ME 410 Day 5

Topics

- Review
- Fuel Conversion Efficiency
- Fuel Air Ratio
- Volumetric Efficiency
- Road Load Power
- Relationships between performance parameters

Fuel Conversion Efficiency

This is the ratio of power actually produced to the energy found in the fuel.

$$\eta_f = \frac{P}{\dot{m}_f Q_{HV}}$$

The symbol Q_{HV} is the heating value of the fuel, units being energy/mass.

Please note that at this phase we have two different engine efficiencies to discuss.

- Mechanical efficiency η_m (This varies depending on operating condition. Can be high as 90%, or as low as 0% at idle.)

- Fuel conversion efficiency (enthalpy efficiency) η_f (This is one of several thermodynamic efficiencies.) It is a fairly strong function of the engine's compression ratio.

Fuel Air Ratio

(And Air Fuel Ratio)

$$F/A = \frac{\dot{m}_f}{\dot{m}_a}$$

$$A/F = \frac{\dot{m}_a}{\dot{m}_f}$$

Ratios involving the mass flow rate of air and the mass flow rate of fuel.

May as well mention this here..

For a given fuel there is an ideal or stoichiometric F/A or A/F for complete combustion of the fuel with no excess air. This is called the stoichiometric fuel air or air fuel ratio. Symbols are

$$(F/A)_s \text{ and } (A/F)_s$$

- SI Engines $12 \le A/F \le 18$
- CI Engines $18 \le A/F \le 70$

The diesels operate much leaner.

Volumetric Efficiency

This measures the efficiency of the induction of air and or mixture into the cylinder. (Applicable to 4-stroke only)

It is defined as the ratio of actual air volumetric flow rate into the cylinder divided by the maximum theoretical volumetric flow rate.

The maximum theoretical volumetric flow rate is the rate at which cylinder volume is displaced during intake strokes.

$$\dot{V}_{th} = \frac{V_d N}{2}$$

The “2” is there because there is an intake every second revolution.

The actual volumetric flow rate is

$$\dot{V}_{air} = \frac{\dot{m}_a}{\rho_{a,i}}$$

where $\rho_{a,i}$ stands for the inlet air density. The ratio is the volumetric efficiency

$$\eta_v = \frac{\dot{V}_{air}}{\dot{V}_{th}} = \frac{2\dot{m}_a}{\rho_{a,i} V_d N}$$

If we actually know m_a the mass of the air inducted per cycle we can write

$$\eta_v = \frac{m_a}{\rho_{a,i} V_d}$$

- Naturally aspirated engines -- 80-90%
- CI is slightly higher than SI

Road Load Power

The formula in the text is mostly applicable to cars. The overall concept is that we can estimate the power needed to drive a vehicle by recognizing two resistances

- Rolling resistance. Force is proportional to the vehicle weight.

  $$F_{roll} = C_R W_v = C_R M_v g$$

  Here C_R is coefficient of rolling resistance. (Strongly tire related. Values from 0.012 to 0.015 for cars)

- Aerodynamic resistance. Force is proportional to frontal area of vehicle, and to the vehicle speed squared.

  $$F_{air} = \frac{1}{2}\rho_a C_D A_v S_v^2$$

  here C_D is the drag coefficient, $(0.3 \le C_D \le 0.5)$, A_v is the frontal area, ρ_a the air density, and S_v the vehicle speed.

Therefore the power which is force times speed looks like,

$$P_r = (F_{roll} + F_{air})S_v$$

What follows is a sample calculation of road load power with EES.

A car with drag coefficient of 0.4 and rolling resistance coefficient of 0.012 is travelling at 60 mph. Vehicle weight is 2400 lb. Vehicle frontal area is 15 ft^2. How much power is needed to produce this driving condition?

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"Vehicle Data"

C_R = 0.012
C_D = 0.4
A_v = 15                                                        "[ft^2]"
W_v = 2400                                                      "[lbf]"

"Atmospheric Data"

T1=59                                                      "[F]"
P1=1                                                            "[atm]"
rho_air=DENSITY(Air,T=T1,P=P1) *convert(lbm,slug)"[slug/ft^3]"

"Speed Data"

S_v = 60*convert(mph,ft/sec)                                    "[ft/sec]"

"Power Calculation"

P_r = ( C_R * W_v + 1/2*rho_air*C_D*A_v*S_v^2)*S_v"[ft-lbf/sec]"

P_hp = P_r*convert(ft-lbf/sec,hp)                                    "[hp]"

“The result is 13.44 hp.  What do you think?”
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Relationships between the Parameters (Section 2.14)

Start with Power...

$$P = \frac{W_c N}{n_R}$$

But ..

$$W_c = \eta_f m_f Q_{HV}$$

And..

$$m_f = m_a (F/A)$$

So substituting back up the chain..

$$P = \frac{\eta_f m_a N Q_{HV} (F/A)}{n_R}$$

Bringing back a previous equation ..

$$\eta_v = \frac{m_a}{\rho_{a,i} V_d} \qquad \text{so} \quad m_a = \eta_v \rho_{a,i} V_d$$

$$P = \frac{\eta_f \, \eta_v \, \rho_{a,i} \, V_d \, N Q_{HV} (F/A)}{2}$$

(n_R is 2 for 4-stroke.)

Depending on how we interpret work/cycle and the fuel conversion efficiency, this can be either brake power or indicated power.

Dividing by $2\pi N$ gives torque.

$$T = \frac{\eta_f \, \eta_v \, \rho_{a,i} \, V_d \, Q_{HV} (F/A)}{4\pi}$$

We recall the mep formula,

$$mep = \frac{P n_R}{V_d N} = \frac{2P}{V_d N}$$

and combining with the formula for P,

$$mep = \eta_f \, \eta_v \, \rho_{a,i} \, Q_{HV} (F/A)$$

Finally, specific power is power per piston area, A_p. When we divide V_d by A_p, L results.

$$\frac{P}{A_p} = \frac{\eta_f \, \eta_v \, \rho_{a,i} \, L N Q_{HV} (F/A)}{2}$$

Now using $\overline{S}_p = 2LN$

$$\frac{P}{A_p} = \frac{\eta_f \, \eta_v \, \rho_{a,i} \, Q_{HV} (F/A)}{4} \overline{S}_p = \frac{1}{4} mep \, \overline{S}_p$$

For high power, torque, mep, and specific power we need

- high fuel conversion efficiency
- high volumetric efficiency
- high inlet air density (hence supercharging and turbocharging)
- Max possible F/A
- High mean piston speed

Unfortunately, these variables are not independent. For example, the fuel conversion efficiency depends on the F/A ratio. Use with caution.