# Internal Combustion Engine 1

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# Examples

# Example 1

- Isooctane $C_8H_{18}$ is supplied to a four-cylinder spark-ignition engine at a rate of $2\ g/s$. Calculate the air flow rate required for stoichiometric combustion. If the engine operates at 1500 $rev/min$, estimate the mass of fuel and air entering each cylinder per cycle. The engine has a displaced volume of 2.4 *liters*. Determine the **volumetric efficiency** and calculate the **power output**, assuming a fuel **conversion efficiency of 0.3**.
  - Fuel is Isooctane $C_8H_{18}$
  - k = 4 number of cylinder
  - $m_f = 2\ g/sec = 0.002\ kg/sec$
  - $V_d = 2.4\ liters = 2.4 \times 10^{-3} m^3$

# Example 1 - Solution

- For stoichiometric combustion

$$C_aH_b + (a + \frac{b}{4})(O_2 + 3.76N_2) \rightarrow aCO_2 + \frac{b}{2}H_2O + 3.76(a + \frac{b}{2})N_2$$

- $a = 8$ and $b = 8$

$$C_8H_{18} + 12.5(O_2 + 3.76N_2) \rightarrow 8CO_2 + 9H_2O + 47N_2$$

$$(m_f)_{stoic} = n_f \times M_f \quad \text{and} \quad (m_a)_{stoic} = n_a \times M_a$$

- $(m_f)_{stoic} = 1 \times (8(12) + 18(1.008)) = 144.144\ kg$
- $(m_a)_{stoic} = 12.5 \times (32 + 3.76(28)) = 1716\ kg$

# Example 1 - Solution

$$(A/F)_{stoic} = \frac{(m_a)_{stoic}}{(m_f)_{stoic}} = \frac{1716}{114.144} = 15.03$$

To determine the actual air mass $(m_a)_{act}$ for a stoichiometric Air-Fuel ratio, we can use $(A/F)_{stoic}$.

$$(A/F)_{stoic} = \frac{(m_a)_{act}}{(m_f)_{act}} = \frac{(m_a)_{act}}{0.002} = 15.03$$

$$(m_a)_{act} = 0.03006\ kg/sec$$

# Example 1 - Solution

To find volume efficiency we use the following formula:

$$\eta_v = \frac{V_{a\ per\ cylce}}{V_d}$$

$$V_a = \frac{m_a}{\rho_a} \Rightarrow V_{a\ per\ cylce} = \frac{V_a}{cycle/sec}$$

$\rho_{\text{at } 25^\circ \text{ and } 1\ atm} = 1.184\ kg/m^3$

$$V_a = \frac{0.03006}{1.184} = 0.0254\ m^3/sec$$

# Example 1 - Solution

To find $V_{a\ per\ cycle}$ we need to convert $N$ from $rpm$ to $cycle/sec$, assuming a 4-stroke engine:

$$\text{No. of cycles per min.} = \frac{N}{2} = \frac{1500}{2} = 750\ cycle/min$$

$$\text{No. of cycles per sec.} = \frac{\text{No. of cycles per min.}}{60} = \frac{750}{60} = 12.5\ cycle/sec$$

$$V_{a\ per\ cylce} = \frac{0.0254}{12.5} = 2.032 \times 10^{-3}\ m^3/cycle$$

$$\eta_v = \frac{2.032 \times 10^{-3}}{0.0024} = 84.7\%$$

# Example 1 - Solution

$$\eta_f = \frac{P_{out}}{m_f \times Q_{HV}}$$

If $\eta_f = 0.3$

$$0.3 = \frac{P_{out}}{0.002 \times 44300}$$

$$P_{out} = 26.58\ kW$$

# Example 2

The molar composition of dry exhaust gas of a Propane-fueled SI engine ($C_3H_8$) is given below (water was removed before the measurement). Calculate the equivalence ratio and then perform the exhaust gas analysis.

- $CO_2 = 10.8\%$
- $O_2 = 4.5\%$
- $CO = 0\%$
- $H_2 = 0\%$

$$\boldsymbol{C_3H_8 + 5(O_2 + 3.76N_2) \rightarrow 3CO_2 + 4H_2O + 18.8N_2}$$

# Example 2 - Solution

- Mass of fuel

$$12 \times 3 + 8 \times 1 = 44 \ kg$$

- Mass of air

$$5(16 \times 2 + 14 \times 2 \times 3.76) = 686.4 \ kg$$

- Stoichiometric air-fuel ratio

$$(A/F)_{stoic} = \frac{686.4}{44} = 15.6$$

# Example 2 - Solution

To determine the actual Air-Fuel mass ratio $A/F$, consider the following reaction:

$$aC_3H_8 + b(O_2 + 3.76N_2) \rightarrow 0.108CO_2 + 0.045O_2 + c \times 3.76N_2$$

Balancing the elements:

| | | |
|---|---|---|
| Carbon balance: | $3a = 0.108$ | $a = 0.036$ |
| Oxygen balance: | $b = 0.108 + 0.045$ | $b = 0.153$ |
| Nitrogen balance: | $3.76 \times b = 3.76 \times c$ | $c = 0.153$ |

$$0.036C_3H_8 + 0.158(O_2 + 3.76N_2) \rightarrow 0.108CO_2 + 0.045O_2 + 0.575N_2$$

# Example 2 - Solution

- Mass of fuel

$$0.036 \times 12 \times 3 + 0.036 \times 8 \times 1 = 1.584\ kg$$

- Mass of air

$$0.158(16 \times 2 + 14 \times 2 \times 3.76) = 21.69\ kg$$

- Actual air-fuel ratio

$$(A/F)_{act} = \frac{21.69}{1.584} = 13.7$$

# Example 2 - Solution

- Actual air-fuel ratio

$$(A/F)_{act} = \frac{21.69}{1.584} = 13.7$$

- Stoichiometric air-fuel ratio

$$(A/F)_{stoic} = \frac{686.4}{44} = 15.6$$

- Equivalence Ratio

$$\phi = \frac{(A/F)_{stoic}}{(A/F)_{act}} = \frac{15.6}{13.7} = 1.14$$

# Example 2 - Solution

- Exhaust Gas Analysis:

$$\text{Total No. of moles of product} = \mathbf{0.108 + 0.045 + 0.575 = 0.728}$$

- Dry Analysis:

$$\boldsymbol{CO_2\% = \frac{0.108}{0.728} = 14.84\%}$$

$$\boldsymbol{O_2\% = \frac{0.045}{0.728} = 6.18\%}$$

$$\boldsymbol{N_2\% = \frac{0.575}{0.728} = 78.98\%}$$

# End of Lecture 9

**End of Lecture 9**