Second Semester Examination
2022/2023 Academic Session

July / August 2023

EME 432 – Internal Combustion Engine
(Enjin Pembakaran Dalam)

Duration: 3 hours
(Masa: 3 Jam)

Please check that this examination paper consists of SIX (6) pages of printed material before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi ENAM (6) muka surat yang bercetak sebelum anda memulakan peperiksaan ini.]

Instructions: Answer ALL **FOUR (4)** questions.

*[**Arahan**: Jawab **EMPAT (4)** soalan]*

Note:

Answer to each question must begin from a new page.

1. (a) Plot and identify the stages of combustion on Diesel combustion chart in term of Heat Release Rate (HRR) versus crank angle. Explain the **FOUR (4)** stages of Diesel combustion in the chart.

(40 marks)

(b) Explain abnormal combustion in Diesel engine, and how it is influenced by the ignition delay (ID) period, fuel injection timing and cetane number of diesel fuel (fuel ignition quality).

(30 marks)

(c) A large Compression-Ignition (CI) engine operating at 310 rpm has open combustion chamber and direct injection, with 26-cm bores, 73-cm stroke, and a compression ratio of 16.5:1. Fuel injection in each cylinder starts at 21^{o} bTDC and lasts for 0.019 s. Ignition delay period (ID) is 0.0065 s.

Calculate:

(i) ID in degrees of engine rotation.

(10 marks)

(ii) Crank angle position when combustion starts.

(10 marks)

(iii) Crank angle position when injection stops.

(10 marks)

2. (a) (i) Define lean and rich mixture in terms of stoichiometric air-fuel ratio (AFR_{stoik}), actual air-fuel ratio (AFR_{actual}), and equivalence ratio (Φ).

(10 marks)

(ii) Explain **TWO (2)** effects on the engine performance if the air fuel mixture is lean and **TWO (2)** effects on the engine performance if the air fuel mixture is rich.

(20 marks)

(iii) Explain engine flooding and the cause of this problem in spark-ignition (SI) engine.

(10 marks)

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(b) The following is the stoichiometric reaction of Isooctane (C_8H_{18}) combustion in a three-cylinder spark-ignition (SI) engine.

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

(i) Derive the actual combustion reaction of Isooctane (C_8H_{18}) if it is burned with 20% excess air by assuming that the same amount of CO_2 and H_2O is found in the combustion products.

(10 marks)

(ii) Calculate the stoichiometric air-fuel ratio (AFR_{stoich}), actual air-fuel ratio (AFR_{actual}), and equivalence ratio (Φ).

(40 marks)

(iii) Based on your answers in 2(b)(ii), discuss **TWO (2)** possible effects on the engine performance.

(10 marks)

3. (a) Sketch the architecture diagram and explain **TWO (2)** advantages and **TWO (2)** disadvantages of hybrid car systems that comprise gasoline SI engines with regenerative battery-electric motor drives.

(30 marks)

(b) A company is developing a 2-cylinder, four-stroke SI gasoline engine of 1.0 litre total capacity for use in a small hybrid car. The following data apply:

- T_i = 300 K
- p_i = 100 kPa
- R = 287 $J.kg^{-1}.K^{-1}$
- Volumetric efficiency, η_{vol} = 85%
- F/A ratio = 0.0687
- Q_{LHV} = 44 $MJ.kg^{-1}$
- Fuel density = 740 $kg.m^{-3}$
- Fuel conversion efficiency, $\eta_{f,i}$ = 30% at maximum power
- Mechanical efficiency, η_{mech} = 90%
- Mean piston speed at maximum power, S_p = 15 $m.s^{-1}$
- Bore = 1.1(Stroke)
- Maximum engine power output = 37.43 kW

(i) Calculate the engine speed (rpm) at maximum power.

(10 marks)

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(ii) At a part-load condition, the SI engine is operated at half the bmep at maximum power and half the maximum engine speed at maximum power, the car can cruise at 100 km.h^{-1} without electrical power. Under these conditions calculate the fuel consumption rate (litres per 100 km) if brake thermal efficiency, η_b= 33% at that part load condition.

(30 marks)

(c) A two-wheeled vehicle is operated with a bi-fuel system (i.e., LPG or gasoline). In gasoline mode it only burns gasoline. In LPG mode it uses LPG 80% of the time and gasoline 20% of the time (when the LPG tank is run out and needs to be refilled). Assuming the vehicle is driven 10,000 km annually and the conversion kit costs RM 450. Use the following data in your calculations:

Fuel type	**LPG (butane)**	**Gasoline**
Cost	RM 25/ 15kg	RM 1.95/ liter
Fuel economy	40 km/L	45 km/L
Density	590 g/liter	720 g/liter
Composition	C_4H_{10}	C_8H_{18}

(i) Calculate the Return of Investment (ROI) time (years) of the system conversion.

(15 marks)

(ii) Discuss the technological feasibility based on the calculated ROI.

(15 marks)

4. (a) Describe **THREE (3)** fundamental differences between a Turbocharger and a Supercharger.

(15 marks)

(b) A diesel truck is initially powered with a natural-aspirated Compression-Ignition diesel engine and operating at the sea level condition of 1.013 bar and 10°C with the following engine performance:

- Brake power = 275 kW
- Speed = 1800 rpm
- A/F ratio = 20:1
- Brake specific fuel consumption, BSFC = 0.24 kg/kwh
- Engine capacity= 0.0245 m^3
- Volumetric efficiency = 80%

To operate this vehicle at higher altitude, the engine is fitted with a mechanical supercharger where the atmospheric pressure is 0.75 bar. Given that the power consumed by the supercharger is 9% of the total power produced by the engine, and the temperature of the air leaving the supercharger is 30°C. Assume that the A/F ratio and the volumetric efficiency remain the same. Calculate the increase in air pressure required in the supercharger to maintain the same net output of 275 kW.

(50 marks)

(c) The 3-way catalyst significantly reduces the SI engine emissions. The emission reduction capability of a warmed-up catalyst is limited by the diffusion of the gaseous species to the catalyst surface so that the concentration c of the emission species is governed by:

$$c(x) = c(O) \times \exp\left(-\frac{4Sh}{h^2/_D} \times \frac{L}{U} \times \frac{x}{L}\right)$$

Here x is the distance along the catalyst, Sh is the Sherwood number (Sh = 4 for a square channel), h is the hydraulic diameter of the cell-channel, D is the diffusivity of the emission species in the exhaust gas, L is the length of the catalyst, and U is the flow velocity through the cell-channel.

For a targeted catalyst efficiency, $\eta_{cat} = 1 - [c(L)/c(O)]$ is specified.

The catalyst is sized to get the targeted conversion efficiency at maximum power, which closely corresponds to the maximum exhaust mass flow rate. Do the following analysis for a modern engine with the following specifications:

Catalyst:
Ceramic monolith with 600 cpsi (cells per square inch), and a wall thickness of 0.2 mm. The frontal area is 117.8 cm^2. Catalyst operates at 800K and 1 bar.

Other useful properties:
Exhaust mass flow rate = 0.133 kg/s, universal gas constant = 8314 J/kmol-K, molecular weight of exhaust gas = 29 kg/kmol.

The targeted efficiency for reducing propane (a surrogate for the hydrocarbons) is 99.7%. The diffusivity of propane in exhaust gas at 800K and 1 bar is 5.63×10^{-5} m^2/s.

Calculate:

(i) the flow velocity inside the channels of the catalyst.

(20 marks)

(ii) the minimum length of the catalyst to attain the targeted catalyst efficiency.

(15 marks)

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