



Palestine Technical University- Kadoorie (PTUK)

Mechanical Engineering Department

Summer Semester, 2023/2024

12210592: Internal Combustion Engine 1

Midterm Exam

**Student Name**

Key solution

**Student ID**

**Instructor Name**

Dr. Hammam S. R. Daraghma

**Due Date**

14<sup>th</sup>, Aug. 2024

**Date of Submission**

A 4-litre, 4-cylinder, 4-stroke internal combustion engine is operating at 2500 RPM. The engine has a compression ratio of 12 and a cylinder bore diameter of 7.5 cm. The measured brake power is 120 hp, and the mechanical efficiency is 80%. Calculate the following:

- Indicated Power (3 marks)
- Indicated Mean Effective Pressure (3 marks)
- Power Lost on Friction (3 marks)
- Specific Output (3 marks)

$$N = \frac{2500}{60} = 41.7 \text{ rps}$$

$$V = 4 \text{ L} = 4 \times 10^{-3} \text{ m}^3$$

$$1 \text{ hp} = 746 \text{ W}$$

$$\eta_m = \frac{BP}{IP} \Rightarrow 0.8 = \frac{120}{IP}$$

$$1- \quad IP = \frac{120}{0.8} = 150 \text{ hp} = 150 \times 746 = 111.9 \times 10^3 \text{ W}$$

$$2- \quad IP = IMEP \times L \times A \times \frac{N}{2}$$

$$111.9 \times 10^3 = IMEP \times (4 \times 10^{-3}) \left( \frac{41.7}{2} \right)$$

$$IMEP = 1.34 \times 10^6 \text{ Pa}$$

$$\text{For each cylinder} = 335 \times 10^3 \text{ Pa} = 335 \text{ kPa}$$

$$3- \quad FP = IP - BP = 150 - 120 = 30 \text{ hp} = 22380 \text{ W}$$

$$4- \quad \text{specific output} = \frac{BP}{V_s} = \frac{120 \times 746}{4 \times 10^{-3}} = 22.38 \times 10^6 \frac{\text{W}}{\text{m}^3}$$

*ans.*

A 6-litre, 8-cylinder, 4-stroke internal combustion engine is operating at 3500 RPM. The engine has a compression ratio of 16 and a cylinder bore diameter of 9.0 cm. The measured brake power is 200 hp, and the mechanical efficiency is 90%. Calculate the following:

- Indicated Power (3 marks)
- Indicated Mean Effective Pressure (3 marks)
- Power Lost on Friction (3 marks)
- Specific Output (3 marks)

$$N = \frac{3500}{60} = 58.3 \text{ rps}$$

$$V = 6 \text{ L} = 6 \times 10^{-3} \text{ m}^3$$

$$1 \text{ hp} = 746 \text{ W}$$

$$\eta_m = \frac{BP}{IP} \Rightarrow 0.9 = \frac{200}{IP}$$

$$1- \quad IP = \frac{200}{0.9} \approx 222 \text{ hp} = 222 \times 746 = 165.6 \times 10^3 \text{ W}$$

$$2- \quad IP = IMEP \times L \times A \times \frac{N}{2}$$

$$165.6 \times 10^3 = IMEP \times (6 \times 10^{-3}) \left( \frac{58.3}{2} \right)$$

$$IMEP = 9.47 \times 10^5 \text{ Pa}$$

$$\text{For each cylinder} = 118 \times 10^3 \text{ Pa} = 118 \text{ kPa}$$

$$3- \quad FP = IP - BP = 222 - 200 = 22 \text{ hp} = 16412 \text{ W}$$

$$4- \quad \text{specific output} = \frac{BP}{V_s} = \frac{200 \times 746}{4 \times 10^{-3}} = 37.3 \times 10^6 \frac{\text{W}}{\text{m}^3}$$

*ans.*

A 3-litre, 6-cylinder, 4-stroke internal combustion engine is operating at 4000 RPM. The engine has a compression ratio of 10 and a cylinder bore diameter of 6.0 cm. The measured brake power is 100 hp, and the mechanical efficiency is 75%. Calculate the following:

