SHROFF S. R. ROTARY INSTITUTE OF CHEMICAL TECHNOLOGY (SRICT)
DEPARTMENT OF MECHANICAL ENGINEERING.

Chapter 2. Fuel-Air Cycle and Actual Cycle

Subject: Internal Combustion Engine

Introduction

Ideal Gas Cycle (Air Standard Cycle)

- Idealized processes
- Idealize working Fluid

Fuel-Air Cycle

- Idealized Processes
- Accurate Working Fluid Model

Actual Engine Cycle

- Accurate Models of Processes
- Accurate Working Fluid Model

Outline

Chapter 2. Fuel-Air Cycle and Actual Cycle

Air Standard Cycle

- Assumption
- Otto Cycle
- Diesel Cycle
- Dual Cycle

Fuel Air Cycle

Assumptions

Factors considered

- Composition of cylinder Gases
- Variable Specific Heat
- Dissociation
- Number of Moles

Effect of Operating Variables

- Compression ratio
- Fuel-Air ratio

Comparison with Air-Standard Cycle

Outline

Actual Cycle

Introduction

Losses of Actual Cycle

- Leakage
- Imperfect mixing of fuel and air
- Fluid Friction
- Progressive Burning Loss
- **Burning Time Loss**
- **Heat Loss**
- **Exhaust Gas Blow down**
- Running Friction
- Pumping losses

Major Losses (Burning Time Loss, Heat Loss, Exhaust Gas Blow down)

Other Topics

- Volumetric Efficiency
- Valve Timing Diagram
- Port Timing Diagram

Air Standard Cycles

1) Carnot : Maximum Efficiency cycle & Reversible Cycle

2) Otto : Spark- Ignition Engine

3) Diesel : Compression Ignition Engine

4) Brayton : Gas Turbine Engine

Air Standard Cycle

Assumption

- Working fluid is air. It does not undergo any chemical change throughout the cycle.
- All Processes are internally reversible. Engine Friction and heat losses & other irreversibilities are not considered.
- Combustion process is replaced by constant temperature heat input from external Source.
- Heat rejection is used to restore fluid to initial state
- Intake and Exhaust process are not considered
- Specific heats are independent of temperature.

Air Standard Cycle

Otto cycle:

- In Otto cycle combustion is so rapid that the piston does not move during the combustion process and thus combustion is assumed to take place at constant volume.
- Higher compression ratio leads to auto-ignition (without spark) and cause knock. It damage engine thus there is upper limit of high compression ratio.

$$\eta_{otto} = 1 - \frac{1}{r^{\gamma-1}}$$

$$P_m = \frac{P_1(\alpha - 1)r^{\gamma}\eta_{otto}}{(\gamma - 1)(r - 1)}$$

Air Standard Cycle

Diesel Cycle:

- Due to ignition delay and finite time required for fuel to injection and combustion process continues till the beginning of power stroke.
- This keeps the cylinder pressure at peak levels for a longer period. Therefore the combustion process can be approximated as constant pressure heat addition.
- Remaining processes are similar to that of otto cycle.

$$\eta_{diesel} = 1 - \frac{1}{r^{\gamma-1}}\left[\frac{(\rho^{\gamma} - 1)}{\gamma(\rho - 1)}\right]$$

$$P_m = \frac{P_1 \gamma(\rho - 1) r^{\gamma} \eta_{diesel}}{(\gamma - 1)(r - 1)}$$

Air Standard Cycle

Dual Cycle:

- Both Otto cycle (constant volume heat addition) and Diesel Cycle (Constant pressure heat addition) are over simplified and unrealistic.
- In actual case combustion takes place neither at constant volume (time required for chemical reaction) not at constant pressure (Rapid uncontrolled combustion)
- Dual cycle is used to model the combustion process. It is a compromise between Otto and diesel cycle, where heat addition takes place partly at constant volume and partly at constant pressure.
- This is also known as mixed cycle. In fact, Otto (ρ=1) and Diesel (α=1) cycles are special case of dual cycle.

$$\eta_{dual} = 1 - \frac{\rho^{\gamma}\alpha - 1}{r^{\gamma-1}[(\alpha - 1) + \alpha\gamma(\rho - 1)]}$$

$$P_m = \frac{P_1 r^{\gamma}[(\alpha - 1) + \alpha\gamma(\rho - 1)]\eta_{dual}}{(\gamma - 1)(r - 1)}$$

Fuel Air Cycle

- At Compression ratio 7, Air standard efficiency is 55% while actual is 30%
- This divergence is due to partly due to non-instantaneous burning, incomplete combustion, valve operation etc.
- However, the main reason lies with the over simplification of using value of properties of the working fluid.
- In air standard we assumed working fluid is air and properties like specific heat is constant regardless of temperature.

Fuel Air Cycle

Fuel Air Cycle Consideration

- Actual composition in cylinder is fuel + Air + Water vapour + Residual gas
- F/A ratio change during operation and hence changes in amount of CO_2 & H_2O etc.
- C_p Change with temperature (except mono-atomic gas) and hence adiabatic index (γ)
- Changes in no. of molecules in cylinder with the change in pressure and temperature.
- The dissociation effect

Fuel Air Cycle Assumption:

- No chemical change in either fuel or air prior the combustion.
- All processes are adiabatic Process
- Compression and Expansion process are frictionless
- Velocities are negligibly small
- Combustion takes place instantaneously at top dead centre.
- The fuel is mixed well with air.

Fuel Air Cycle

Important of Fuel Air Cycle

- The air-standard analysis allows, how the efficiency is improved by raising the compression ratio of air.
- However, it does not give any idea about effect of F/A ratio on thermal efficiency.
- F/A cycle allow study of F/A ratio on thermal efficiency.
- Allows study of P_{max} and T_{max} as F/A ratio is varied. This helps in structural design of the engine.
- Gives a good estimate of the power expected from an actual engine.

Fuel Air Cycle

Composition of Cylinder Gases

1. The actual composition of the cylinder contents are

- (Fuel +Air + Water vapor + residual gas)
- The fuel air ratio changes during the engine operation
  - The change in air-fuel ratio affects the composition of gases before and after combustion particularly the percentage of CO_2, CO, H_2O etc.. in the exhaust gas.
- The amount of exhaust gases in the clearance volume various with speed and load on the engine.
  - The fresh charge composition varies its composition because when it enters in the cylinder comes in contact with the burnt gases

Fuel Air Cycle

Composition of Cylinder Gases

- The composition of the working fluid, which changes during the engine operating cycle, is indicated in the following table

Process	SI Engine	CI Engine
Intake	Air, **Fuel**, Recycled exhaust & Residual gas	Air, Recycled exhaust & Residual gas
Compression	Air, **Fuel** Vapor, Recycled exhaust & Residual gas	Air, Recycled exhaust & Residual gas
Expansion	Composition products (CO_2, CO, H_2, O_2, NO, OH, O, H,…)	Composition products (CO_2, CO, H_2, O_2, NO, N_2, OH, H_2O, O, H,…)
Exhaust	Composition products (mainly N_2, CO_2, H_2O) **If $\Phi<1$ O_2 or If $\Phi>1$ CO & H_2**	Composition products (mainly N_2, CO_2, H_2O & O_2)

Composition of Cylinder Gases

- The effect of cylinder composition on the performance of the engine can easily computed by means of suitable numerical techniques.

- The computer analysis can produce fast and accurate results.
- Thus, fuel-air analysis can be done more easily through computer rather than manual calculation

Variable Specific Heats

2. The variation of specific heat with temperature

- All gases except mono-atomic gases, show an increase in specific heat with temperature.
- The increase in specific heat does not follow any particular law.
- However between the temperature range 300 K – 1500 K the specific heat curve is nearly a straight line which may be approximately expressed in form

$$C_P = a_1 + K_1 T$$

$$C_V = b_1 + K_1 T$$

Where a_1, b_1, and k_1 are constants

The gas constant R= C_p- C_v = a_1-b_1

Fuel Air Cycle

Variable Specific Heats

- Above 1500 K the specific heat increases is much more rapid and may be expressed in the form

$$C_P = a_1 + K_1 T + K_2 T^2$$

$$C_V = b_1 + K_1 T + K_2 T^2$$

- Since the difference between C_p & C_v is constant, the value of γ decreases with increase in temperature.

$$\gamma = \frac{C_P}{C_V} = \frac{R + C_V}{C_V} = 1 + \frac{R}{C_V}$$

- Thus, if the variation of specific heats is taken in to account during the compression stroke, the final temperature and pressure would be lower compared to the value obtained at constant specific heat.

Fuel Air Cycle

Loss Due to Variable Specific Heats

- The magnitude of drop of temperature at the end of compression is proportional to the drop in values of ratio of specific heats.

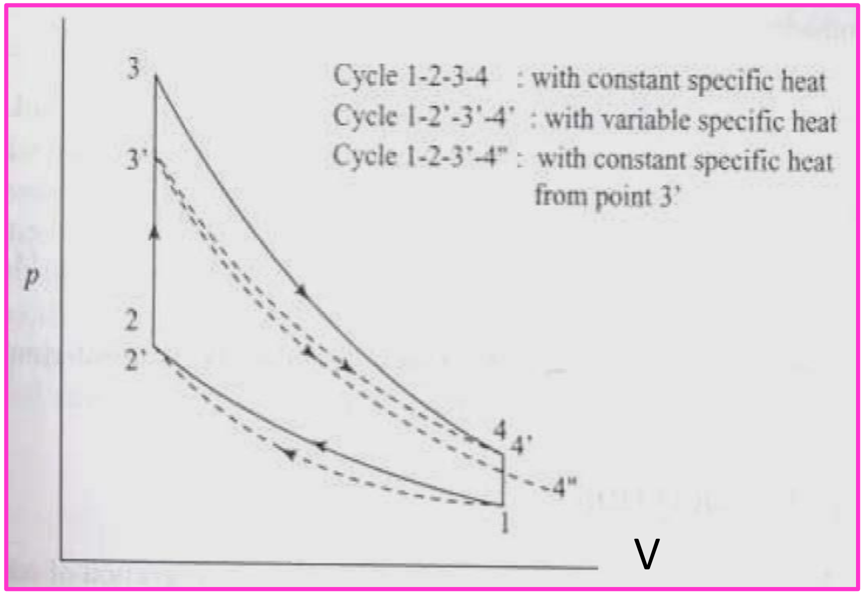
  ➢ **For process 1-2**

  - With constant specific heat

$$T_2 = T_1\left(\frac{v_1}{v_2}\right)^{\gamma-1}$$

  - With variable specific heat

$$T_{2'} = T_1\left(\frac{v_1}{v_2}\right)^{\gamma-1}$$



Where $\gamma = \dfrac{C_p}{C_v}$, $v_{2'} = v_2$, $\left(\dfrac{v_1}{v_2}\right) = \left(\dfrac{v_1}{v_{2'}}\right) = r$

