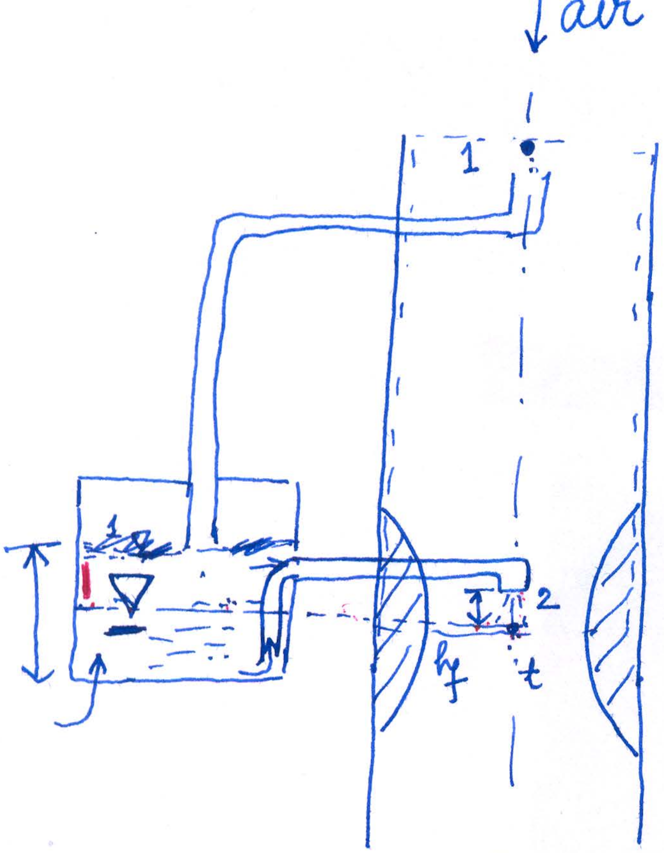
28/3/17 (1)



1 - up in barrel

t - throat minimum c-s

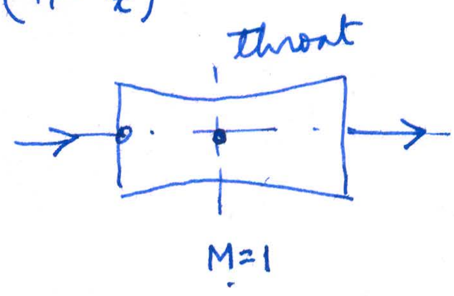
$$\cancel{\dot{Q}} - \cancel{\dot{W}} = \dot{m}\left(h + \frac{V^2}{2} + gz\right)_t - \dot{m}\left(h + \frac{V^2}{2} + gz\right)_1$$

$$h_t + \frac{V_t^2}{2} = h_1 + \frac{V_1^2}{2}$$

$$\frac{V_t^2}{2} = (h_1 - h_t) = c_p(T_1 - T_t)$$

$$V_t = \sqrt{2c_p(T_1 - T_t)}$$

$$c_p = \frac{\gamma R}{\gamma - 1}$$



$$V_t = \sqrt{\frac{2\gamma R T_1}{\gamma-1}\left(1 - \frac{T_t}{T_1}\right)}$$

$$= \sqrt{\frac{2\gamma R T_0}{\gamma - 1}\left(1 - \frac{T_t}{T_0}\right)} \quad T$$

$$c_p T_0 = c_p T + \frac{V^2}{2}$$

$0 \rightarrow$ total or stagnation

$$T_0 = T + \frac{V^2}{2c_p}$$

$$\frac{T_0}{T} = 1 + \frac{V^2}{\frac{2\gamma R}{\gamma - 1} T} \qquad \gamma R T = a^2$$

$$a = \sqrt{\gamma R T}$$

$$= 1 + \left(\frac{\gamma-1}{2}\right)\frac{V^2}{\gamma R T}$$

$$= 1 + \left(\frac{\gamma - 1}{2}\right) M^2 \qquad M = \frac{V}{a}$$

= Mach number

$$= 1 + \frac{\gamma - 1}{2}$$

$$= \frac{\gamma+1}{2} = \frac{1.4+1}{2} = \frac{2.4}{2} = 1.2$$

$$\frac{T_0}{T} = \left(\frac{P_0}{P}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{P_1}{P_t}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\dot{m}_a = C_{Dt}\, \rho_t\, A_t\, V_t \qquad \rho$$