- Indicated Power (3 marks)
- Indicated Mean Effective Pressure (3 marks)
- Power Lost on Friction (3 marks)
- Specific Output (3 marks)

$$N = \frac{4000}{60} = 66.7 \text{ rps}$$

$$V = 3 \text{ L} = 3 \times 10^{-3} \text{ m}^3$$

$$1 \text{ hp} = 746 \text{ W}$$

$$\eta_m = \frac{BP}{IP} \Rightarrow 0.75 = \frac{100}{IP}$$

$$1 - IP = \frac{100}{0.75} = 133.3 \text{ hp} = 133.3 \times 746 = 99.5 \times 10^3 \text{ W}$$

$$2 - IP = IMEP \times L \times A \times \frac{N}{2}$$

$$99.5 \times 10^3 = IMEP \times (3 \times 10^{-3}) \left( \frac{66.7}{2} \right)$$

$$IMEP = 99.5 \times 10^5 \text{ Pa}$$

$$\text{For each cylinder} = 166 \times 10^3 \text{ Pa} = 166 \text{ kPa}$$

$$3 - FP = IP - BP = 133.33 - 100 = 33.3 \text{ hp} = 24842 \text{ W}$$

$$4 - \text{specific output} = \frac{BP}{V_s} = \frac{100 \times 746}{3 \times 10^{-3}} = 24.9 \times 10^6 \frac{\text{W}}{\text{m}^3}$$

*ans.*

A 7-litre, 8-cylinder, 4-stroke internal combustion engine is operating at 2800 RPM. The engine has a compression ratio of 14 and a cylinder bore diameter of 8.5 cm. The measured brake power is 180 hp, and the mechanical efficiency is 85%. Calculate the following:

- Indicated Power (3 marks)
- Indicated Mean Effective Pressure (3 marks)
- Power Lost on Friction (3 marks)
- Specific Output (3 marks)

$$N = \frac{2800}{60} = 46.7 \text{ rps}$$

$$V = 7\text{L} = 7 \times 10^{-3} \text{ m}^3$$

$$1 \text{ hp} = 746 \text{ W}$$

$$\eta_m = \frac{BP}{IP} \Rightarrow 0.85 = \frac{180}{IP}$$

$$1- \quad IP = \frac{180}{0.85} = 211.8 \text{ hp} = 211.8 \times 746 = 158 \times 10^3 \text{ W}$$

$$2- \quad IP = IMEP \times L \times A \times \frac{N}{2}$$

$$158 \times 10^3 = IMEP \times (7 \times 10^{-3}) \left( \frac{46.7}{2} \right)$$

$$IMEP = 96.7 \times 10^5 \text{ Pa}$$

$$\text{For each cylinder} = 120.8 \times 10^3 \text{ Pa} = 120.8 \text{ kPa}$$

$$3- \quad FP = IP - BP = 211.8 - 180 = 31.8 \text{ hp} = 23723 \text{ W}$$

$$4- \quad \text{specific output} = \frac{BP}{V_s} = \frac{180 \times 746}{7 \times 10^{-3}} = 19.18 \times 10^6 \frac{\text{W}}{\text{m}^3}$$



*ans.*

A 2-litre, 4-cylinder, 4-stroke internal combustion engine is operating at 3000 RPM. The engine has a compression ratio of 11 and a cylinder bore diameter of 7.0 cm. The measured brake power is 90 hp, and the mechanical efficiency is 70%. Calculate the following:

- Indicated Power (3 marks)
- Indicated Mean Effective Pressure (3 marks)
- Power Lost on Friction (3 marks)
- Specific Output (3 marks)

$$N = \frac{3000}{60} = 50 \text{ rps}$$

$$V = 2\text{L} = 2 \times 10^{-3} \text{ m}^3$$

$$1 \text{ hp} = 746 \text{ W}$$

$$\eta_m = \frac{BP}{IP} \Rightarrow 0.7 = \frac{90}{IP}$$

$$1- \quad IP = \frac{90}{0.7} = 129 \text{ hp} = 129 \times 746 = 96.2 \times 10^3 \text{ W}$$

$$2- \quad IP = IMEP \times L \times A \times \frac{N}{2}$$

$$96.2 \times 10^3 = IMEP \times (2 \times 10^{-3}) \left( \frac{50}{2} \right)$$

$$IMEP = 1.924 \times 10^6 \text{ Pa}$$

$$\text{For each cylinder} = 481 \times 10^3 \text{ Pa} = 335 \text{ kPa}$$

$$3- \quad FP = IP - BP = 129 - 90 = 39 \text{ hp} = 29094 \text{ W}$$

$$4- \quad \text{specific output} = \frac{BP}{V_s} = \frac{90 \times 746}{2 \times 10^{-3}} = 33.6 \times 10^6 \frac{\text{W}}{\text{m}^3}$$