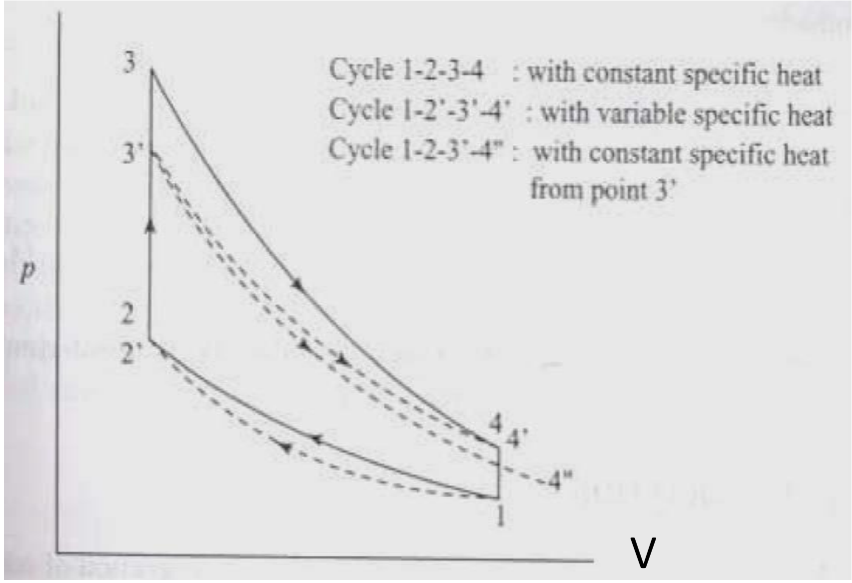
Loss Due to Variable Specific Heats

- ***Process 2-3***

Constant volume combustion (Heat addition), from point 2' will give a temperature $T_{3'}$ with the variation in specific heat, instead of T_3.

$$m_f Q_{HV} = C_V (T_3 - T_2) = C_{V'} (T_{3'} - T_{2'})$$

$$\left.\begin{aligned} 1.\quad & T_{2'} < T_2 \\ 2.\quad & C_{V'} > C_V \end{aligned}\right\} T_{3'} < T_3$$



Fuel Air Cycle

For the expansion Process

- For process 3'-4" (Constant specific Heat from point 3')

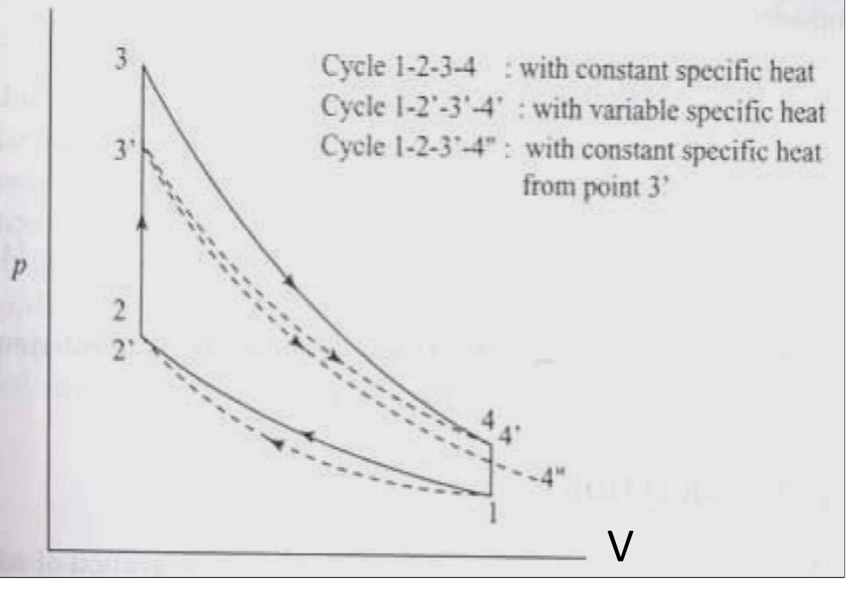
$$T_{4''} = T_{3'}\left(\frac{v_3}{v_{4''}}\right)^{\gamma-1}$$

- For the process 3'-4' (with variable specific heat)

$$T_{4'} = T_{3'}\left(\frac{v_3}{v_{4'}}\right)^{\gamma-1}$$

Q. Why is $T_{4'} > T_{4''}$?

A: Because specific heat ratio increase with decrease in temperature.



Dissociation

3. The effect of dissociation

- Dissociation is the disintegration of combustion products, at high temperature above 1600 k
- Dissociation is the reverse process to combustion
- Dissociation is the heat absorption (endothermic process)
- Combustion is heat liberation (Exothermic process)
- In IC engine, mainly dissociation of CO_2 and little dissociation of H_20

Fuel Air Cycle

Dissociation

- The dissociation of CO_2 in to CO and O_2 starts commencing around 1000 ^{0}C

$$2CO_2 \rightarrow 2CO + O_2 + Heat$$

- The dissociation of H_2O occurs at temperature above 1300 ^{0}C

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

- The presence of CO and O_2 in the gases tends to prevent dissociation of CO_2; this is noticeable in a rich fuel mixture which by producing more CO, suppresses dissociation of CO2

Fuel Air Cycle

Dissociation

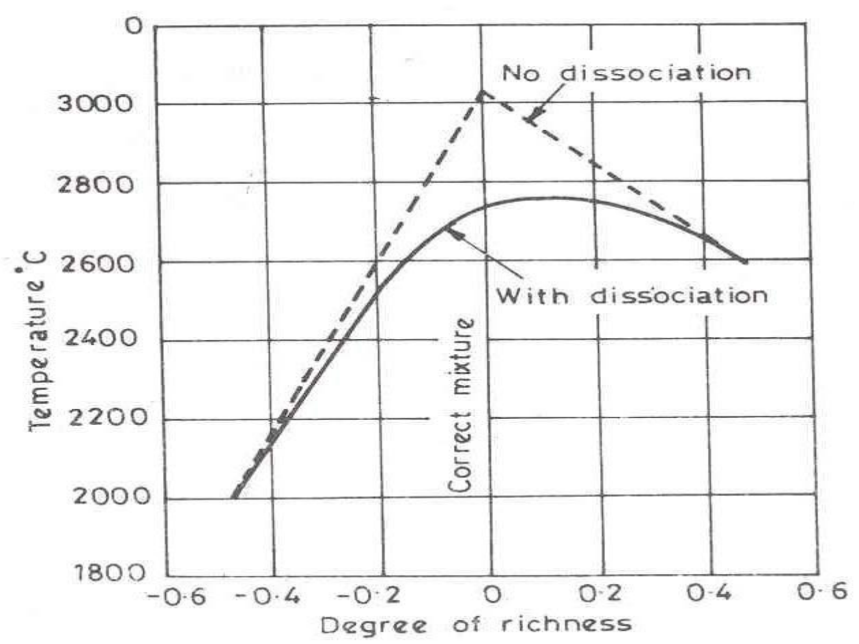
- There is no dissociation in the burnt gases of a lean fuel-air mixture.
- This mainly due to the fact that the temperature produced is too low for this phenomenon to occur.
- The maximum dissociation occurs in the burnt gases of the chemically correct fuel-air mixture when the temperature are expected to be high but decreases with the leaner and richer mixtures.

The Effect of Dissociation

- On Exhaust Gas Temperature, Fig below shows the reduction in the temperature of the exhaust gas mixtures due to dissociation w.r.t air- fuel ratio

- With no dissociation maximum temperature is attained @ chemically correct A-F ratio

- With dissociation maximum temp is obtained when mixture is slightly rich



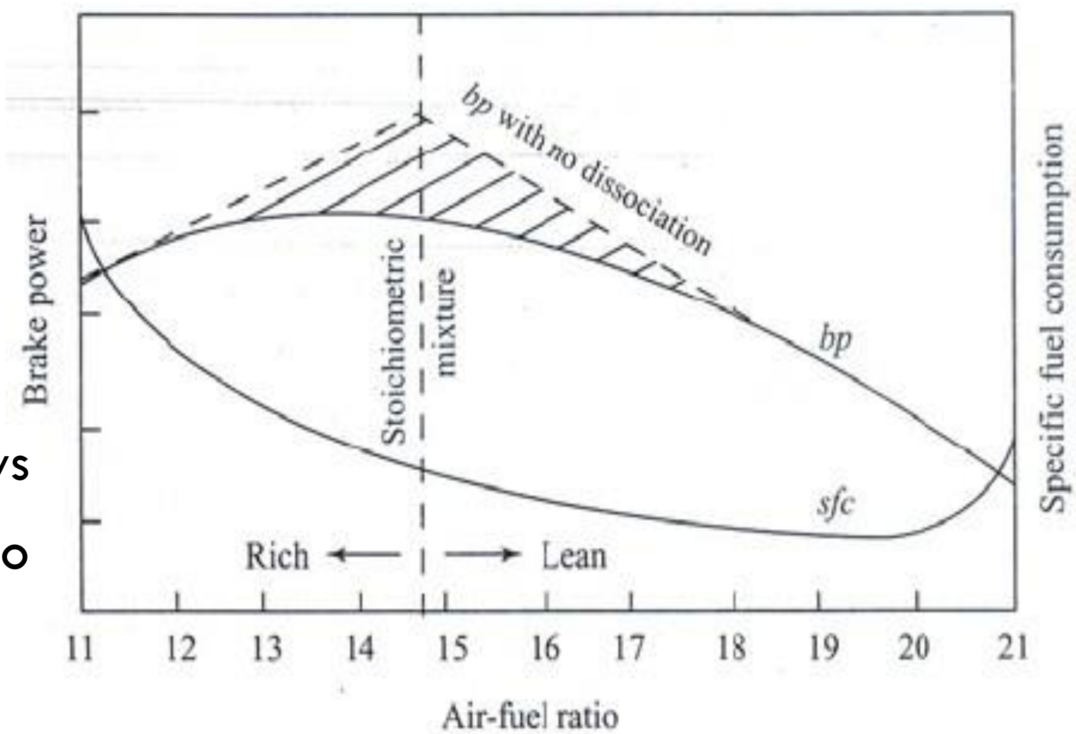
Fuel Air Cycle

The Effect of Dissociation

- On Power output, If there is no dissociation
  - The Brake power output is max @ stoichiometric mix