$$= C_{Dt} \cdot \frac{P_t}{R T_t} \cdot A_t \cdot V_t$$

$$= C_{Dt} \cdot \frac{P_0\left(\frac{P_t}{P_0}\right)}{R T_0 \left(\frac{T_t}{T_0}\right)} \cdot A_t \cdot V_t$$

$$= C_{Dt} \cdot \left(\frac{P_t}{P_0}\right)^{\frac{1}{\gamma}} \cdot \frac{A_t P_0}{\sqrt{R T_0}} \cdot \sqrt{\frac{2\gamma}{\gamma-1}\left(1 - \frac{T_t}{T_0}\right)}$$

$1 \rightarrow 0$ stagnation condition because velocity is zero.

For fuel

$$\frac{p_1}{\rho} + \cancel{\frac{v_1^2}{2}} + gz_1 = \frac{p_2}{\rho} + \frac{V_2^2}{2} + gz_2$$

$$\frac{V_2^2}{2} = \frac{p_1 - p_2}{\rho} - gh_f$$

$$= \frac{(p_1 - p_2) - \rho g h_f}{\rho}$$

$$V_2 = \sqrt{\frac{2\left[(p_1 - p_2) - \rho g h_f\right]}{\rho}}$$

ρ = density of fuel.

$p_2 = p_t$

$p_1 = p_0$

$$\boxed{\dot{m}_f = C_{Dc} \rho_f A_f V_2}$$

$$\dot{m}_f = C_{Dc} \rho_f A_c V_c$$

$\rho_f \Downarrow \rho$, $V_c \Downarrow V_2$

$$= C_{Dc} \cdot \rho_f \cdot A_c \cdot \sqrt{\frac{2p_1}{\rho}\left(1 - \frac{p_2}{p_1} - \frac{\rho_f g h_f}{p_1}\right)}$$

$c \rightarrow$ capillary

$C_{Dc} \rightarrow$ Discharge coefficient of capillary

$C_{Dt} \rightarrow$ Discharge coefficient of throat

$A_c = \checkmark$

$$V_t = \sqrt{\frac{2 \times 1.4 \times 287 \times 300}{1.4 - 1}\left(1 - \frac{1}{1.2}\right)}$$

$= 317$ m/s

$$0.194 = 0.94\ \frac{101 \times 10^3 \times \cancel{1.89}\ (1/1.89)}{287 \times 300 \times 0.833}\ A_t \cdot 317$$

$= \cancel{0.658}\ 0.7 \times 317\ A_t$

$$A_t = \frac{0.194}{0.7 \times 317} = 8.7 \times 10^{-4}\ m^2$$

$$\frac{T_0}{T_t} = \left(\frac{P_0}{P_t}\right)^{\frac{\gamma - 1}{\gamma}}$$

$$1.2 = \left(\frac{P_0}{P_t}\right)^{\frac{1.4-1}{1.4}}$$

$$\frac{P_0}{P_t} = (1.2)^{\frac{1.4}{.4}}$$

$= 1.89$

Each barrel throat area $= \frac{8.7 \times 10^{-4}}{2}\ m^2$

$= 4.37 \times 10^{-4}\ m^2$

diameter of throat d_t

$$\frac{\pi}{4} d_t^2 = 4.37 \times 10^{-4}.$$

$$d_t = \frac{4.37 \times 10^{-4} \times 4}{\pi}$$

$= 0.0236$ m

$= 2.36$ cm

$d_c = 1.14$ mm

Lecture 14/3/17 continuation

(c) Lower heating value (LHV) of fuel. [MJ/kg]

(d) Energy released when one kg of this fuel is burned in the engine with a combustion efficiency of 98%

$C_4H_8 + 6(O_2 + 3.76N_2) \rightarrow 4CO_2 + 4H_2O + 22.56N_2$

$Q_{LHV} = Q_{HHV} - \Delta h_{vap}$; $Q_{HHV} = 46.9$ MJ/kg of fuel

$\Delta h_{vap} = h_{fg} = 2442.3$ kJ/kg of water

1 kmole fuel --- 4 kmole of H_2O

$C_4H_8 = 4 \times 12 + 8 \times 1 = 56$ kg/kmole

56 kg -- -- $4 \times 18 = 72$ kg of water

$H_2O = 2 \times 1 + 16 = 18$ kg/kmole

1 .. -- $\frac{72}{56} = \frac{9}{7}$ kg of water

1 . - - $\frac{9}{7} \times 2442.3$ kJ $= 3.1$ MJ

$\therefore$ $Q_{LHV} = (46.9 - 3.1)$ MJ $= 43.8$ MJ/kg of fuel (c)

(d) Heat released

$Q_{in} = 1 \times 43.8 \times 0.98 = 42.9$ MJ ~~kg~~.