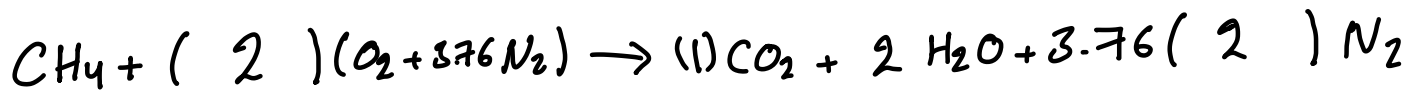
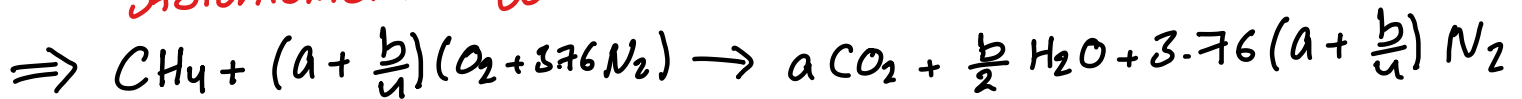
*ans.*

An internal combustion engine uses methane ( $CH_4$ ) as a fuel. The molecular weights of air and acetylene are 29 and 16 g/mol, respectively. It is required to:

- Write the balanced chemical equation for acetylene with stoichiometric oxygen. (2 marks)
- Write the balanced chemical equation for acetylene with 10% excess air. (2 marks)
- Obtain the stoichiometric air/fuel ratio. (2 marks)
- Obtain the actual air/fuel ratio. (2 marks)
- Calculate the fuel-equivalence ratio. (2 marks)
- Determine if the fuel mixture is rich or lean. (1 mark)

$$a = 1, b = 4 \Rightarrow y = \frac{b}{a} = 4$$

*Stoichiometric oxygen*



$$\# \text{ of moles of air} = 2 + 2 \times 3.76 = 9.52 \text{ moles}$$

$$\# \text{ of moles of fuel} = 1 \text{ mole}$$

$$(A/F)_s = \frac{\# \text{ of moles of air} \times \text{molar mass of air}}{\# \text{ of moles of fuel} \times \text{molar mass of fuel}}$$

$$= \frac{9.52 \times 29}{1 \times 16} = 17.255$$

ans.

10% excess air



$$\text{Carbon balance } 1 = a \Rightarrow a = 1$$

$$\text{Hydrogen balance } 4 = 2b \Rightarrow b = 2$$

$$\text{Oxygen balance } (2.1)(2) = 2a + b + 2c \Rightarrow c = 0.2$$

$$\text{Nitrogen balance } (2.1)(2)(3.76) = 2d \Rightarrow d = 7.896$$



$$\# \text{ of moles of air} = 2.1 + 2.1 \times 3.76 = 9.996 \text{ moles}$$

$$\# \text{ of moles of fuel} = 1 \text{ mole}$$

$$(\text{A/F})_a = \frac{\# \text{ of moles of air} \times \text{molar mass of air}}{\# \text{ of moles of fuel} \times \text{molar mass of fuel}}$$

$$= \frac{9.996 \times 29}{1 \times 16} = 18.11775$$

$$\phi = \frac{(\text{A/F})_s}{(\text{A/F})_a} = \frac{17.255}{18.11775} = 0.952 < 1$$

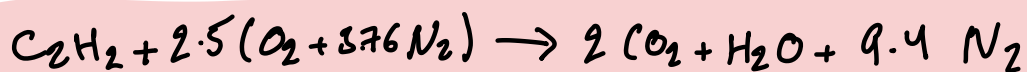
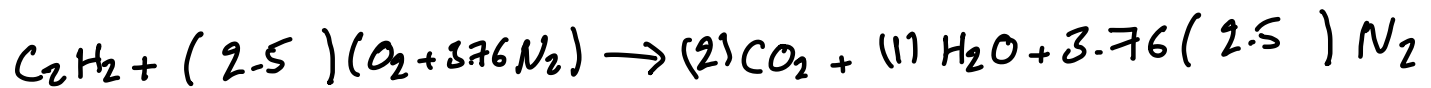
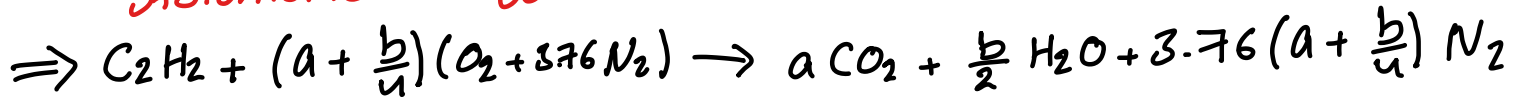
$\Rightarrow$  Fuel lean