- If there is dissociation
  - The Brake Power is Max @ slightly Rich Mixture

- The shaded area shows the loss of power due to dissociation



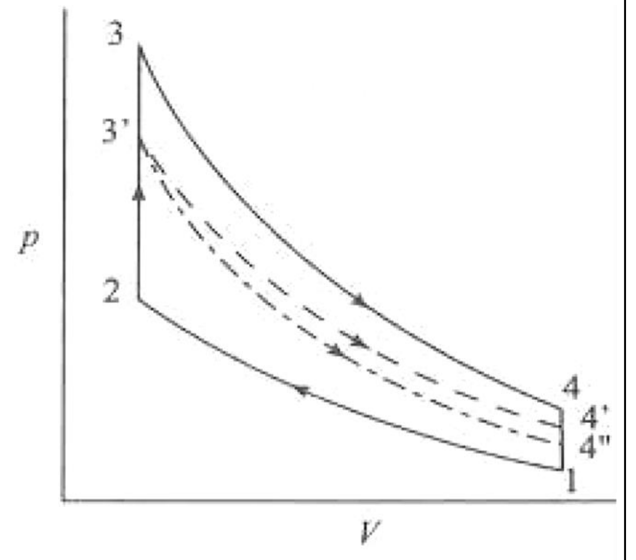
Fuel Air Cycle

The Effect of Dissociation

- Dissociation effect are not pronounced in CI engine as in an SI engine. This is mainly due to
  - The presence of a heterogeneous mixture and
  - Excess air to ensure complete combustion
- Both these factors tend to reduce the peak gas temperature attained in CI engine

The Effect of Dissociation

- On the p-v diagram of Otto Cycle
  - Because of lower maximum temperature due to dissociation. the maximum pressure is also reduced and state after combustion will be replaced by 3’ instead of 3.
  - If there was no re-association due to fall of temp during Exp proc.
    - It would be represented by 3’ ⟶ 4”
  - If there is re-association
    - the Expansion follows the path 3’ ⟶ 4’



Effect of number of moles

- The number of molecules in the cylinder varies as the pressure and temperature change

- The number of molecule presented after combustion depend upon
  - Fuel-Air ratio
  - Pressure and temperature ($PV=nRT$)

- **The number of mole does a direct effect on the amount of work that the cylinder gas impact on the piston**

Effect of Operating variables

- The effect of the common engine operating variables on the thermal efficiency, pressure and temperature within the engine cylinder is better understood by fuel-air cycle analysis

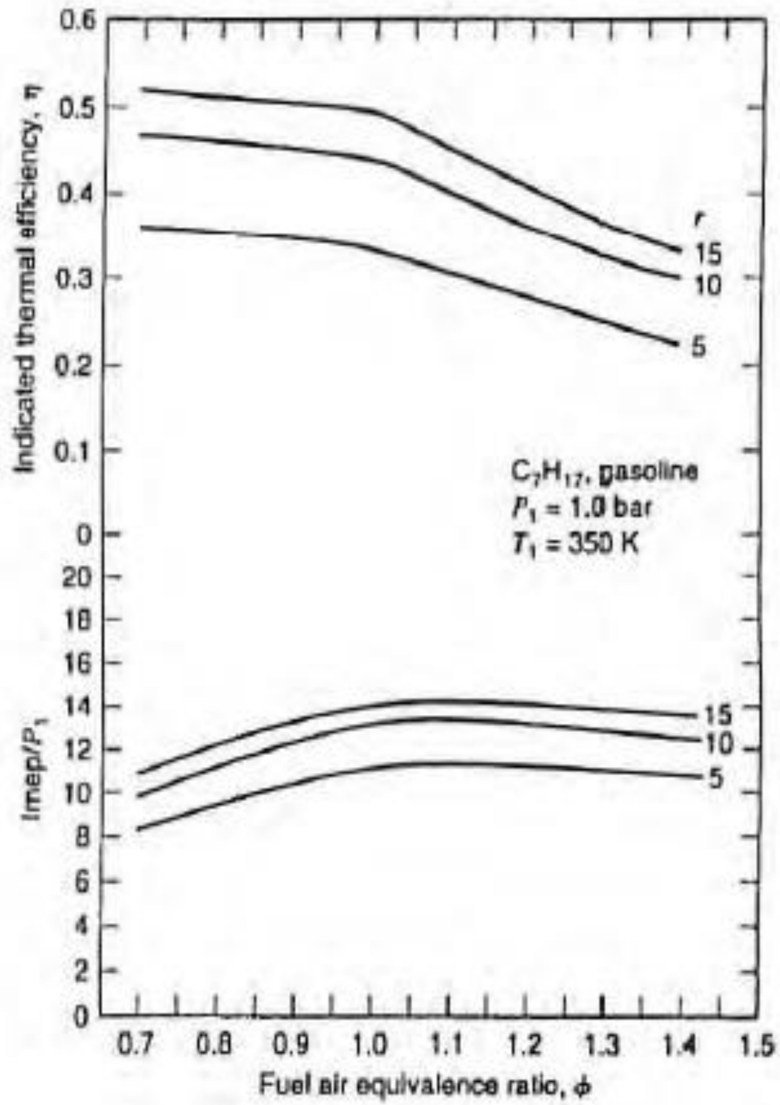
- The major operating variables

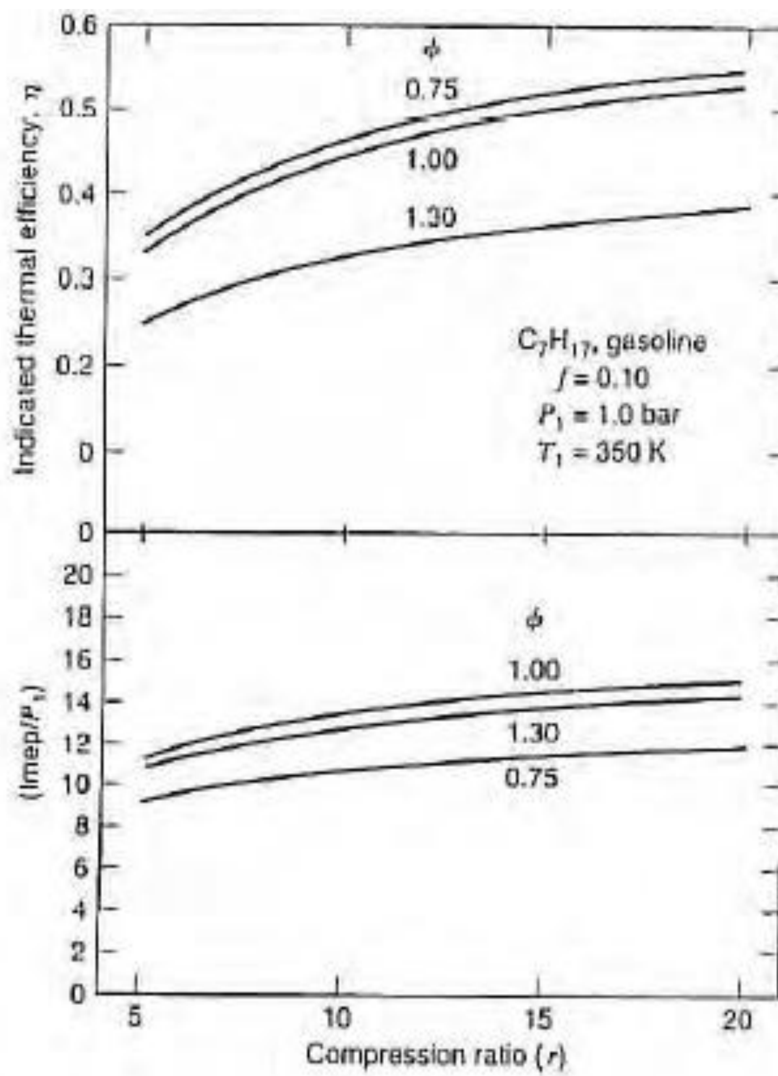
  Compression ratio

  Equivalence ratio

Fuel Air Cycle

Fuel air otto cycle model for different equivalent ration and compression ratio





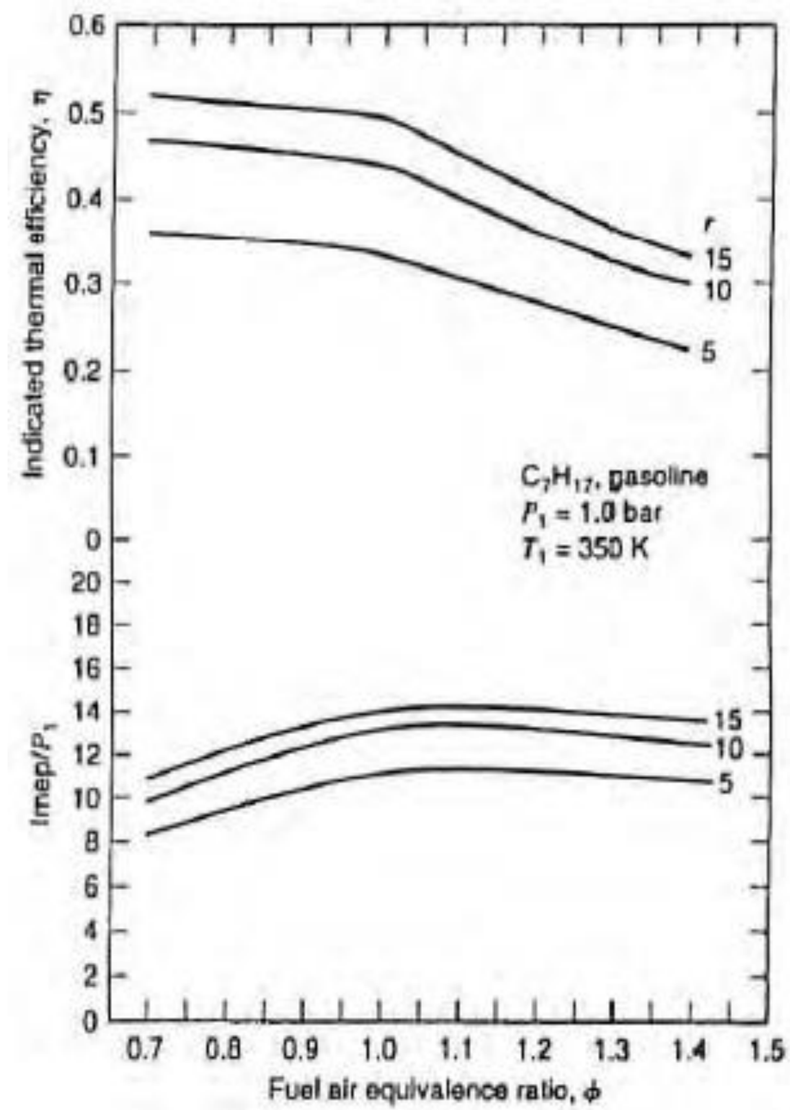
Fuel Air Cycle

Effect of Compression Ratio

- The fuel-air cycle efficiency increases with the compression ratio in the same manner as the air-standard cycle efficiency, principally for the same reason, due to more scope of the expansion work

- The indicated thermal efficiency *increases with lean mixtures and compression ratios*

- MEP is maximum at slightly rich mixture (5-10%).



