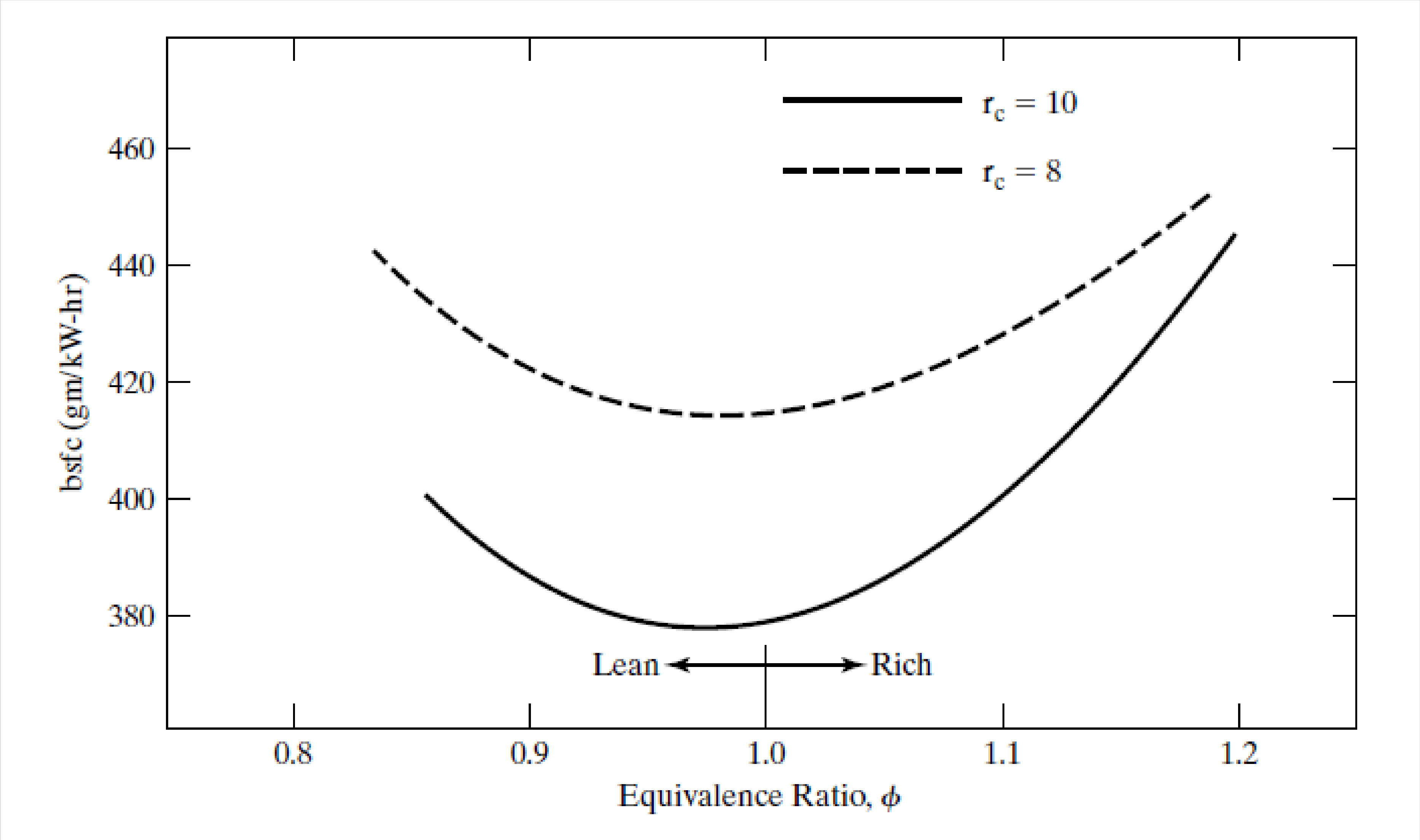
Brake specific fuel consumption decreases as engine speed increases, reaches a minimum, and then increases at high speeds.



Fuel consumption decreases as engine speed increases due to the shorter time for heat loss during each cycle. At higher engine speeds fuel consumption again increases **because of high friction losses**.