An internal combustion engine uses acetylene ( $C_2H_2$ ) as a fuel. The molecular weights of air and acetylene are 29 and 26 g/mol, respectively. It is required to:

- Write the balanced chemical equation for acetylene with stoichiometric oxygen. (2 marks)
- Write the balanced chemical equation for acetylene with 20% excess air. (2 marks)
- Obtain the stoichiometric air/fuel ratio. (2 marks)
- Obtain the actual air/fuel ratio. (2 marks)
- Calculate the fuel-equivalence ratio. (2 marks)
- Determine if the fuel mixture is rich or lean. (1 mark)

$$a = 2, b = 2 \Rightarrow y = \frac{b}{a} = 1$$

*Stoichiometric oxygen*



$$\# \text{ of moles of air} = 2.5 + 2.5 \times 3.76 = 11.9 \text{ moles}$$

$$\# \text{ of moles of fuel} = 1 \text{ mole}$$

$$(A/F)_s = \frac{\# \text{ of moles of air} \times \text{molar mass of air}}{\# \text{ of moles of fuel} \times \text{molar mass of fuel}}$$

$$= \frac{11.9 \times 29}{1 \times 26} = 13.273$$

ans.

20% excess air

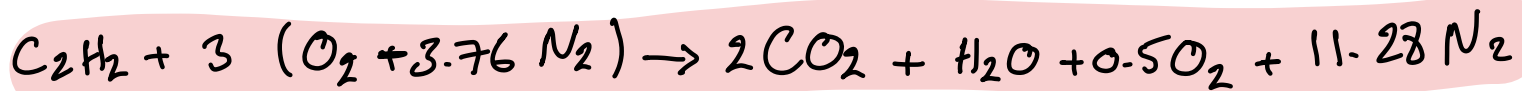


Carbon balance  $2 = a \Rightarrow a = 2$

Hydrogen balance  $2 = 2b \Rightarrow b = 1$

Oxygen balance  $(3)(2) = 2a + b + 2c \Rightarrow c = 0.5$

Nitrogen balance  $(3)(2)(3.76) = 2d \Rightarrow d = 11.28$



# of moles of air =  $3 + 3 \times 3.76 = 14.28$  moles

# of moles of fuel = 1 mole

$$(A/F)_a = \frac{\text{\# of moles of air} \times \text{molar mass of air}}{\text{\# of moles of fuel} \times \text{molar mass of fuel}}$$

$$= \frac{14.28 \times 29}{1 \times 26} = 15.93$$

$$\phi = \frac{(A/F)_s}{(A/F)_a} = \frac{13.273}{15.93} = 0.833 < 1$$

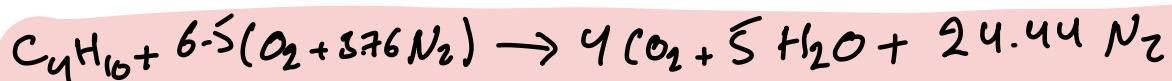
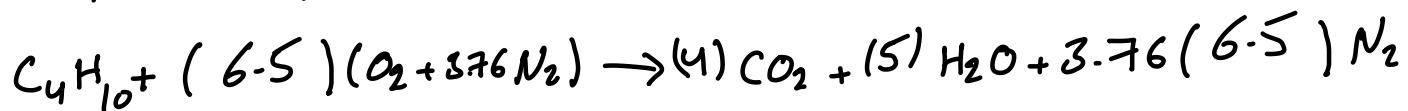
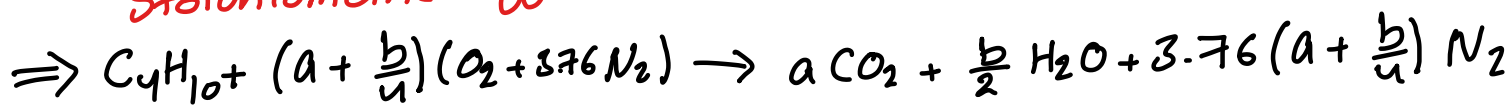
$\Rightarrow$  Fuel lean

