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 ______________________

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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)

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

$V = 4\,l = 4 \times 10^{-3}\ m^3$

$1\ hp = 746\ W$

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

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

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

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

$IMEP = 1.34 \times 10^6\ Pa$

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

3- $FP = IP - BP = 150 - 120 = 30\ hp = 22380\ W$

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

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)

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

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

1 hp $= 746$ W

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

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

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

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

$IMEP = 9.47 \times 10^5$ Pa

For each cylinder $= 118 \times 10^3$ Pa $= 118$ KPa

3- $FP = IP - BP = 222 - 200 = 22$ hp $= 16412$ W

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

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)

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

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

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

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

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

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

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

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

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

$ans.$

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)

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

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

1 hp = 746 W

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

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

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

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

$IMEP = 96.7 \times 10^5$ Pa

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

3- $FP = IP - BP = 211.8 - 180 = 31.8$ hp $= 23723$ W

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

$ans.$

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)

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

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

$1 hp = 746 W$

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

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

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

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

$IMEP = 1.924 \times 10^6 Pa$

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

3- $FP = IP - BP = 129 - 90 = 39 hp = 29094 W$

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

$ans.$

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

$$\Rightarrow CH_4 + \left(a + \frac{b}{4}\right)(O_2 + 3.76N_2) \rightarrow a\,CO_2 + \frac{b}{2} H_2O + 3.76\left(a + \frac{b}{4}\right) N_2$$

$$CH_4 + (\ 2\ )(O_2 + 3.76N_2) \rightarrow (1)\,CO_2 + 2\,H_2O + 3.76(\ 2\ )\,N_2$$

$$CH_4 + 2(O_2 + 3.76N_2) \rightarrow CO_2 + 2H_2O + 7.52\,N_2$$

# of moles of air = 2 + 2 * 3.76 = 9.52 moles

# of moles of fuel = 1 mole

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

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

ans.

10% excess air

$$\Rightarrow CH_4 + 2.1(O_2 + 3.76N_2) \longrightarrow a\,CO_2 + b\,H_2O + c\,O_2 + d\,N_2$$

Carbon balance $1 = a \Rightarrow a = 1$

Hydrogen balance $4 = 2b \Rightarrow b = 2$

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

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

$$CH_4 + 2.1(O_2 + 3.76N_2) \longrightarrow CO_2 + 2H_2O + 0.2O_2 + 7.896N_2$$

# of moles of air $= 2.1 + 2.1 * 3.76 = 9.996$ moles

# of moles of fuel = 1 mole

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

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

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

$\Rightarrow$ 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

$$\Rightarrow C_2H_2 + \left(a + \frac{b}{4}\right)(O_2 + 3.76N_2) \rightarrow a\,CO_2 + \frac{b}{2}H_2O + 3.76\left(a + \frac{b}{4}\right)N_2$$

$$C_2H_2 + (2.5)(O_2 + 3.76N_2) \rightarrow (2)CO_2 + (1)H_2O + 3.76(2.5)N_2$$

$$C_2H_2 + 2.5(O_2 + 3.76N_2) \rightarrow 2CO_2 + H_2O + 9.4N_2$$

# of moles of air $= 2.5 + 2.5 * 3.76 = 11.9$ moles

# of moles of fuel = 1 mole

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

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

ans.

20% excess air

$$\Rightarrow C_2H_2 + 3(O_2 + 3.76N_2) \rightarrow a\,CO_2 + b\,H_2O + c\,O_2 + d\,N_2$$