Effect of Compression Ratio

- The variation of indicated thermal efficiency with respect to equivalence ratio for various compression ratios.

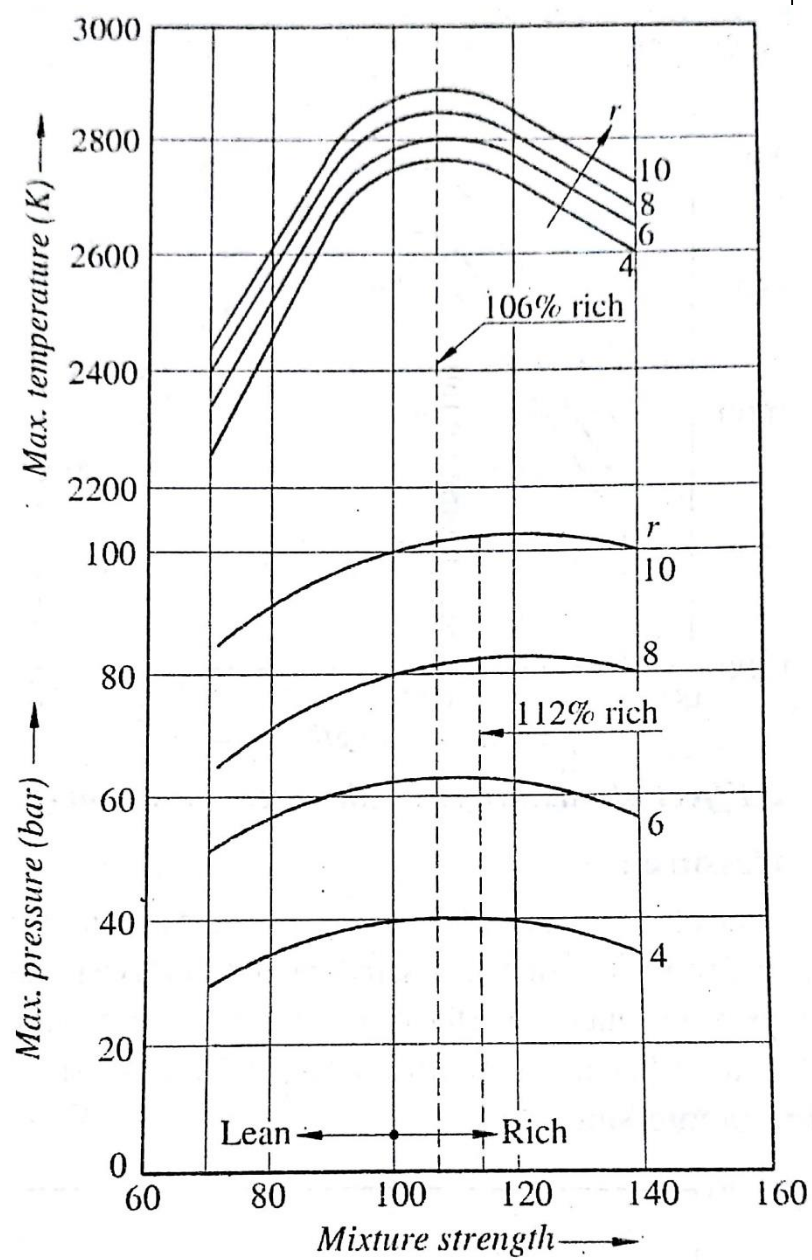
Table 3.2. Effect of different compression ratios and fuel-air ratios on thermal efficiency in Otto cycle

Compression ratio	*Air cycle efficiency* η_i	*Fuel-air cycle efficiency at* F_R				
		0.6	*0.8*	*1.0*	*1.2*	*1.4*
7.0	0.540	0.448	0.420	0.403	0.340	0.287
8.0	0.565	0.470	0.449	0.423	0.357	0.300
9.0	0.585	0.488	0.467	0.442	0.372	0.312
10.0	0.602	0.503	0.483	0.459	0.385	0.322
11.0	0.617	0.517	0.496	0.473	0.396	0.330
12.0	0.630	0.530	0.508	0.486	0.406	0.338

Fuel Air Cycle

Effect of Fuel-Air Ratio on Max. Temp. & Max. Pressure

- *At a given compression ratio* the temperature after combustion reaches a maximum when the mixture is slightly rich (6%).
- At chemically correct ratio there is still some oxygen present because of chemical equilibrium effect a rich mixture will cause more fuel to combine with oxygen at the point thereby raising the temperature T_3.
- The pressure during combustion depends up on the temperature and number of molecules. So, maximum pressure is achieved with about 10% rich mixture.



Effect of Fuel-Air Ratio on MEP

- The nature of variation of MEP is similar to that of maximum temperature and pressure. Max. at rich mixture (5%)

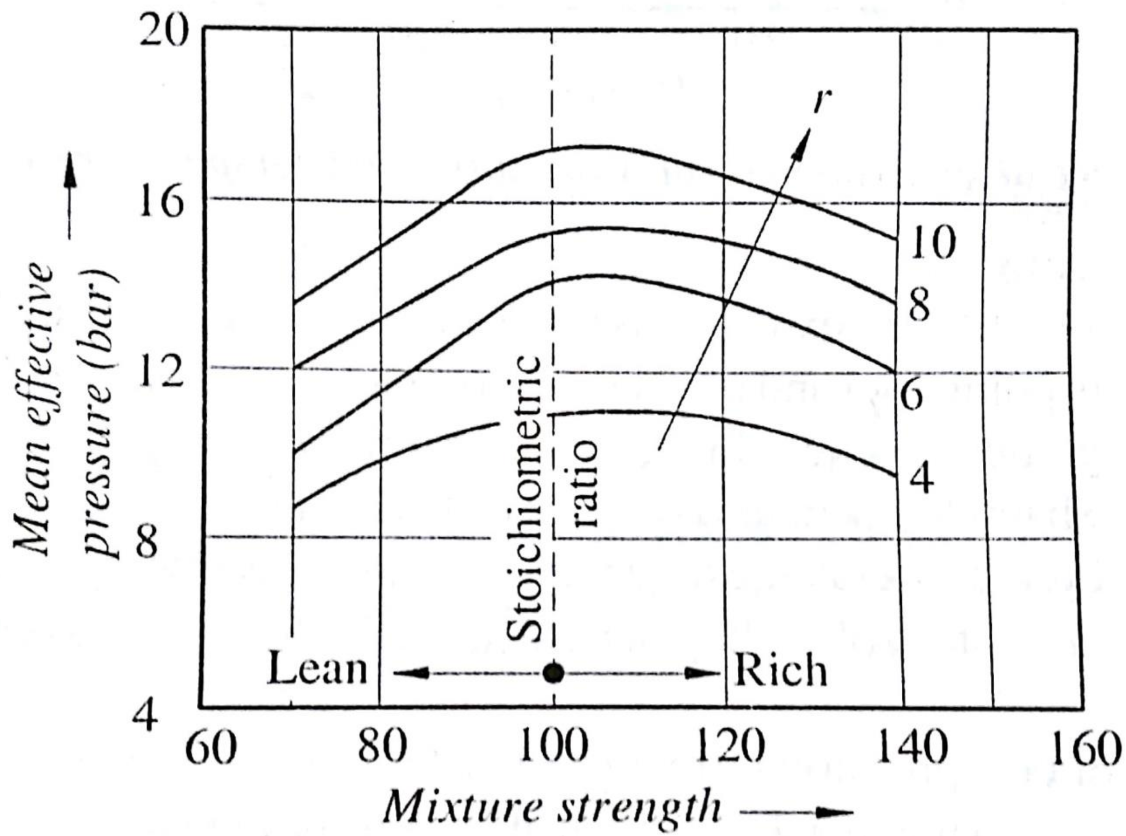


Fig. Effect of mixture strength on mean effective pressure

Fuel Air Cycle

Effect of Fuel-Air Ratio on Exhaust gas temperature

- The behaviour of T_4 with compression ratio is different from that of T_3 .
- Unlike T_3, the exhaust gas temperature T_4 is lower at high compression ratios, because the increased expansion causes the gas to do more work and less heat to be rejected at the end of the stroke.
- Max. Exhaust temperature is at chemically correct fuel-air mixture.