An internal combustion engine uses acetylene ( $C_4H_{10}$ ) as a fuel. The molecular weights of air and acetylene are 29 and 58 g/mol, respectively. It is required to:

- Write the balanced chemical equation for acetylene with stoichiometric oxygen. (2 marks)
- Write the balanced chemical equation for acetylene with 5% excess air. (2 marks)
- Obtain the stoichiometric air/fuel ratio. (2 marks)
- Obtain the actual air/fuel ratio. (2 marks)
- Calculate the fuel-equivalence ratio. (2 marks)
- Determine if the fuel mixture is rich or lean. (1 mark)

$$a = 4, b = 10 \Rightarrow y = \frac{10}{4} = 2.5$$

*Stoichiometric oxygen*



$$\# \text{ of moles of air} = 6.5 + 6.5 \times 3.76 = 30.81 \text{ moles}$$

$$\# \text{ of moles of fuel} = 1 \text{ mole}$$

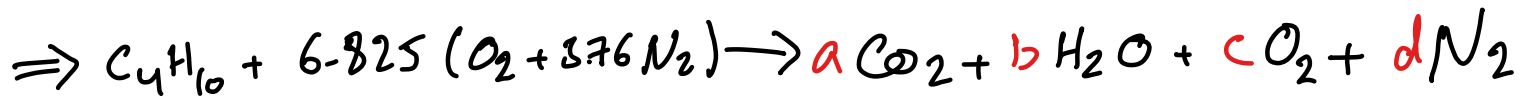
$$(A/F)_s = \frac{\# \text{ of moles of air} \times \text{molar mass of air}}{\# \text{ of moles of fuel} \times \text{molar mass of fuel}}$$

$$= \frac{30.81 \times 29}{1 \times 58} = 15.405$$



ans.

5% excess air

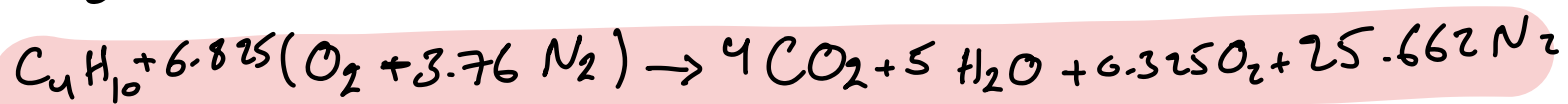


Carbon balance  $4 = a \Rightarrow a = 4$

Hydrogen balance  $10 = 2b \Rightarrow b = 5$

Oxygen balance  $(6.825)(2) = 2a + b + 2c \Rightarrow c = 0.325$

Nitrogen balance  $(6.825)(2)(3.76) = 2d \Rightarrow d = 25.662$



# of moles of air =  $6.825 + 6.825 \times 3.76 = 32.487$  moles

# of moles of fuel = 1 mole

$$(A/F)_a = \frac{\text{\# of moles of air} \times \text{molar mass of air}}{\text{\# of moles of fuel} \times \text{molar mass of fuel}}$$