Ambient 25°C

C_8H_{18} isooctane 20% excess air.

$$C_8H_{18} + 1.2 \times 12.5(O_2 + 3.76N_2) \rightarrow 8CO_2 + 9H_2O + 2.5O_2 + 56.4N_2$$

Partial pressure of H_2O: ↳ Mole fraction $y = \dfrac{9}{8+9+2.5+56.4} = \dfrac{30}{253}$

Total pressure i.e. atmospheric pressure = 101 kPa.

$$\therefore \quad P_{H_2O} = \frac{30}{253} \times 101 = 11.98 \text{ kPa.}$$

$$T_{sat} = 49.1^\circ C$$

⇒ Inlet air with relative humidity 55%.

$$\varphi = 55\% = 0.55 = \frac{P_v}{P_g}$$

absolute humidity $\omega = \cancel{m_a}\ \dfrac{m_v}{m_a}$

$$P_v V = m_v R_v T_m$$

$$P_a V = m_a R_a T_m$$

$$\frac{m_v}{m_a} \cdot \frac{R_v}{R_a} = \frac{P_v}{P_a}$$

$$\omega = \frac{P_v}{P_a} \cdot \frac{R_a}{R_v} = \frac{P_v}{P_a} \cdot \frac{R_u/M_a}{R_u/M_v}$$

$$= \frac{P_v}{P_a} \cdot \frac{M_v}{M_a}$$

$$= \frac{P_v}{P_a} \cdot \frac{18}{28.97}$$

$$= 0.622 \frac{P_v}{P - P_v}$$

$$= 0.622 \times \frac{1.74}{101 - 1.74}$$

$$= 0.0109$$

$$m_v = 0.0109 \times 15 \times 4.76 \times 29$$

$$= 22.57 \text{ kg}$$

$$N_v = 1.25 \text{ mole}$$

$P_{sat} @ 25^\circ C = 3.17$ kPa

$$\varphi = 0.55 = \frac{P_v}{P_g} = \frac{P_v}{3.17}$$

$$P_v = 1.74 \text{ kPa}$$

$$C_8H_{18} + 1.2 \times 12.5(O_2 + 3.76N_2) + 1.25H_2O \rightarrow 8CO_2 + 9H_2O + 2.5O_2 + 56.4N_2 + 1.25H_2O$$

$$y_v = \frac{10.25}{8 + 10.25 + 2.5 + 56.4} = 0.133$$

$$P_v = 13.42 \text{ kPa.}$$

$$T_{sat} = 51.42^\circ C$$

$C_8H_{18} + 12.5 \times (O_2 + 3.76 N_2) \rightarrow 8CO_2 + 9H_2O + 12.5 \times 3.76 N_2$

Reactant 700K, Product at 1200K

$C_p = 1.7113$ kJ/kg-K. $= 195.1$ kJ/kmol.K

$\bar{h}_f^o$ $C_8H_{18} = -208450$ kJ/kmol. (g)

$H_{react} = [-208450 + 195.1 \times (700-298)] + 12.5 \times [0 + 12499]$

$+ 12.5 \times 3.76 \times [0 + 11937]$

$= -130019.8 + 156237.5 + 561039$

$= 587256.7$ kJ/~~kmol~~

$H_{Prod} = 8 \times [-393522 + \overset{44473}{\cancel{17754}}] + 9 \times [-241826 + \overset{34506}{\cancel{14140}}] + 12.5 \times 3.76 \times [0 + 28109]$

$= -3337149$

$\therefore$ $Q_{in} = H_{Prod} - H_{react}$

$= -3337149 - 587256.7$

$= -3924405.7$ kJ/kmol of fuel

P182

A taxicab is equipped with a flexible-fuel four-cylinder SI engine running on a mixture of methanol and gasoline at an equivalence ratio of 0.95. How the air-fuel ratio changes when fuel flow to the engine shifts from M10 (10% methanol) to M85 (85% methanol)?