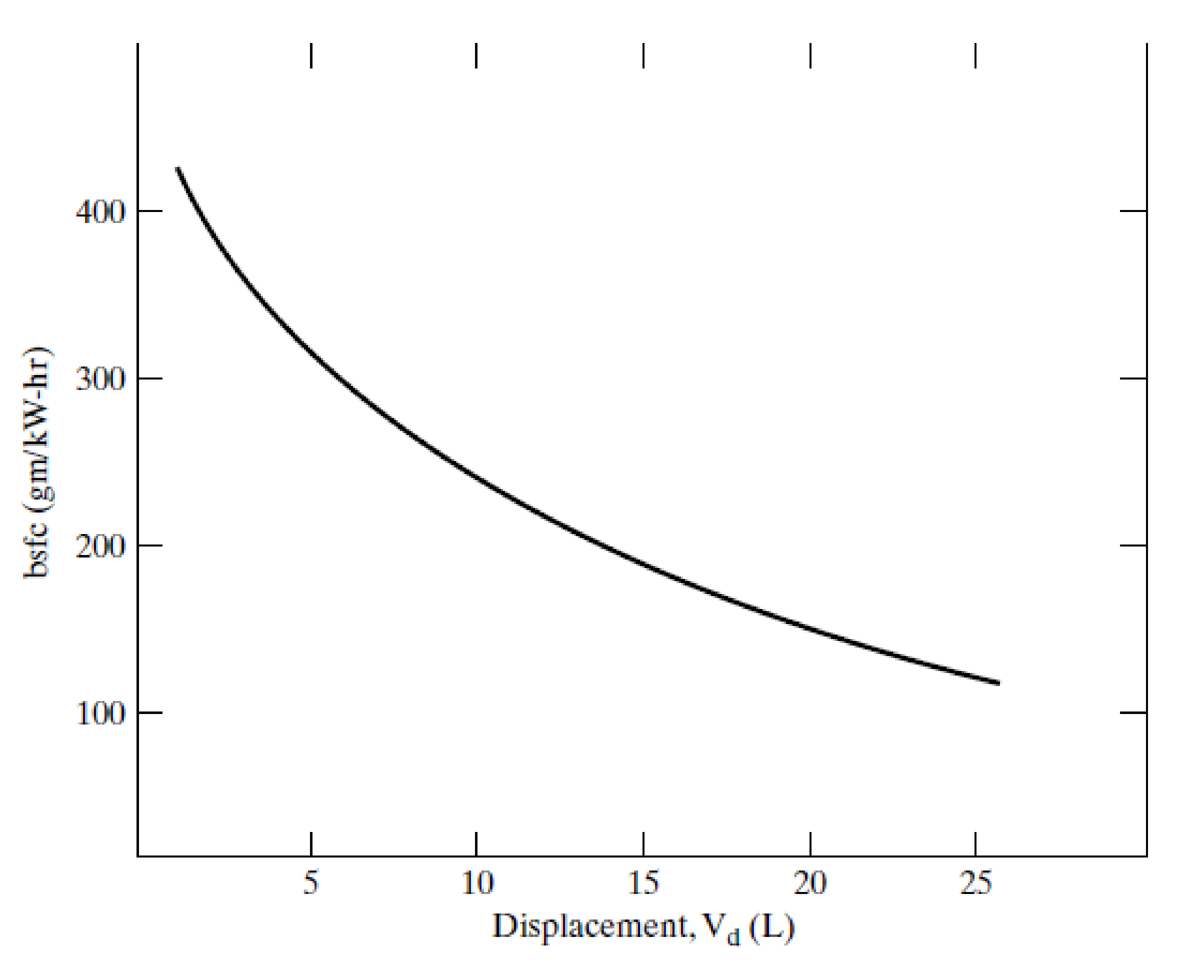
As compression ratio is increased fuel consumption decreases due to greater thermal efficiency.

SPECIFIC FUEL CONSUMPTION



Brake specific fuel consumption as a function of fuel equivalence ratio. Consumption is minimum at a slightly lean condition, increasing with both richer and leaner mixtures.

SPECIFIC FUEL CONSUMPTION



Brake specific fuel consumption as a function of engine displacement.
Generally, average fuel consumption is less with larger engines. One reason for this is less heat loss due to the **higher volume-to-surface-area ratio** of the combustion chamber in a large engine. Also, larger engines operate **at lower speeds which reduces friction losses**.