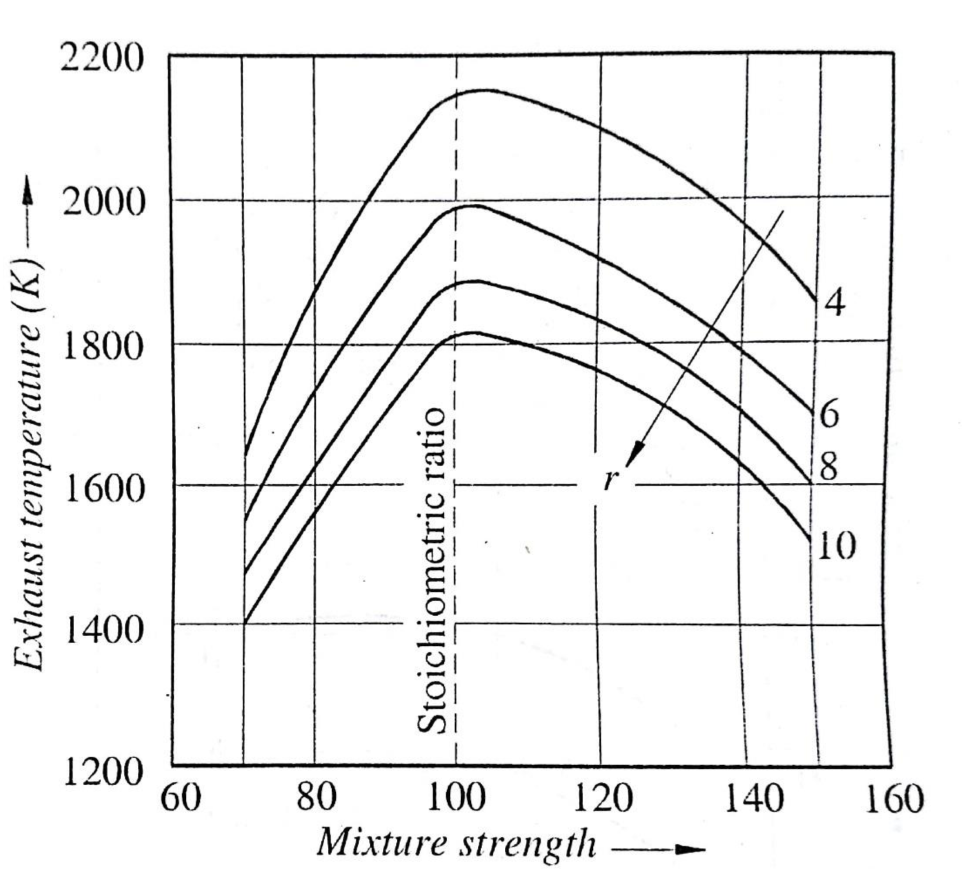


Fig. Effect of mixture strength on exhaust temperature

Fuel Air Cycle

Effect of Fuel-Air Ratio on Maximum Power

- The variation is as shown in Figure, as the mixture becomes richer, after a certain point power output falls as can be seen from the experimental curve

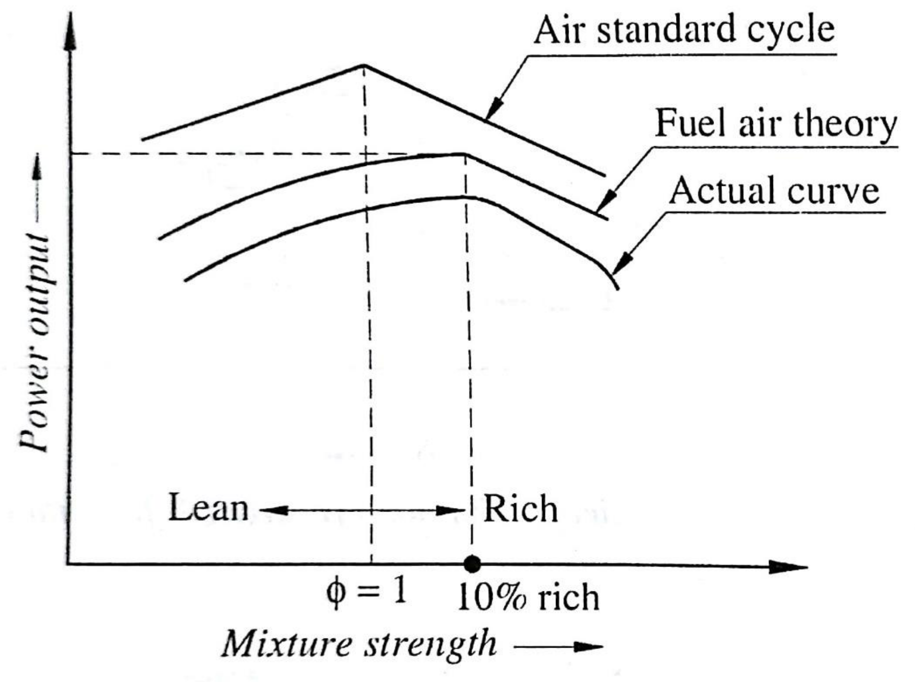


Fig. Effect of mixture strength on power

- This is because in addition to higher specific heats and chemical equilibrium losses, there is insufficient air which will result in formation of CO and H_2 during combustion, which represents direct wastage of fuel

Effect of Fuel-Air Ratio on Thermal Efficiency

- As the mixture used is lean, the temperature rise during the combustion will be less.
- The low temperature results in low specific heat.
- So, thermal efficiency increase as decrease in specific heat.

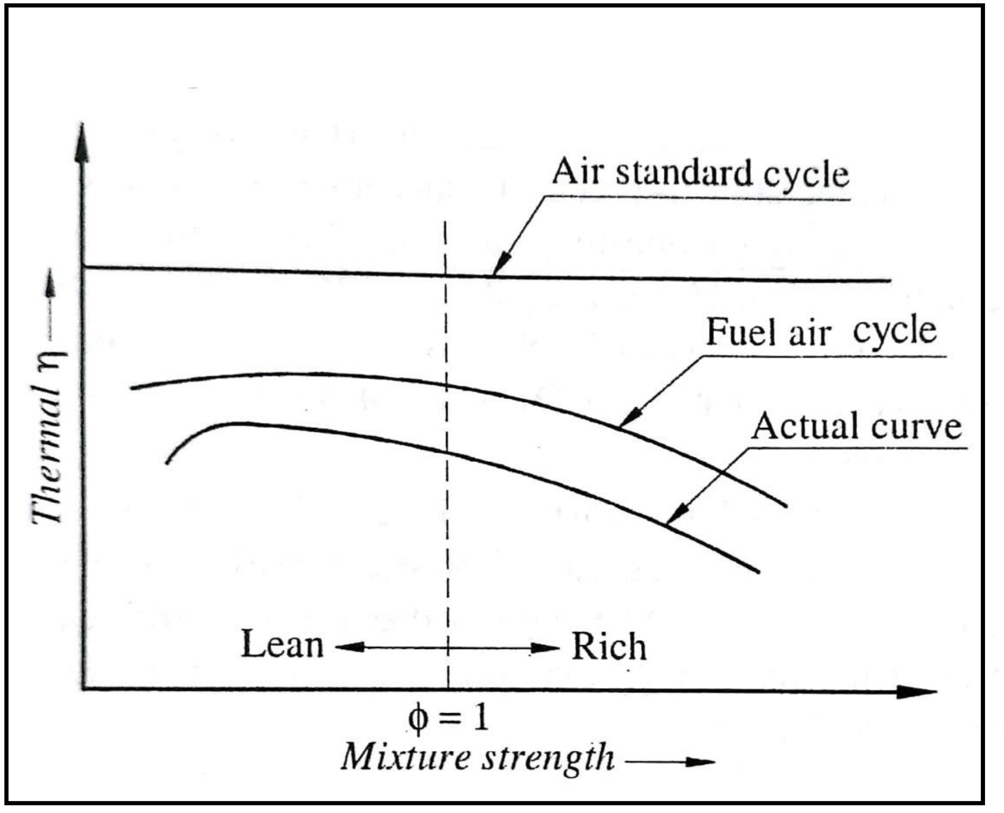
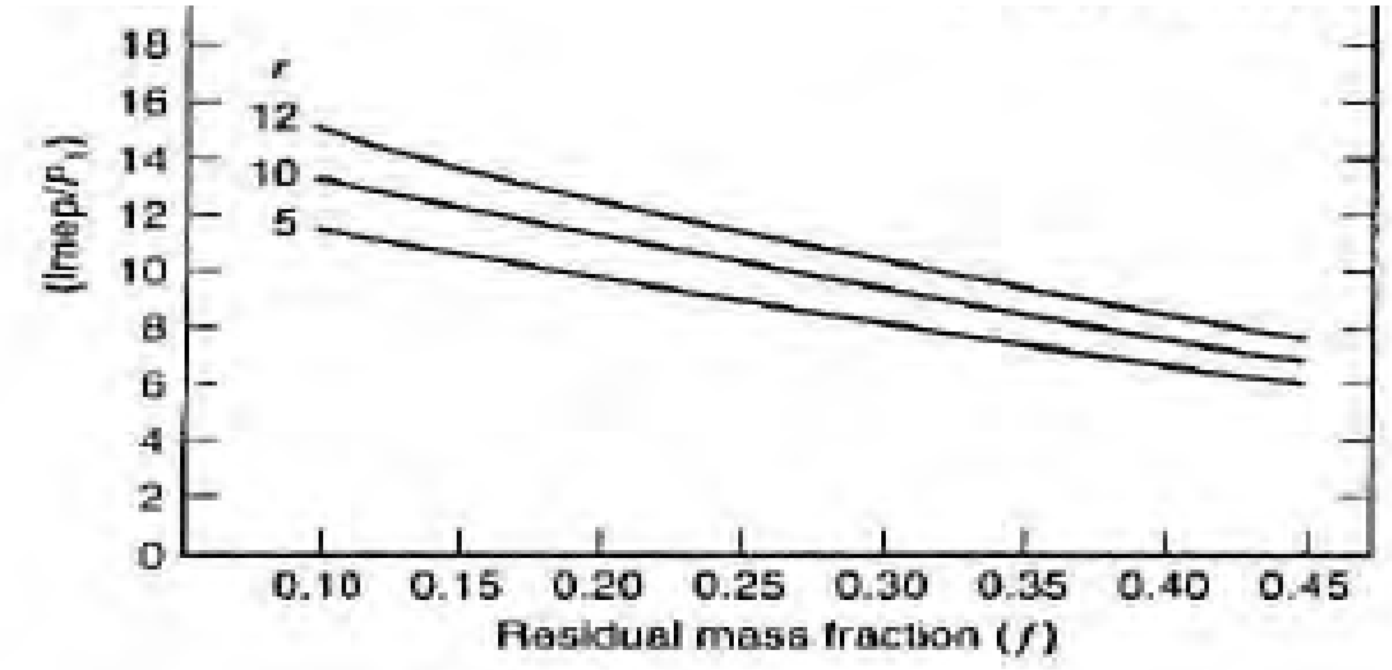


Fig. Effect of mixture strength on thermal efficiency

Effect of residual charactersics



Notice that *imep* falls with increasing *f; it falls because the residual gas displaces fuel-air and because it warms the* fuel-air, thereby reducing the charge density.

