Fuel-air cycles

- Till now, we discussed **Air standard cycles**, which assumes air to be the working fluid of the cycles.
- The assumption of 'air-standard' simplifies the analysis, hence useful as an exercise to **understand** the processes as well to perform **crude comparison** between cycles and their applicability to a particular engine.
- However, air-standard cycles differ with the actual **indicator diagrams** (pressure vs sp. Volume diagram as measured during the operation of a real cycle) by a **huge margin**
- For example, for an SI engine with compression ratio 8, the actual thermal efficiency is about **28%** while air-starndard cycle predicts it to be **56%** - twice as much.

Fuel-air cycles

- To bridge the gap in an systematic manner, we use another assumption which is more realistic but not close the complexity of an actual cycle.
- The analysis based on the **actual properties** of the working fluid (**a mixture of air, fuel and residual gases from the pervious cycle**) is called a **fuel-air cycle**.
- This not-so-complicated assumption improves the predictability of the model by a great deal. The MEP (Mean effective pressure) and thermal efficiency values predicted from the fuel-air cycles are much closer to the actual indicated MEP or efficiency.
- This indicates that majority of the deviation from the air-standard cycle is due to the **deviation in fluid-properties** rather than the deviation in processes.

Unique features of fuel-air cycles

- The **actual composition** is considered to be the working fluid
- The **composition is not constant** throughout the cycle as relative amounts of CO_2, water vapour etc. changes with the fuel-air ratio which changes continuously during the cycle
- The **change in specific heat with temperature** is incorporated in the analysis
- Not all the combustion processes are complete. The fuel-air cycles include the effect of backward reaction (**dissociation**).
- Amount of **residual gases** affects the cycle performance as well

Assumptions

- Before the combustion, there is no side reaction, hence **no chemical change** of the working fluid
- Subsequent to combustion, the charge (working fluid) is under **chemical equilibrium**
- The standard assumptions of **no heat transfer** through the cylinder walls or strokes are **frictionless** are applicable to fuel-air cycles as well.
- The effect of **fluid motion** inside the cylinder is **neglected**.
- The fuel is **completely vapourised** inside the cylinder and **mixing** with air is perfect.
- All the **processes** (such as isobaric, isochoric or isentropic) are assumed to be similar to those of the air-standard cycles. For example, for constant volume heat addition process, fuel is assumed to be burnt instantaneously at the TDC (top dead center).

Model Performance

- After incorporating some of the effects from the actual engine processes, and keeping most of the simplifying assumptions, we obtain the fuel-air cycles.
- The efficiency of an actual engine is **~85%** of that estimated from the fuel-air cycle analysis (unlike 50% with air-standard cycles)
- The estimated **peak pressure** of the cycle matches closely with the actual value
- **Exhaust temperature** of the charge is also estimated closely.

Variation of specific heat

- Except mono-atomic gases, specific heat varies with T for all gases.
- For example, for air,