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

$$C_2H_2 + 3(O_2 + 3.76N_2) \rightarrow 2CO_2 + H_2O + 0.5O_2 + 11.28N_2$$

# of moles of air $= 3 + 3 * 3.76 =$ 14.28 moles

# of moles of fuel $=$ 1 mole

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

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

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

$\Rightarrow$ 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

$$\Rightarrow C_4H_{10} + \left(a + \frac{b}{4}\right)(O_2 + 3.76N_2) \rightarrow a\,CO_2 + \frac{b}{2}H_2O + 3.76\left(a + \frac{b}{4}\right)N_2$$

$$C_4H_{10} + (6.5)(O_2 + 3.76N_2) \rightarrow (4)\,CO_2 + (5)\,H_2O + 3.76(6.5)\,N_2$$

$$C_4H_{10} + 6.5(O_2 + 3.76N_2) \rightarrow 4\,CO_2 + 5\,H_2O + 24.44\,N_2$$

# of moles of air $= 6.5 + 6.5 * 3.76 = 30.81$ moles

# of moles of fuel $= 1$ mole

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

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

ans.

5 % excess air

$\Rightarrow C_4H_{10} + 6.825(O_2 + 3.76N_2) \rightarrow a\,CO_2 + b\,H_2O + c\,O_2 + d\,N_2$

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

$C_4H_{10} + 6.825(O_2 + 3.76N_2) \rightarrow 4CO_2 + 5H_2O + 0.325O_2 + 25.662N_2$

# of moles of air $= 6.825 + 6.825 * 3.76 = 32.487$ moles

# of moles of fuel $= 1$ mole

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

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

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

$\Rightarrow$ 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

$\Rightarrow C_3H_6 + (a + \frac{b}{4})(O_2 + 3.76N_2) \rightarrow a\,CO_2 + \frac{b}{2} H_2O + 3.76(a + \frac{b}{4}) N$

$C_3H_6 + (4.5)(O_2 + 3.76N_2) \rightarrow (3)\,CO_2 + (3)\,H_2O + 3.76(4.5) N$

$C_3H_6 + 4.5(O_2 + 3.76N_2) \rightarrow 3\,CO_2 + 3\,H_2O + 16.92\,N_2$

# of moles of air $= 4.5 + 4.5 * 3.76 = 21.42$ moles

# of moles of fuel $= 1$ mole

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

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

ans.

15 % excess air

$\Rightarrow C_3H_6 + 5.175(O_2 + 3.76N_2) \longrightarrow a\,CO_2 + b\,H_2O + c\,O_2 + d\,N_2$

Carbon balance $3 = a \Rightarrow a = 3$

Hydrogen balance $6 = 2b \Rightarrow b = 3$

Oxygen balance $(5.175)(2) = 2a + b + 2C \Rightarrow C = 0.675$

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

$C_3H_6 + 5.175(O_2 + 3.76N_2) \rightarrow 3\,CO_2 + 3\,H_2O + 0.675\,O_2 + 19.458\,N_2$

# of moles of air $= 5.175 + 5.175 * 3.76 = 24.633$ moles

# of moles of fuel $= 1$ mole

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

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

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

$\Rightarrow$ 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

$$\Rightarrow C_2H_4 + (a + \frac{b}{4})(O_2 + 3.76N_2) \rightarrow a\,CO_2 + \frac{b}{2} H_2O + 3.76(a + \frac{b}{4}) N$$

$$C_2H_4 + (3)(O_2 + 3.76N_2) \rightarrow (2)\,CO_2 + (2)\,H_2O + 3.76(3) N$$

$$C_2H_4 + 3(O_2 + 3.76N_2) \rightarrow 2CO_2 + 2H_2O + 11.28 N_2$$

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

\# of moles of fuel $= 1$ mole

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

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

ans.

10% excess air

$$\Rightarrow C_2H_4 + 3.3\ (O_2 + 3.76 N_2) \longrightarrow a\,CO_2 + b\,H_2O + c\,O_2 + d\,N_2$$

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

Hydrogen balance $4 = 2b \Rightarrow b = 2$

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

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

$$C_2H_4 + 3.3\,(O_2 + 3.76\,N_2) \longrightarrow 2\,CO_2 + 2\,H_2O + 0.3\,O_2 + 12.408\,N_2$$

# of moles of air $= 3.3 + 3.3 * 3.76 = 15.708$ moles

# of moles of fuel $= 1$ mole

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

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

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

$\Rightarrow$ Fuel lean