Comparison of Air-Standard & Fuel-Air cycles

- By Air standard cycle analysis, it is understood how the efficiency is improved by increasing the compression ratio.
- Air standard cycle analysis do not consider the effect of Fuel-Air ratio on the thermal efficiency because the working medium was assumed to be air
- In general, fuel-air cycle analysis is used to study
  - The effect of fuel-air ratio on engine thermal efficiency
  - How the peak pressure and temperature during the cycle varying and its influence on many engine operating variables.

Fuel Air Cycle

Comparison of Air-Standard & Fuel-Air cycles

- Fuel-Air cycle analysis suggest that the thermal efficiency will *deteriorate* as the mixture supplied to the engine is enriched.
- Thermal efficiency will increase as the mixture is made leaner due to less variable specific heats.
- Beyond a certain leaning, the combustion become erratic with loss of efficiency.
- In general the maximum efficiency is within the lean zone very near the stoichiometric ratio.

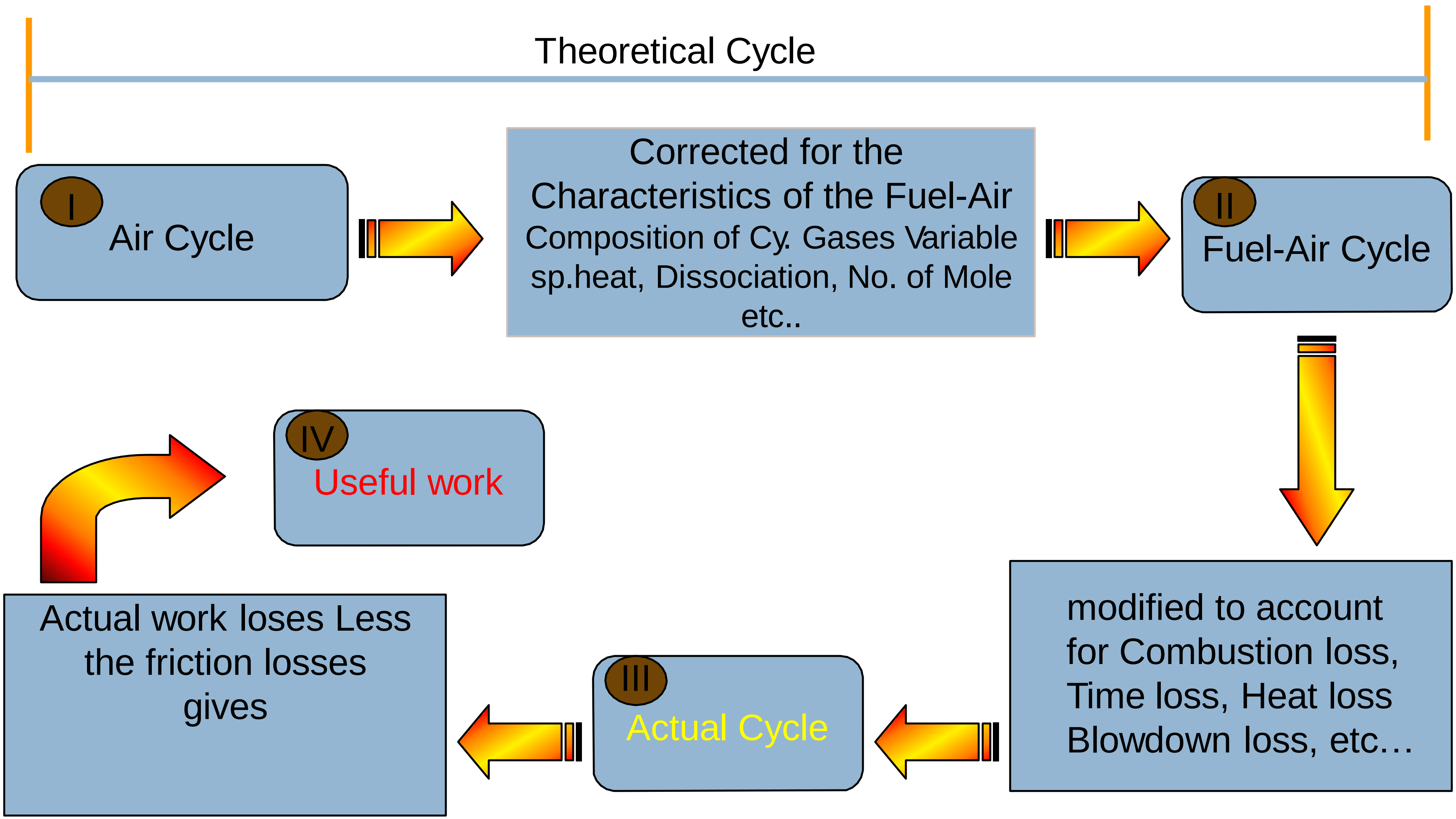
Actual Cycle

Introduction

- The analysis of the fuel air cycle predict better results but still not so close as desire.
- The actual cycle analysis considers additional losses to the losses that considered in Fuel-Air Cycle.
- This analysis predicts very close results compared to the results obtained actually by running the engine and taking measurements by sophisticated instruments.

Actual Cycle

Introduction



Loss of Actual Cycle

- Leakage
- Imperfect mixing
- Fluid friction
- Progressive Burning
- Burning **Time losses** (due to motion of piston during combustion)
- Exhaust **Blowdown losses**
- **Heat losses**
- **Pumping loss** (Gas Exchange)

The Major Loss of Actual Cycle

- Burning Time loss factor

  Loss due to time required for mixing of fuel and air and also for combustion.

- Heat loss factor

  Loss of heat from gases to cylinder walls.

- Exhaust blowdown factor

  Loss of work on the expansion stroke due to early opening of the exhaust valve.

Actual Cycle

Leakage

- The gas leak through the region between piston, piston ring and cylinder and enter into the crank case.
- This leakage loss reduces the cylinder pressure during combustion and thus reduces the net power output of the engine.
- Leakage can be estimated by measuring blow by that is the mass of the gases flowing out from the crank case breather.

Actual Cycle

Imperfect mixing of fuel and air

- In practice, it is not possible to obtain homogeneous mixture during combustion because of insufficient turbulence.
- This may result in the appearance of CO, H_2 and unburned fuel in the exhaust.
- It decrease efficiency of engine. It can be reduced by using lean mixture.

Imperfect mixing of fuel and air

- Even if the unburned fuel and oxygen combine later during the expansion stroke, resulting in no loss of fuel in the exhaust, still there will be a loss in efficiency, since the sensible energy present with the combustion of this part of fuel is not utilized at TDC and hence does not contribute to the pressure rise at that point.

Fluid friction

- At high speeds, turbulence inside the engine cylinder causes friction between fluid particles.
- Each part of cycle include fluid friction, but overall effect of fluid friction as compare to other loss on the actual cycle is very little.

Actual Cycle

Progressive Burning

- In Fuel-Air cycle we assumed combustion is instantaneous at TDC.
- In actual, combustion starts from spark which ignites a very small portion of the charge immediately adjacent to it and continues until flame front passed through the entire charge.
- This phenomenon of burning is called progressive burning.

Actual Cycle

Progressive Burning

- The time (travel of flame front) required for this varies with fuel composition, combustion chamber shape and size, location of spark plug and engine operation condition.
- This losses due to leakage, imperfect mixing and progressive burning are too small and cannot be evident on the P-V diagram.
- The remaining losses, namely the time loss, the heat loss, the exhaust blow down loss are significant and can be shown on P-V Diagram.

Actual Cycle

Burning Time Loss

- The crankshaft normally rotates through 40° or more between the time the spark is produced and the time the charge is completely burned.
- As the crankshaft rotates, the piston moves and if the piston motion during combustion is taken into account the burning time losses are determined, which result in loss of work and efficiency.
- The time in degree crank angle depends upon the flame speed and the distance between the piston of spark plug and farthest side of combustion chamber.

Actual Cycle

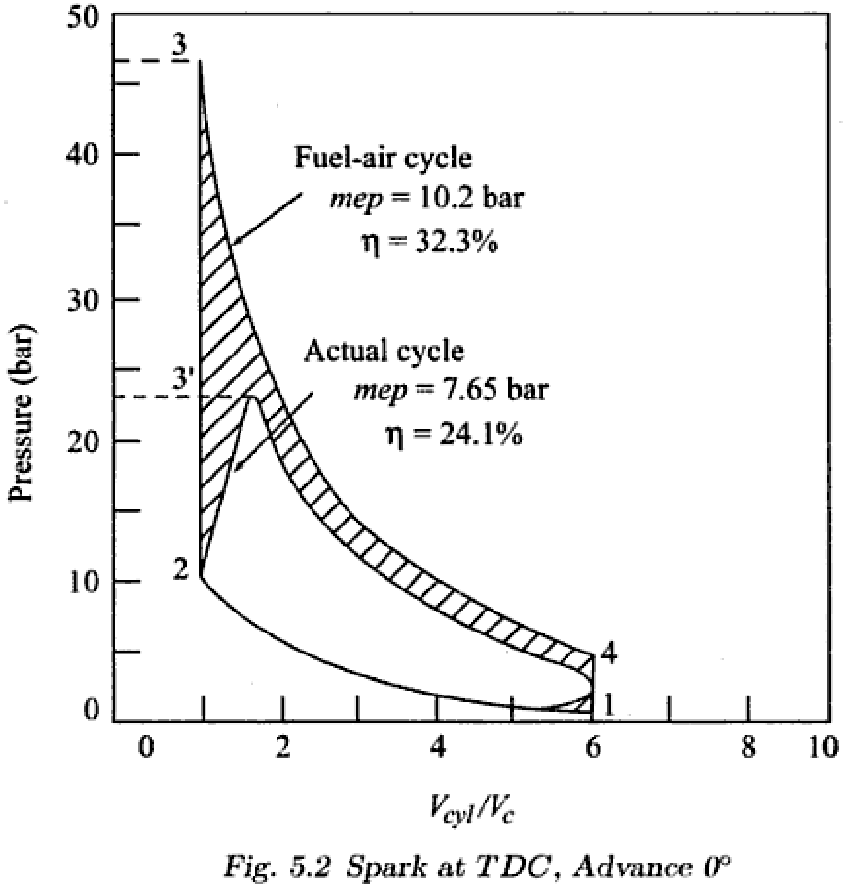
Burning Time Loss

However, the burning time losses are quite large if,

1) F/A ratio is made to lean or too rich
2) The throttle is partially closed, reducing the suction pressure
3) The point of ignition is not properly set.