$$C_P\ @\ 300K = 1.005 kJ/kgK$$
$$C_P\ @\ 2000K = 1.345 kJ/kgK$$

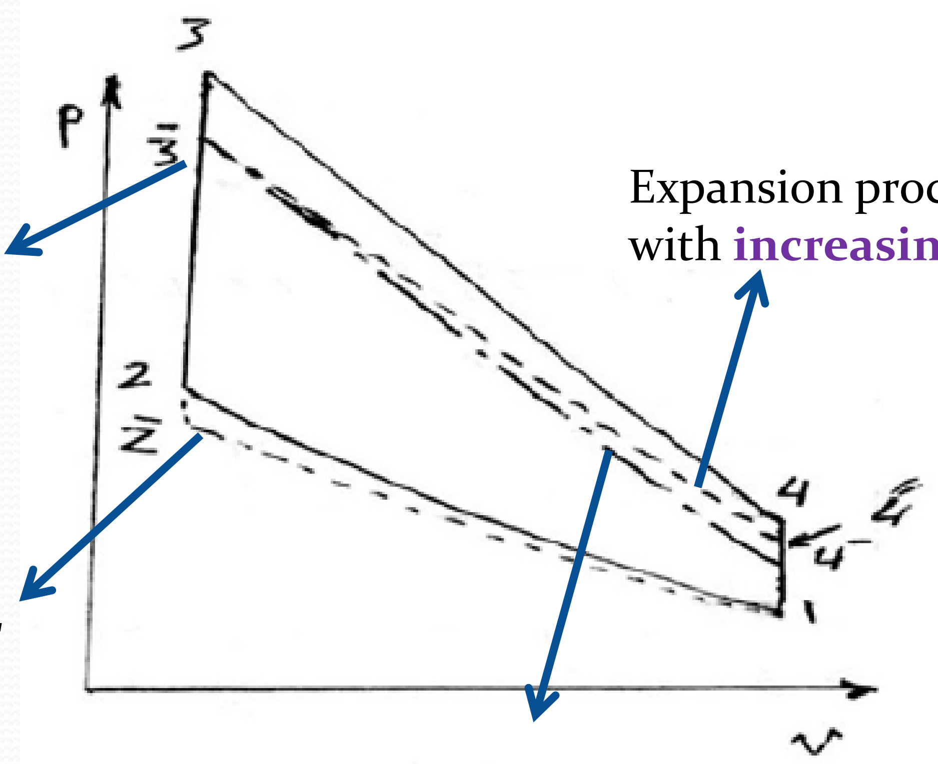
- Similarly,

$$C_V\ @\ 300K = 0.717 kJ/kgK$$
$$C_V\ @\ 2000K = 1.057 kJ/kgK$$

Variation of specific heat

- Since difference between C_P and C_V remains the same for all T, the value of **γ decreases with increase in T**.
- So, the **compression** and **expansion** processes are directly affected.
- With the inclusion of variation of specific heat, the **temperature and pressure** after the compression stroke will be **lower** than that of the air-standard cycle
- Same amount of heat will cause **less temperature-rise** due to increase in specific heat
- The **magnitude of the drop** in temperature is proportional to the drop in the value of ratio of specific heat

Variation of specific heat



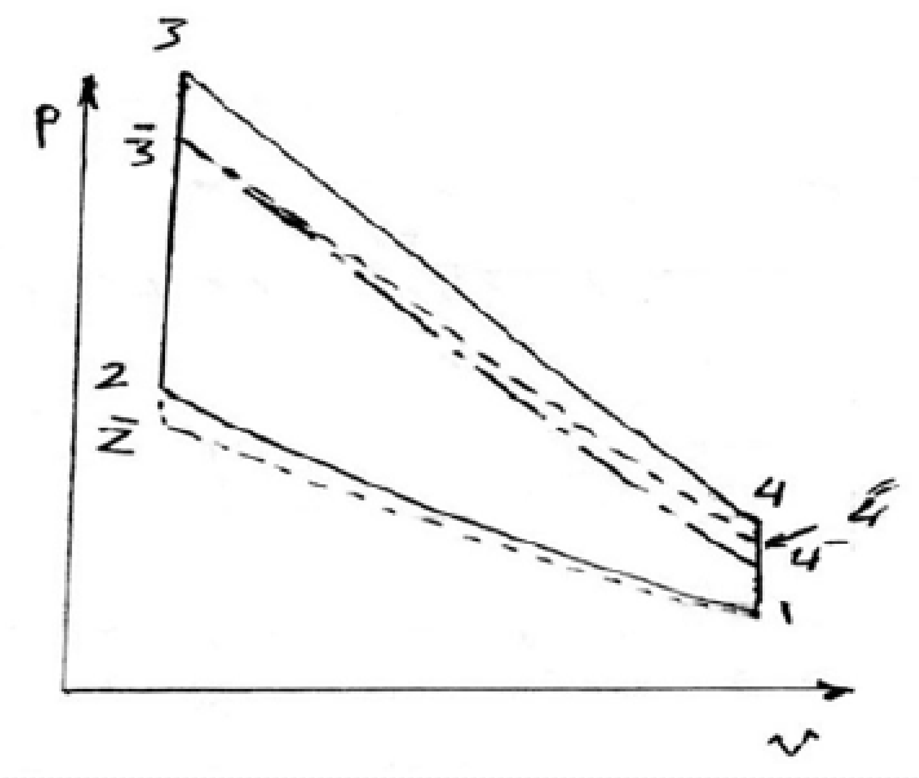
Reach lower P and T with **decreasing C_V**

