Internal Combustion Engines (ICE's)

→ These are the standard 4-stroke gasoline fueled engines in most of your cars. The cycle is named the Otto Cycle after the German inventor Nicolaus Otto who 1st ran the cycle in late 1800s. The Otto Cycle is very similar to the Brayton Cycle

1→2) Compression ← Typically isentropic

2→3) Combustion

3→4) Expansion

4→0) Heat Rejection

0→1) Recharge/Intake

the difference between the Brayton & Otto is that the Otto is not continuous. The Otto cycle occurs in a piston→cylinder device

☆ Show figure.

→ The Diesel cycle is very similar to the Otto cycle, except that the combustion & expansion processes are combined through the use of fuel injection during combustion. The heat transfer occurs at constant pressure, not volume like the Otto.

ICE Definitions

Compression Ratio: $CR = \frac{V_{displacement} + V_{clear}}{V_{disp}}$

Displacement Volume = Volume Swept by Cylinder $= V_{disp} = \pi \frac{d_{bore}^2}{4}(\text{stroke})$ ← distance piston travels

$V_{BDC} = V_{clear} + V_{disp}$

Clearance Volume = Volume in Cylinder @ Top Dead Center $= V_{clear} = \frac{V_{disp}}{(CR-1)}$

Mean Effective Pressure $= MEP = \frac{W_{net}}{(v_1 - v_2)} \Rightarrow W_{net} = P_{const}(v_1 - v_2)$

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Example: Comparison of Otto & Diesel Cycles

a) Calculate & plot the thermal efficiency & mean effective pressure for an air standard Otto Cycle for compression ratios between 5 & 35 with a maximum cycle temperature of 2,500K. Assume that the state of the air before compression is 300K, 1bar.

Open EES & create subprogram

Subprogram Otto (CR: eta_Otto, mep_Otto) "allows program to be called later"

→Define State 1 T[1]=300[K]
P[1]=1[bar]*convert(bar, Pa)
v[1]=volume(Air, T=T[1], P=P[1])
u[1]=intEnergy(Air, T=T[1])
s[1]=entropy(Air, T=T[1], P=P[1])

→Define State 2 s[2]=s[1] ⇐ isentropic compression, What other property can we get?
v[2]=v[1]/CR ⇐ constant mass compression
T[2]=temperature(Air, s=s[2], v=v[2])
P[2]=pressure(Air, s=s[2] v=v[2])
u[2]=intenergy(Air, s=s[2] v=v[2])
W_12=u[2]-u[1] → work per unit mass compression (into system)

→Define State 3 T[3]=2500[K]
v[3]=v[2] ⇐ constant volume heat addition
u[3]=intenergy(Air, T=T[3])
s[3]=entropy(Air, T=T[3], v=v[3])
P[3]=pressure(Air, T=T[3], v=v[3])
W_23=0 ⇐ ΔV=0, Q_23=u[3]-u[2]

```
→Define State 4 v[4]=v[1] "back@BDC"
        s[4]=s[3]  "isentropic expansion"
        T[4]=temperature(Air,s=s[4],v=v[4])
        P[4]=pressure(Air,s=s[4],v=v[4])
        u[4]=intenergy(Air,s=s[4],v=v[4])
       W_34=u[3]-u[4]    "Work out of system per unit mass"
→For Cycle  W_net_otto=(W_34+W_23-W_12)
      eta_otto= W_net_otto/q_23
      mep_otto=W_net_otto/(v[1]-v[2])
end
```

Now test it:

```
    CR=15
    Call Otto(CR: eta_Otto, mep_Otto)
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→ Works

$\eta_{otto}=0.596$

$MEP_{otto}=1.142 MPa$

B) Calculate & plot the thermal efficiency & MEP for an air standard diesel cycle for compression ratios between 6 & 55 with a maximum cycle temperature of 2,500K. Assume air coming in is at 300K, 1bar.

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Subprogram Diesel(CR: eta_diesel, mep_diesel)
  Copy & paste up to State 3:
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→Define State 3  T[3]=2500[K]
                 P[3]=P[2]
                 v[3]=volume(Air,T=T[3],P=P[3])
                 u[3]=intenergy(Air,T=T[3])
                 s[3]=entropy(Air,T=T[3],v=v[3])
                 q_23-W_23=u[3]-u[2]      "energy balance 2→3"
                 W_23=P[3]*(v[3]-v[2])
→Define State 4  v[4]=v[1]
                 s[4]=s[3]
                 T[4]=temperature(Air,s=s[4],v=v[4])
                 P[4]=pressure(Air,s=s[4],v=v[4])
                 u[4]=intenergy(Air,s=s[4],v=v[4])
                 W_34=u[3]-u[4]     "work out of cycle"
→For Cycle  W_net_Diesel=W_34+W_23-W_12
            eta_diesel=W_net_diesel/q_23
            mep_diesel=W_net_diesel/(v[1]-v[2])
end
```

test Call Diesel(CR:eta_diesel, mep_diesel) η_D= ~~0.42~~

→Make Table, vary CR from 5→35, Plot η vs. CR

MEP=~~1.2~~kPa

Conclusions: 1) Efficiency of Otto is higher @ all CR's

2) MEP (and thus work per cycle) of Diesel is higher @ CR>11, 3) Both MEP have maximum Otto≈15 Diesel≈28

4) CR's in real engines are not this high due to irreversibilities, lots of them

But the CR for Diesel is usually 2x that of 4 stroke. Show EES animations