Actual Cycle

Burning Time Loss



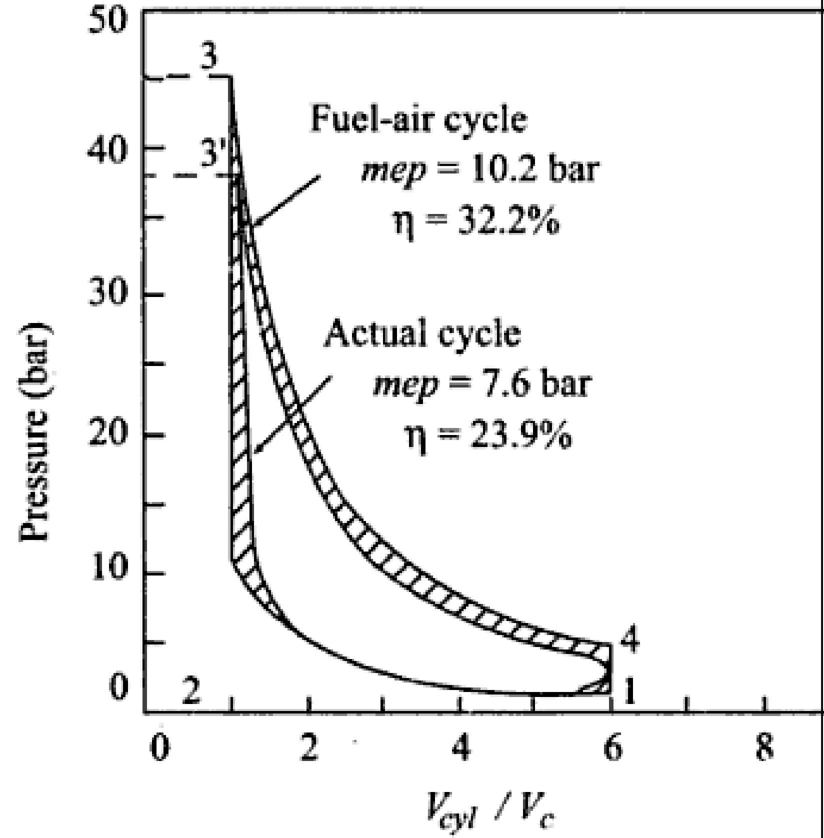


Fig. spark advance at (a) 0° and (b) 35° in Petrol Engine

Actual Cycle

Burning Time Loss

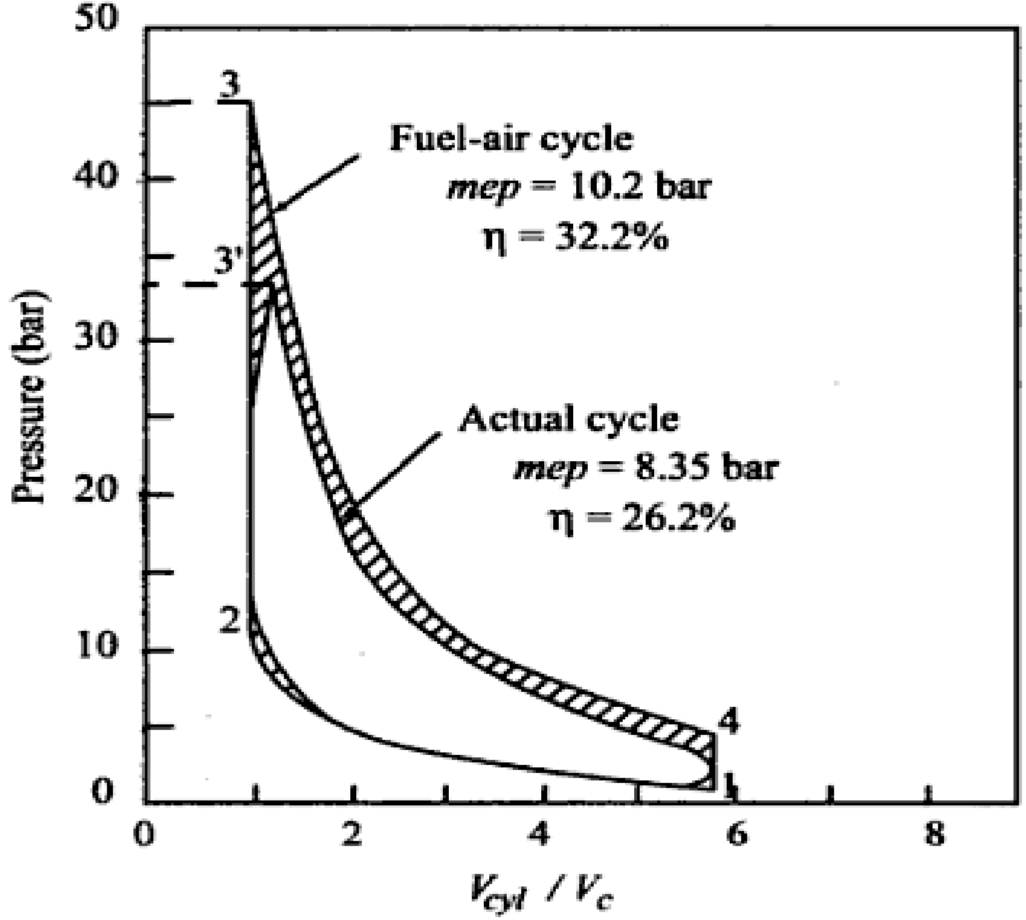


Fig. optimum spark advance (15°- 30°) in Petrol Engine

Actual Cycle

Time Loss Factor

- Table shows the engine performance for various ignition timings (r_c =6).
- The effect of spark advance on the power output by means of the p-V diagram

Cycle	Ignition advance	Max. cycle pressure bar	*mep* bar	efficiency %	$\frac{\text{Actual } \eta}{\text{Fuel cycle } \eta}$
Fuel-air cycle	0°	44	10.20	32.2	1.00
Actual cycle	0°	23	7.50	24.1	0.75
"	17°	34	8.35	26.3	0.81
"	35°	41	7.60	23.9	0.74

Actual Cycle

Heat Loss factor

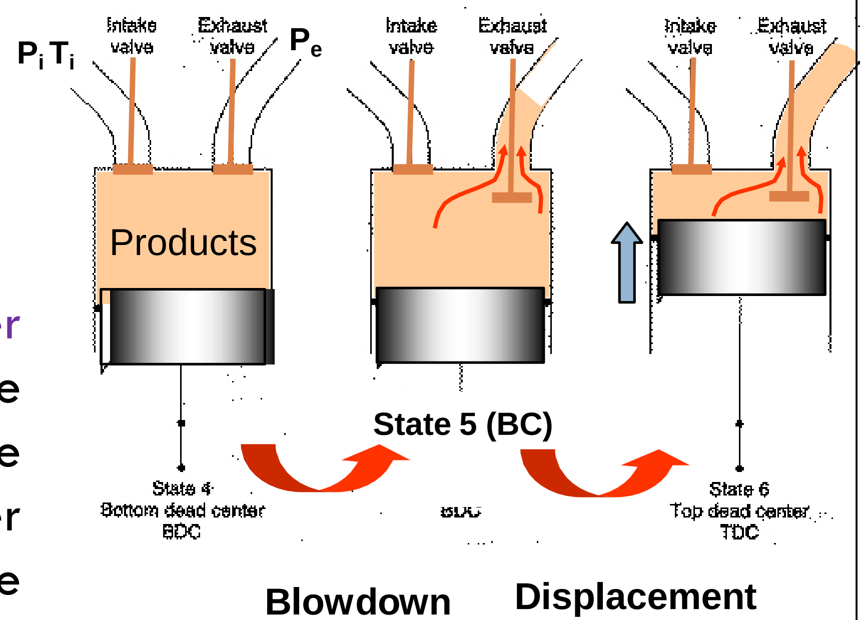
- Some part of combustion heat that passed through cylinder is taken away by the engine oil, cooling media and rest by radiation.
- As a result of loss of heat to the cylinder walls the work and efficiency of the cycle are reduced because some of the heat energy liberated by combustion is not utilized for producing work during expansion.
- However, the loss of heat during combustion reduces the maximum temperature, Specific heat and dissociation of CO_2 and H_2O is also reduced, which results in complete combustion, but the improvement in work and efficiency is only marginal.

Exhaust Gas Blowdown

The actual exhaust process consists of two phases:

i) Blowdown

ii) Displacement



Blowdown – At the end of the power stroke when the exhaust valve opens the cylinder pressure is much higher than the exhaust manifold pressure, so the cylinder gas flows out through the exhaust valve and the pressure drops to P_e.

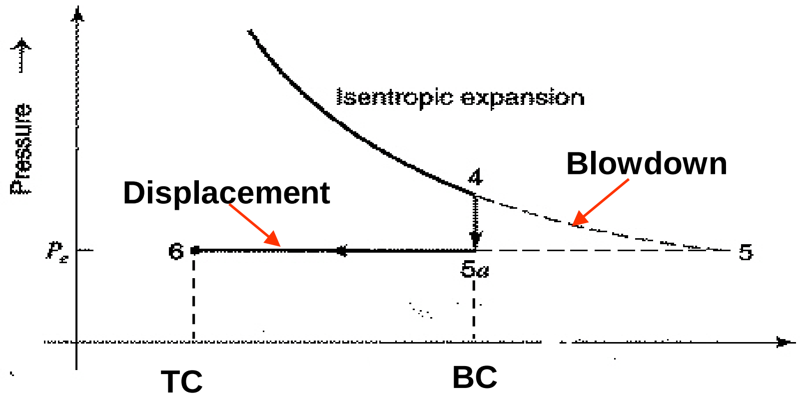
Displacement – Remaining gas is pushed out of the cylinder by the piston from BDC moving to TDC.