Expansion process with **increasing γ**

Reach lower P and T with **decreasing γ**

Expansion process with **constant γ**

Variation of specific heat

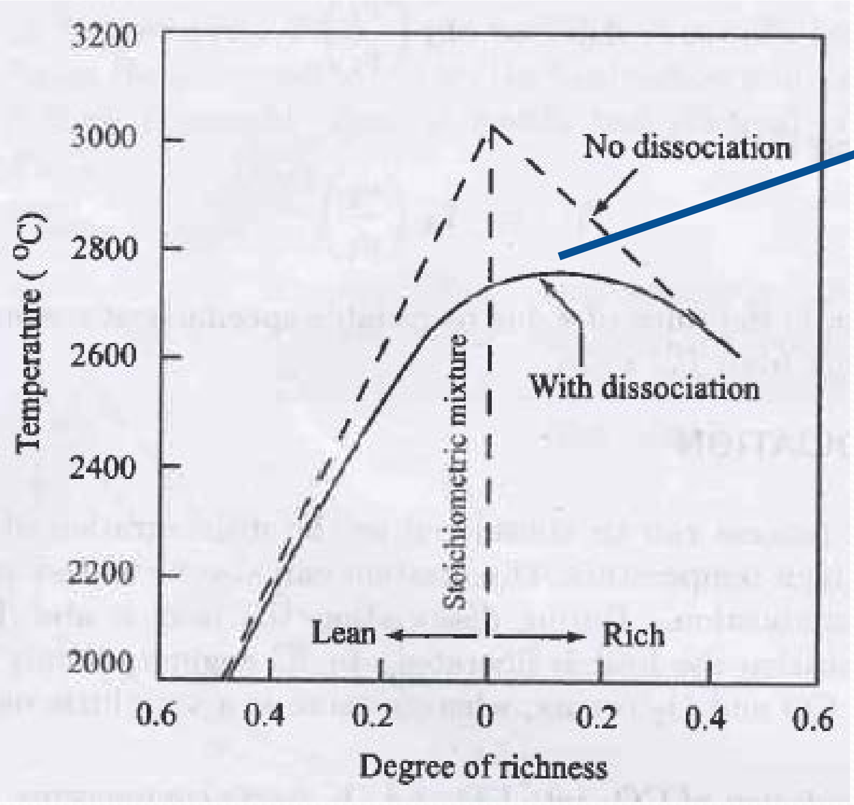


Variation of specific heat with T decreases output power and efficiency of an IC engine

Dissociation reaction

- Since chemical equilibrium as well as the rate of reaction depend on the composition of the air-fuel mixture, the degree of dissociation (or reverse reaction) is a function of A/F ratio.