10% Methanol 90% gasoline by mass

CH_3OH ~~C_8H_{18}~~ C_8H_{15}

32 kg/kmole 111 kg/kmole

Number of mole 3.125×10^{-3} 8.1×10^{-3}

Mole fraction 0.278 0.722

$$0.722\ C_8H_{15} + 0.278\ CH_3OH + 8.9005\,(O_2 + 3.76 N_2) \rightarrow 6.054\ CO_2 + 5.971\ H_2O + 8.9005 \times 3.76\ N_2$$

$$\text{Stoichiometric } A/F = \frac{8.9005 \times 4.76 \times 28.97}{0.722 \times 111 + 0.278 \times 32} = 13.78$$

A/F ratio with $0.95 = \phi$;

$$= \frac{13.78}{0.95}$$

$$= \underline{14.51}$$

M85 85% Methanol 15% gasoline

Number of mole $\frac{0.85}{32} = 0.0266$ 1.35×10^{-3}

mole fraction 0.952 0.048

$$0.952\ CH_3OH + 0.048\ C_8H_{15} + 1.992\,(O_2 + 3.76 N_2) \rightarrow 1.336\ CO_2 + 2.264\ H_2O + 1.992 \times 3.76\ N_2$$

$$\text{Stoichiometric } A/F = \frac{1.992 \times 4.76 \times 28.97}{0.952 \times 32 + 0.048 \times 111}$$

$$= 7.67$$

$$A/F \text{ ratio} = \frac{7.67}{0.95} = \underline{8.08}.$$

P205 Ex.

A 5.6-liter V8 engine with a compression ratio of 10.2:1 is equipped with cylinder ~~cut-out~~ cutout, which converts it to a 2.8 liter four-cylinder engine at low load requirements. The engine operates on an Otto cycle using gasoline, and with eight cylinders at 1800 RPM it has an AF = 14.9, a volumetric efficiency of 57%, a combustion efficiency of 91%, and a mechanical efficiency of 92%. If cylinder cutout occurs, the engine speeds up to produce the same brake power output. Using only four cylinders at this condition, the engine has an AF = 14.2, a volumetric efficiency of 66% and a combustion efficiency of 99%, but a mechanical efficiency of only 90%. ~~At~~ Ambient temperature 27°C, pressure ~~of~~ 101 kPa.

$Q_{HV} = 43\ MJ/kg$

Calculate:

1. percent reduction in fuel consumption operating on four cylinders to produce same brake power output.

2. Engine speed needed to produce same power output using only four cylinders.

Ans $r_c = 10.2$, $\eta_{ith} = 1 - \frac{1}{r_c^{\gamma-1}} = 1 - \frac{1}{10.2^{1.35-1}} = 0.556.$

$$\eta_v = \frac{\dot m_a}{\rho_a V_d \frac{N}{60} \cdot \frac{1}{2}} = \frac{\dot m_a}{1.17 \times 5.6\times10^{-3} \times \frac{1800}{60}\cdot\frac{1}{2}} = \frac{\dot m_a}{0.09828} \qquad \rho_a = \frac{P_a}{RT_a} = \frac{101}{0.287\times300} = 1.17\ kg/m^3$$

$\dot m_a = 0.57 \times 0.09828 = 0.056\ kg/sec.$

$\dot m_f = \frac{0.056}{AF} = \frac{0.056}{14.9} = 3.76\times10^{-3}\ kg/sec.$

$$W_b = \text{Brake power} = \eta_m \times \underbrace{\left(\dot m_f \times Q_{HV} \times \eta_c\right) \times \eta_{ith}}_{\text{indicated power}} = 0.92 \times (3.76\times10^{-3} \times 43000 \times 0.91) \times 0.556 = 75.26\ kW$$

After cutout, $\eta_m = 0.9$, $\eta_c = 0.99$, η_{ith} same.

same power, $75.26 = 0.9 \times (\dot m_f \times 43000 \times 0.99) \times 0.556$; $\dot m_f = 3.53\times10^{-3}\ kg/sec$

% reduction $= (3.53 - 3.76)\times10^{-3} / 3.76\times10^{-3} = \underline{-6.12\%}$