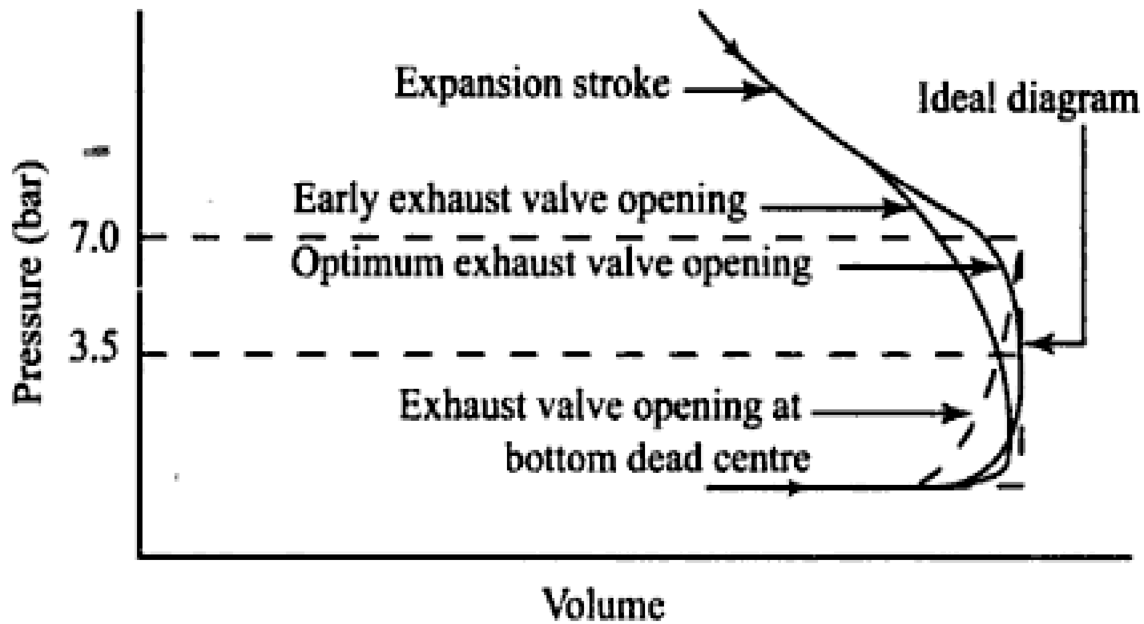
Actual Cycle

Exhaust Gas Blowdown

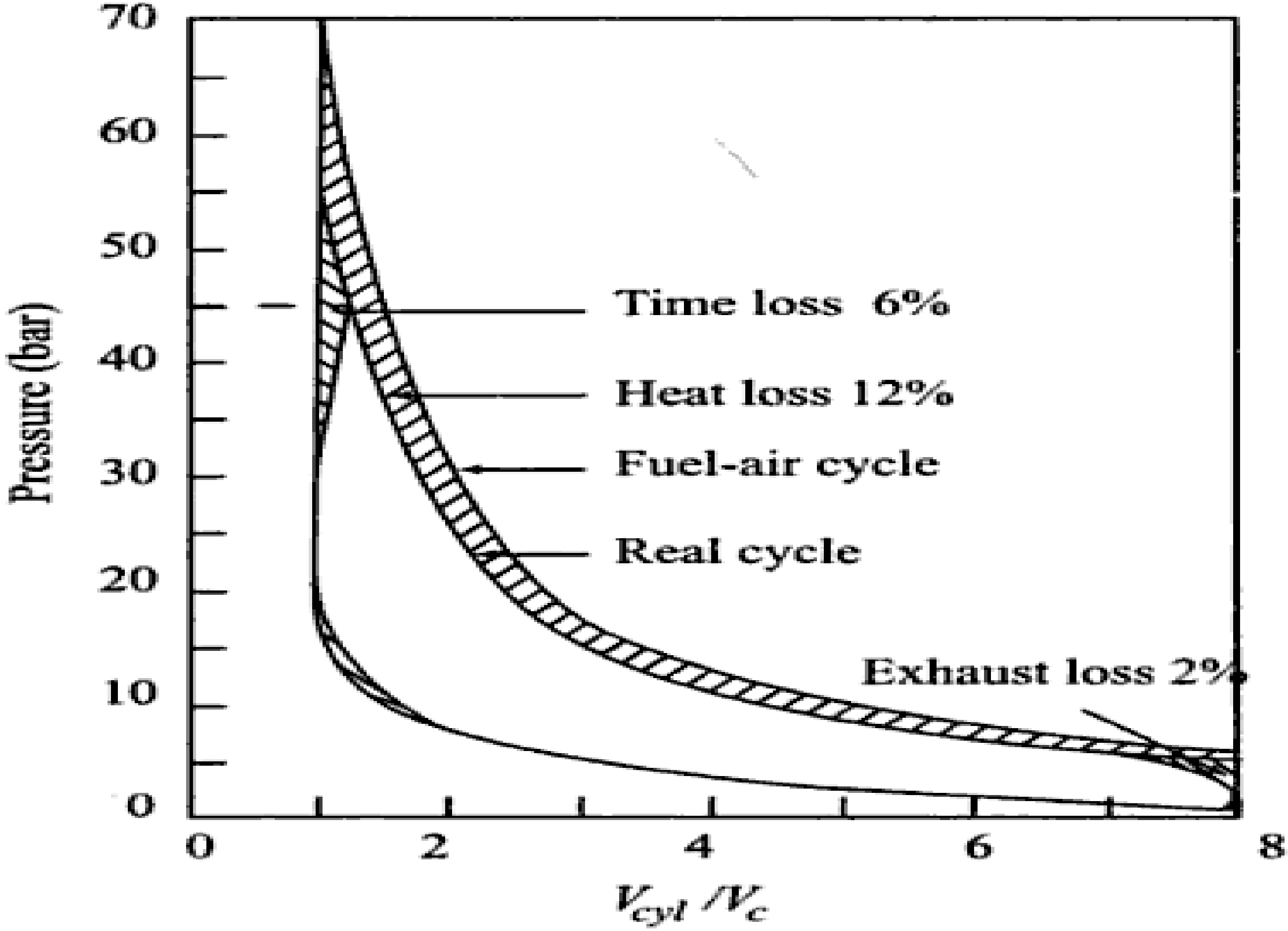
- The cylinder pressure at the end of expansion stroke is high as 7 bar depending on the compression ratio employed.
- If the exhaust valve is opened at BDC, the piston has to do work against high cylinder pressure during the early part of the exhaust stroke.
- If the exhaust valve is opened too early, a part of the expansion stroke is lost
- The best compromise is to open the exhaust valve 40^0 to 70^0 before BDC thereby reducing the cylinder pressure to halfway (say 3.5 bar) before the exhaust stroke begins

Exhaust Gas Blowdown





Actual Cycle



Loss due to Running Friction

- The losses are due to friction between
  - the piston and the cylinder walls
  - In various bearings
  - Energy spent in operating the auxiliary equipment (cooling pump, ignition system, fan…)
- The piston ring friction increases rapidly with engine speed.

Actual Cycle

Pumping loss (Gas Exchange)

- During the induction process, pressure losses occur as the charge passes through the air filter, the carburettor, the intake manifold and across the valve. So, the pressure during suction stroke is below atmosphere.
- The exhaust system consists of an exhaust manifold an exhaust pipe, and often a catalytic converter for emission control and a muffler or silencer. So, the pressure during the exhaust stroke is much higher than the atmosphere.

Actual Cycle

Pumping loss (Gas Exchange)

- The work done spend in expelling the exhaust gases and inducting fresh charge during the suction stroke is called the pumping work and the loop formed is called pumping losses.
- Pumping losses increase during throttle and also with increase in speed of engine.

Volumetric Efficiency

- The timing of intake and exhaust valves
  - Valve timing is the regulation of the points in the cycle at which the valves are set to open and close.
  - Valves requires a finite period of time to open or close for smooth operation

Valve Timing Diagram

Inlet Valve (Advance in Opening & Delay in Closing)

- Due to the effect of inertia and time required to attain the full opening the inlet valve opens somewhat earlier than TDC.
- The K.E. of charge produces a ram effect which force more charge into the cylinder during this additional valve opening.
- So to receive more charge, valve kept open for somewhat more after BDC. In high speed this delay is larger to take more advantage of ram effect.

Valve Timing Diagram

Exhaust Valve (Advance in Opening & Delay in Closing)

- Earlier opening of the exhaust valve before reaching to TDC facilitates the removal of the burnt gases by virtue of the pressure at this point.
- But It also causes some loss of useful work on this stroke. However the overall effect of opening the valve prior to the time the piston reaches BDC results in overall gain in output.
- By closing the exhaust valve a few degree after TDC allows better scavenge due to the velocity of fresh charge and exhaust gas.
- This results in increased volumetric efficiency.

Valve Timing Diagram

Ignition timing (Advance)

- There is time lag between spark and actual ignition.
- Therefore it is necessary to produce the spark before piston reaches the TDC to obtain proper combustion without losses. It is called as ignition advance or angle of advance.

Injection timing (Advance)

- The opening of the fuel valve before TDC is necessary for better evaporation and mixing of the fuel. As there is always lag between ignition and supply of fuel, it always necessary to supply the fuel little earlier.

Valve Timing Diagram

Overlapping & Scavenging

- It is more in diesel (45°) as compare to petrol (13°) because it is uneconomical as we loss some fuel in case of petrol.
- In 2 strokes also, scavenging for petrol is less than diesel due to the same reason.

4 Stroke – Valve Timing

"-" Advance "+" Delay

Process	Ref.	Petrol (Low Speed)	Petrol (High Speed)	Diesel
IVO	TDC	-10°	-10°	-25°
IVC	BDC	+15°	+50°	+30°
Spark or Injection	TDC	-15°	-40°	-15° to +25°
EVO	BDC	-25°	-55°	-45°
EVC	TDC	+5°	+20°	+15°
Suction		200°	240°	235°
Compression		170°	130°	150°
Power		155°	125°	135°
Exhaust		210°	255°	240°
Overlap		25°	30°	40°
Injection		-	-	40°

Port Timing Diagram

2 Stroke – Port Timing

"-" Advance "+" Delay

Process	Ref.	Petrol	Diesel
TPO	BDC	-35°	-45°
TPC	BDC	+35°	+45°
Spark or Injection	TDC	-20°	-15° to +20°
EPO	BDC	-43°	-60°
EPC	BDC	+43°	+60°
Suction		-	-
Compression		137°	120°
Power		137°	120°
Exhaust		86°	120°
Scavenging		70°	90°
Injection		-	35°

Thank You !