Dissociation reaction



Maximum temperature is attained with little rich mixture

Dissociation reaction

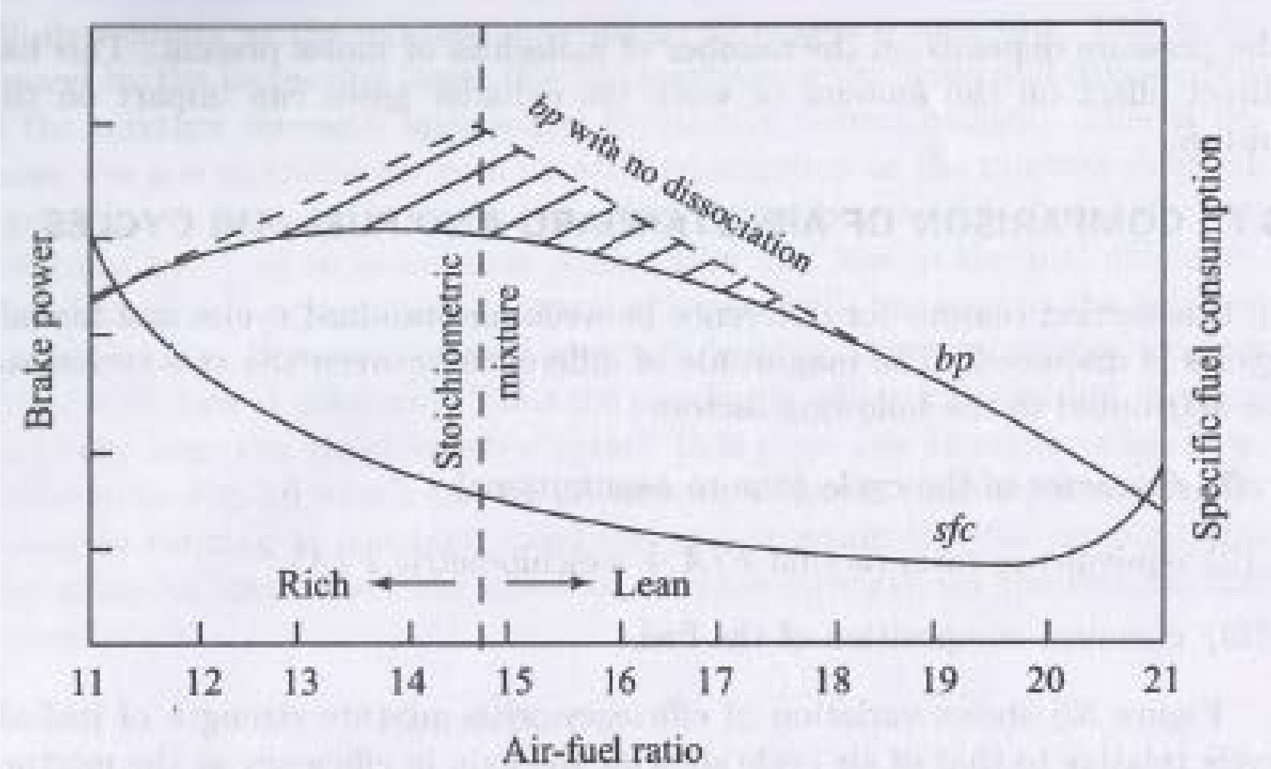


Fig. 3.3 Effect of dissociation on power

Dissociation reaction

Dissociation reduces
maximum pressure and temp

Isentropic expansion
with recombination

Isentropic expansion
without recombination

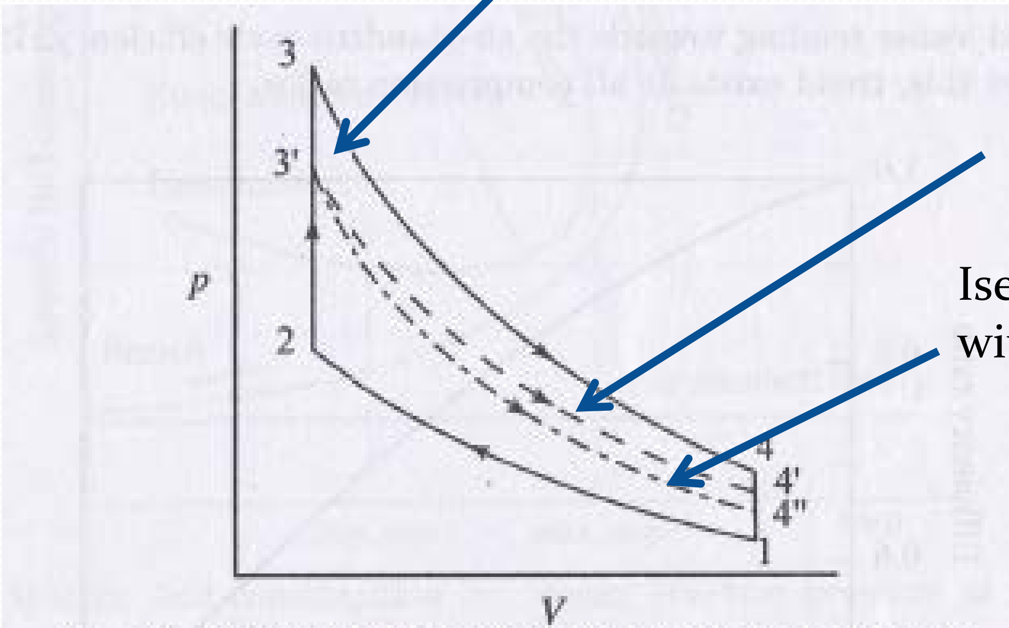


Fig. 3.4 Effect of dissociation shown on a p-V diagram