$$= \frac{32.487 \times 29}{1 \times 58} = 16.24$$

$$\phi = \frac{(A/F)_s}{(A/F)_a} = \frac{15.405}{16.24} = 0.948 < 1$$

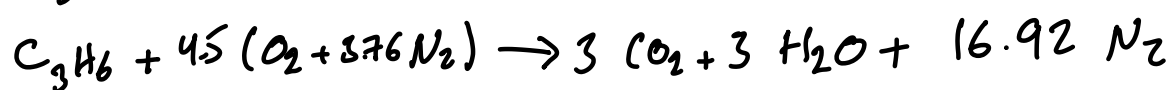
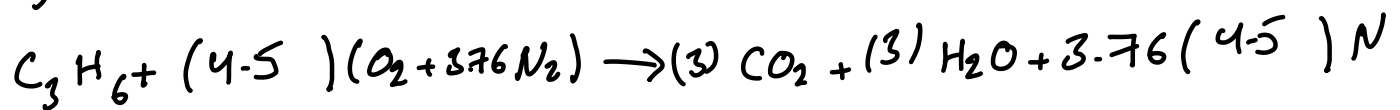
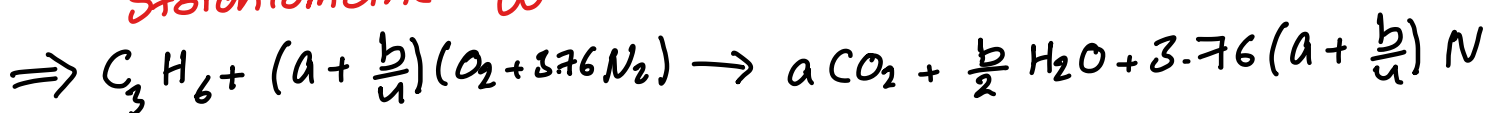
$\Rightarrow$  Fuel lean

An internal combustion engine uses acetylene ( $C_3H_6$ ) as a fuel. The molecular weights of air and acetylene are 29 and 42 g/mol, respectively. It is required to:

- Write the balanced chemical equation for acetylene with stoichiometric oxygen. (2 marks)
- Write the balanced chemical equation for acetylene with 15% excess air. (2 marks)
- Obtain the stoichiometric air/fuel ratio. (2 marks)
- Obtain the actual air/fuel ratio. (2 marks)
- Calculate the fuel-equivalence ratio. (2 marks)
- Determine if the fuel mixture is rich or lean. (1 mark)

$$a = 3, b = 6 \Rightarrow y = \frac{6}{3} = 2$$

Stoichiometric oxygen



$$\# \text{ of moles of air} = 4.5 + 4.5 \times 3.76 = 21.42 \text{ moles}$$

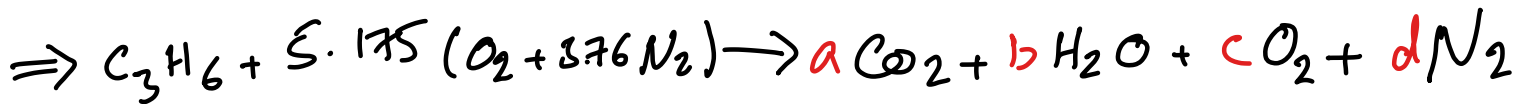
$$\# \text{ of moles of fuel} = 1 \text{ mole}$$

$$(A/F)_S = \frac{\# \text{ of moles of air} \times \text{molar mass of air}}{\# \text{ of moles of fuel} \times \text{molar mass of fuel}}$$

$$= \frac{21.42 \times 29}{1 \times 42} = 14.79$$

ans.

15% excess air



$$\text{Carbon balance } 3 = a \Rightarrow a = 3$$

$$\text{Hydrogen balance } 6 = 2b \Rightarrow b = 3$$

$$\text{Oxygen balance } (5.175)(2) = 2a + b + 2c \Rightarrow c = 0.675$$

$$\text{Nitrogen balance } (5.175)(2)(3.76) = 2d \Rightarrow d = 19.458$$



$$\# \text{ of moles of air} = 5.175 + 5.175 * 3.76 = 24.633 \text{ moles}$$

$$\# \text{ of moles of fuel} = 1 \text{ mole}$$

$$(A/F)_a = \frac{\# \text{ of moles of air} * \text{molar mass of air}}{\# \text{ of moles of fuel} * \text{molar mass of fuel}}$$