Engine speed: $\eta_v = \frac{\dot m_a}{\rho_a V_d \frac{N}{60}\cdot\frac{1}{2}} \Rightarrow N = \frac{\dot m_a}{\eta_v \cdot \rho_a V_d \cdot \frac{1}{60}\cdot\frac{1}{2}} = \frac{3.53\times10^{-3} \times 14.2}{0.66 \times 1.17 \times 2.8\times10^{-3} \times \frac{1}{120}}$

$= \underline{2782\ RPM}$

A six-cylinder, 3.6-liter SI engine is designed to have a maximum speed of 6000 RPM. At this speed the volumetric efficiency of the engine is 0.92. The engine will be equipped with a two-barrel carburetor, one barrel for low speeds and both barrel for high speeds. Gasoline density can be considered to be 750 kg/m³. $T_a = 27^\circ C$, $P_a = 101$ kPa. AF ratio = 15.2, $h_f = 1.5$ cm

Calculate: $\gamma = 1.4$, $R = 287$ J/kg K

1. throat diameter for the carburetor ($C_{Dt} = 0.94$)
2. fuel capillary tube diameter ($C_{Dc} = 0.74$)

Ans: $\rho_a = \frac{P_a}{RT_a} = \frac{101}{0.287 \times 300} = 1.17$ kg/m³

$$\dot{m}_a = C_{Dt}\left(\frac{P_t}{P_0}\right)^{\frac{1}{\gamma}} \frac{A_t P_0}{\sqrt{RT_0}} \cdot \sqrt{\frac{2\gamma}{\gamma-1}\left(1-\frac{T_t}{T_0}\right)}$$

$T_0 = T_a =$ Ambient condition

$P_0 = P_a =$ " "

$P_t =$ Pressure at throat

$T_t =$ Temp at throat

$$\frac{T_0}{T_t} = \frac{\gamma+1}{2} = \frac{1.4+1}{2} = \frac{2.4}{2} = 1.2$$

$$\frac{P_0}{P_t} = \left(\frac{T_0}{T_t}\right)^{\frac{\gamma}{\gamma-1}} = 1.2^{\frac{1.4}{1.4-1}} = 1.893$$

$$\eta_v = 0.92 = \frac{\dot{m}_a}{\rho_a V_d \frac{N}{120}} \quad \therefore \dot{m}_a = 0.92 \times 1.17 \times 3.6 \times 10^{-3} \times \frac{6000}{120}$$

$$= 0.194 \text{ kg/sec}$$

$$0.194 = 0.94 \times \left(\frac{1}{1.893}\right)^{\frac{1}{1.4}} \times \frac{A_t \times 101 \times 10^3}{\sqrt{287 \times 300}} \cdot \sqrt{\frac{2 \times 1.4}{1.4-1}\left(1-\frac{1}{1.2}\right)}$$

$$= 0.94 \times 0.634 \times A_t \times 344.2 \times \frac{7}{6}$$

$$= 239.3\, A_t$$

$A_t = 8.1 \times 10^{-4}$ m² $= 8.1$ cm²

Area of each barrel $= \frac{8.1}{2} = 4.05$ cm².

$\frac{\pi}{4} d_t^2 = 4.05$. $\underline{d_t = 2.27 \text{ cm}}$.

$$\dot{m}_f = C_{Dc} A_c \sqrt{\frac{2 \rho_f P_1}{\rho}\left(1 - \frac{P_2}{P_1} - \frac{\rho g h_f}{P_1}\right)}$$

$\rho = 750$, $g = 9.8$, $h_f = 1.5$ cm $= 1.5 \times 10^{-2}$ m

$\frac{P_2}{P_1} = 0.528$,

$\dot{m}_f = \frac{0.194}{15.2} = 0.0128$ kg/sec

$$0.0128 = 0.74 \times A_c \times \sqrt{\frac{2 \times 750 \times 101 \times 10^3}{750}\left(1 - 0.528 - \frac{750 \times 9.8 \times 1.5 \times 10^{-2}}{101 \times 10^3}\right)}$$

$A_c = \cancel{6.074 \times 10^{-5}}$ m²

2.05×10^{-6}

$\therefore A_c$ of one: 1.024×10^{-6} m². $d_c = 1.14$ mm.