ME419
D. L. Abata, November 2, 2016

Useful Equations

Displacement Volume, Compression Ratio, and Mean Piston Speed

$$V_d = \frac{\pi}{4}B^2 \cdot S \cdot n_{cyl} \quad \varepsilon \equiv \frac{V_{max}}{V_{min}} = \frac{V_c + V_d}{V_c} \quad S_p \equiv \frac{2 \cdot S \cdot N}{60}$$

Work, Power, and Efficiencies

Work (per revolution) $W = 2\pi T$

Power in kW (*N in rpm, all other units are SI*) $P = \frac{W}{t} = \frac{2\pi TN}{60000} = \frac{mep \cdot VN}{60 \cdot x}$

Indicated Power $IP = BP + FP$

Power in kW (*N* in rpm, *Hu* in kJ/kg, all other units are SI)

$$IP = \frac{\eta_v p_{in}}{RT_{in}} \cdot x_a \cdot \frac{V_d N}{60 \cdot x} \cdot Hu \cdot FA \cdot \eta_i \quad \text{and} \quad BP = \frac{\eta_v p_{in}}{RT_{in}} \cdot x_a \cdot \frac{V_d N}{120} \cdot Hu \cdot FA \cdot \eta_i - FP$$

Where η_v and η_i are volumetric and indicated thermal efficiencies

Mechanical Efficiency $\eta_m = \frac{BP}{IP}$

Volumetric Efficiency $\eta_v \equiv \frac{\dot{m}_a}{\dot{m}_{a,ideal}} = \frac{\dot{m}_a}{\frac{\rho V_d N}{60 \cdot x}}$

Mean Effective Pressure (also imep, bmep, fmep)

$mep \equiv \frac{W}{V_d}$, $mep = \frac{60 \cdot x \cdot P}{V_d \cdot N}$ (x=1 for two stoke, x=2 for four stroke)

Fuel Air Ratio and Fuel Consumption $FA \equiv \frac{\dot{m}_f}{\dot{m}_a} = \frac{m_f}{m_a}$

$\dot{m}_f = \frac{P}{Hu \cdot \eta_o}$, and $sfc = \frac{\dot{m}_f}{P} = \frac{1}{Hu \cdot \eta_o}$ $\quad sfc\left(in\ \frac{g}{kW \cdot hr}\right) = \frac{3.6 \times 10^6}{Hu \cdot \eta_o}$ (*Hu* is in kJ/kg)

$AF = \frac{m_a}{m_f} = \frac{M_a}{M_f} \cdot \frac{p_a}{p_f} = \frac{M_a}{M_f} \cdot \frac{p_{tot} - p_f}{p_f}$ where pf = partial pressure (vapor pressure) of the fuel

Air displacement correction factor $x_a = \frac{1}{1 + FA \cdot \frac{M_a}{M_f} + h \cdot \frac{M_a}{M_w} + \frac{m_{EGR}}{m_a} \cdot \frac{M_a}{M_{EGR}}}$ where *h = specific humidity*

Brake specific emissions of pollutant 'X' $bsX = \frac{\dot{m}_x\,(3.6 \times 10^6)}{BP}$

where $\dot{m}_x = \dot{m}_{exh} \cdot y_x \cdot \frac{MW_x}{MW_{exh}}$ and $BP = \frac{2\pi TN}{60000}$

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Turbochargers

Compressors $W_{c,s=c} = c_p T_1 \left[\left(\frac{p_2}{p_1} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right]$ $W_{c,actual} = c_p (T_2 - T_1)$ $\eta_c = \frac{W_{c,s=c}}{W_{c,actual}}$

Turbines $W_{t,s=c} = c_p{}' T_5 \left[1 - \left(\frac{p_6}{p_5} \right)^{\frac{\gamma'-1}{\gamma'}} \right]$ $W_{t,actual} = c_p{}' (T_5 - T_6)$ $\eta_t = \frac{W_{t,actual}}{W_{t,s=c}}$

Pressure Ratio $\frac{p_2}{p_1} = \left\{ 1 + \eta_t \cdot \eta_c \cdot \eta_m \cdot \frac{T_5}{T_1} \cdot \frac{c_p{}'}{c_p} \left[1 - \left(\frac{p_6}{p_5} \right)^{\frac{\gamma'-1}{\gamma'}} \right] \right\}^{\frac{\gamma}{\gamma-1}}$ where $\eta_m \approx 1$ (mechanical efficiency)

Friction

Force required to move two parallel plates (fundamental) $F = \tau \cdot A = A \cdot \mu \frac{du}{dy} = A \cdot \frac{U}{\delta y}$

Force required to rotate a bearing (e.g. journal bearings) $F_f = \mu \frac{U \cdot l \cdot D}{C_r} \cdot \frac{\pi}{\sqrt{1-\varepsilon^2}}$

Power required to rotate a bearing $P_f = F_f \cdot U = \mu \frac{U^2 \cdot l \cdot D}{C_r} \cdot \frac{\pi}{\sqrt{1-\varepsilon^2}}$

Force required to move two plane surfaces (e.g. piston rings) $F_l = \frac{6 \cdot \mu \cdot U \cdot a^2}{h_o^2} \left[\ln(1+m) - \frac{2m}{m+2} \right]$

Friction force per unit length $F_f = f \cdot F_l$

Friction coefficient $f = K_l \sqrt{\frac{\mu \cdot U}{F_l}}$

For SI engines $fmep = 97 + 15 \cdot \left(\frac{N}{1000} \right) + 5 \cdot \left(\frac{N}{1000} \right)^2$

For DI (direct injection) engines $fmep = 75 + 48 \cdot \left(\frac{N}{1000} \right) + 0.4 \cdot {S_p}^2$

For IDI (indirect injection) engines $fmep = 144 + 48 \cdot \left(\frac{N}{1000} \right) + 0.4 \cdot {S_p}^2$