$$= \frac{24.633 * 29}{1 * 42} = 17$$

$$\phi = \frac{(A/F)_s}{(A/F)_a} = \frac{14.79}{17} = 0.87 < 1$$

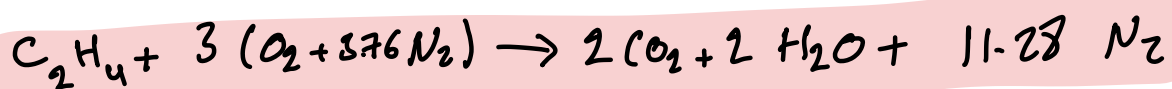
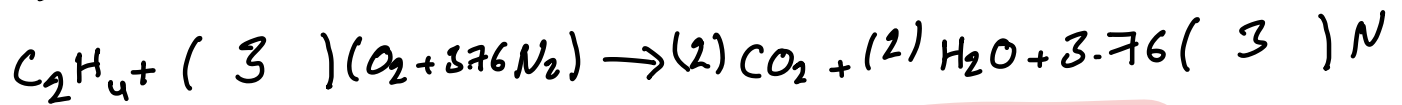
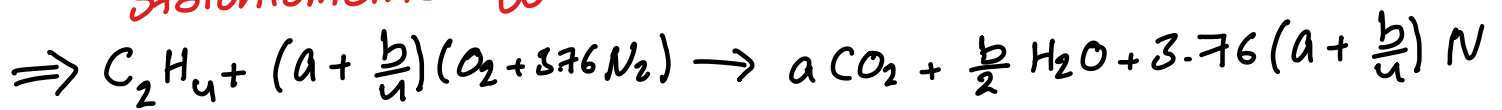
$$\Rightarrow \text{Fuel lean}$$

An internal combustion engine uses acetylene ( $C_2H_4$ ) as a fuel. The molecular weights of air and acetylene are 29 and 28 g/mol, respectively. It is required to:

- Write the balanced chemical equation for acetylene with stoichiometric oxygen. (2 marks)
- Write the balanced chemical equation for acetylene with 10% excess air. (2 marks)
- Obtain the stoichiometric air/fuel ratio. (2 marks)
- Obtain the actual air/fuel ratio. (2 marks)
- Calculate the fuel-equivalence ratio. (2 marks)
- Determine if the fuel mixture is rich or lean. (1 mark)

$$a = 2, b = 4 \Rightarrow y = \frac{4}{2} = 2$$

Stoichiometric oxygen



$$\# \text{ of moles of air} = 3 + 3 \times 3.76 = 14.28 \text{ moles}$$

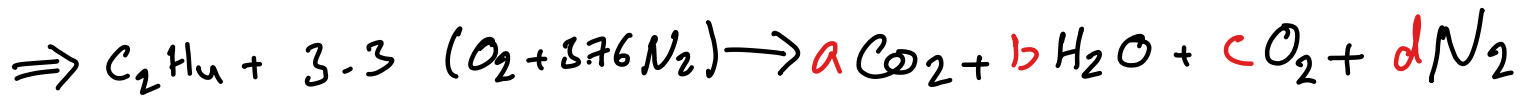
$$\# \text{ of moles of fuel} = 1 \text{ mole}$$

$$(A/F)_s = \frac{\# \text{ of moles of air} \times \text{molar mass of air}}{\# \text{ of moles of fuel} \times \text{molar mass of fuel}}$$

$$= \frac{14.28 \times 29}{1 \times 28} = 14.79$$

ans.

10% excess air

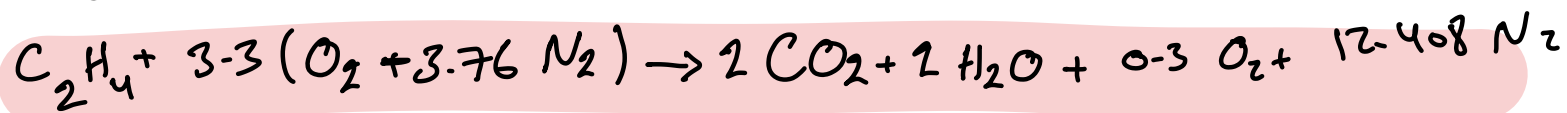


$$\text{Carbon balance } 2 = a \Rightarrow a = 2$$

$$\text{Hydrogen balance } 4 = 2b \Rightarrow b = 2$$

$$\text{Oxygen balance } (3.3)(2) = 2a + b + 2c \Rightarrow c = 0.3$$

$$\text{Nitrogen balance } (3.3)(2)(3.76) = 2d \Rightarrow d = 12.408$$



$$\# \text{ of moles of air} = 3.3 + 3.3 \times 3.76 = 15.708 \text{ moles}$$

$$\# \text{ of moles of fuel} = 1 \text{ mole}$$

$$(A/F)_a = \frac{\# \text{ of moles of air} \times \text{molar mass of air}}{\# \text{ of moles of fuel} \times \text{molar mass of fuel}}$$

$$= \frac{15.708 \times 29}{1 \times 28} = 16.269$$

$$\phi = \frac{(A/F)_s}{(A/F)_a} = \frac{14.79}{16.269} = 0.91 < 1$$

$\Rightarrow$  Fuel lean