ENGINE EFFICIENCIES / THERMAL EFFICIENCY

A **combustion efficiency** η_c is defined to account for the fraction of fuel that burns. Typically, η_c combustion efficiency values in the range 0.95 to 0.98 when an engine is operating properly. For one engine cycle in one cylinder, the heat added is;

$$Q_{\text{in}} = m_f Q_{\text{HV}} \eta_c$$

For steady state,

$$\dot{Q}_{\text{in}} = \dot{m}_f Q_{\text{HV}} \eta_c$$

and **thermal efficiency** is

$$\eta_t = W/Q_{\text{in}} = \dot{W}/\dot{Q}_{\text{in}} = \dot{W}/\dot{m}_f Q_{\text{HV}} \eta_c = \eta_f/\eta_c$$

where

W = work of one cycle

$\dot{W}$ = power

m_f = mass of fuel for one cycle

$\dot{m}_f$ = mass flow rate of fuel

Q_{HV} = heating value of fuel

η_f = fuel conversion efficiency

ENGINE EFFICIENCIES / THERMAL EFFICIENCY

Thermal efficiency can be given as indicated or brake, depending on whether indicated power or brake power is used in related Eqns. It follows that engine mechanical efficiency is given by;

$$\eta_m = (\eta_t)_b/(\eta_t)_i$$

Engines can have indicated thermal efficiencies in the range of 40% to 50%, with brake thermal efficiency usually about 30%. Some large, slow CI engines can have brake thermal efficiencies greater than 50%. Fuel conversion efficiency is defined as;

$$\eta_f = W/m_f Q_{\text{HV}} = \dot{W}/\dot{m}_f Q_{\text{HV}}$$
$$\eta_f = 1/(\text{sfc})Q_{\text{HV}}$$

For a single cycle of one cylinder the thermal efficiency can be written;

$$\eta_t = W/m_f Q_{\text{HV}} \eta_c$$

This is the ***thermal efficiency*** introduced in basic thermodynamic textbooks, sometimes called enthalpy efficiency.

ENGINE EFFICIENCIES / VOLUMETRIC EFFICIENCY

One of the most important processes that governs how *much power and performance* can be obtained from an engine is **getting the maximum amount of air into the cylinder during each cycle**. More air means more fuel can be burned and more energy can be converted to output power.

However, because of the short cycle time available and the flow restrictions presented by the air cleaner, carburetor (if any), intake manifold, and intake valve(s), less than this ideal amount of air enters the cylinder.

Volumetric efficiency is defined as

$$\eta_v = m_a/\rho_a V_d$$

$$\eta_v = n\dot{m}_a/\rho_a V_d N$$

where

m_a = mass of air into the engine (or cylinder) for one cycle

$\dot{m}_a$ = steady-state flow of air into the engine

ρ_a = air density evaluated at atmospheric conditions outside the engine

V_d = displacement volume

N = engine speed

n = number of revolutions per cycle

ENGINE EFFICIENCIES / VOLUMETRIC EFFICIENCY

Standard values of surrounding air pressure and temperature can be used to find density.

$$P_o \text{ (standard)} = 101 \text{ kPa} = 14.7 \text{ psia}$$
$$T_o \text{ (standard)} = 298 \text{ K} = 25°\text{C} = 537°\text{R} = 77°\text{F}$$
$$\rho_a = P_o / RT_o$$

where

P_o = pressure of surrounding air

T_o = temperature of surrounding air

R = gas constant for air = 0.287 kJ/kg-K = 53.33 ft-lbf/lbm-°R

Typical values of volumetric efficiency for an engine at wide-open throttle (WOT) are in the range 75% to 90%, going down to much lower values as the throttle is closed. Restricting air flow into an engine (closing the throttle) is the primary means of power control for a spark ignition engine.

ENGINE EFFICIENCIES / VOLUMETRIC EFFICIENCY

HOMEWORK-2a

Factors Affecting Volumetric Efficiency

1. Inlet Temperature, T_i
2. Intake and Exhaust Pressure, P_i, P_e
3. Engine Temperature, T_{eng}
4. Engine Speed, N
5. Adding Alcohol to Fuel or Spraying Water During Intake
6. Valves Sections – Designs,
7. Valves Timing

SPECIFIC EMISSIONS

The four main engine exhaust emissions that must be controlled are oxides of nitrogen (NOx), carbon monoxide (CO), hydrocarbons (HC), and solid particulates (part). Two common methods of measuring the amounts of these pollutants are **specific emissions (SE)** and the **emissions index (EI)**. Specific emissions typically have units of gm/kW-hr, while the emissions index has units of emissions flow per fuel flow.

Specific Emissions:

$$(SE)_{NOx} = \dot{m}_{NOx}/\dot{W}_b$$

$$(SE)_{CO} = \dot{m}_{CO}/\dot{W}_b$$

$$(SE)_{HC} = \dot{m}_{HC}/\dot{W}_b$$

$$(SE)_{part} = \dot{m}_{part}/\dot{W}_b$$

where

$\dot{m}$ = flow rate of emissions in gm/hr

$\dot{W}_b$ = brake power

Emissions Index:

$$(EI)_{NOx} = \dot{m}_{NOx}[gm/sec]/\dot{m}_f[kg/sec]$$

$$(EI)_{CO} = \dot{m}_{CO}[gm/sec]/\dot{m}_f[kg/sec]$$

$$(EI)_{HC} = \dot{m}_{HC}[gm/sec]/\dot{m}_f[kg/sec]$$

$$(EI)_{part} = \dot{m}_{part}[gm/sec]/\dot{m}_f[kg/sec]$$

<u>EXP:</u> A spark ignition 4-stroke, 6-cylinder gasoline engine has a cylinder inner diameter of 80 mm and a stroke of 85 mm. While operating at 3600 rpm, the power obtained with a fuel/air ratio of 0.07 is 70 kW, and the air consumed is 4.2 kg per minute. If the mechanical efficiency is 80% and the lower calorific value of the fuel is 42000 kJ/kg;

a) Indicated heat efficiency

b) Indicated mean effective pressure

EXP: A 4-stroke, 4-cylinder gasoline engine has a cylinder diameter of 8.8 cm and a stroke length of 9.5 cm. When this engine was tested, 148 Nm of torque was measured at 3000 rpm. The clearance volume of each cylinder is 7.42×10^{-5} m^3. The calorific value of the fuel used is 44000 kJ/kg. Since the mechanical efficiency is 0.80 and the indicated efficiency is 0.45:

a) Ideal thermal efficiency

b) Fuel consumption

c) Brake mean effective pressure

EXP: A 4-cylinder, 4-stroke gasoline engine has a cylinder diameter of 8.8 cm and a stroke of 13 cm. When the engine is at 1500 rpm, a 20% rich mixture is used, and the brake power is 48 kW. The pressure of the air entering the cylinder is 100 kPa and its temperature is 20 °C, and its volume is 0.7 of the sweep volume. The engine's mechanical efficiency is 0.9, and the calorific value of the fuel is 46000 kJ/kg. Theoretically, for combustion to occur, 1 kg of fuel must come together with 14.8 kg of air. Calculate the indicated thermal efficiency and brake mean effective pressure of this engine.

EXP: An engine consumes 0.07 kg of fuel per kg of air, which has a lower calorific value of 42800 kJ/kg, for each kg of air it takes into its cylinder. If the brake efficiency of the engine is 25.7%, to obtain 100 kW brake power:

A) How many kg of air should it consume per minute?

b) If the air is under 0 °C and 101.3 kPa conditions, how much m^3 of air is consumed per minute?

c) If the density of fuel vapor is four times that of air, how much m^3 of mixture is consumed per minute?

HOMEWORK-2b

After Learning of Engine Operating Conditions

1-D Plenemanary Engine Design:

DESIGN EXAMPLE:

A four-cylinder, four-valve-per-cylinder naturally-aspirated automotive SI engine is being designed to provide a maximum torque of 195 N·m in the mid-speed range (~4000 rev/min).

Estimate the required engine *displacement, bore, and stroke, and the maximum brake power* the engine will deliver.

- 1. Video Link

https://www.youtube.com/watch?v=w-kppjjYeYM&ab_channel=putz4747

- 2. Video Link

https://www.youtube.com/watch?v=nSNkB0BXnHM&ab_channel=TaiwanMaritimeinfo