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UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER I
SESSION 2019/2020

COURSE NAME	:	INTERNAL COMBUSTION ENGINE
COURSE CODE	:	BDE 40603
PROGRAMME	:	BDD
EXAMINATION DATE	:	DECEMBER 2019/ JANUARY 2020
DURATION	:	3 HOURS
INSTRUCTION	:	ANSWER **FIVE (5)** QUESTIONS **ONLY**

THIS QUESTION PAPER CONSISTS OF **SIX (6)** PRINTED PAGES

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Q1 (a) Explain the reasons for the difficulty in achieving 100% engine volumetric efficiency.

(2 marks)

(b) A 1500 cm^3, four-stroke cycle, four-cylinder compression ignition (C.I.) engine, operating at 3200 RPM, produces 48 kW of brake power. The engine volumetric efficiency is 0.92 and with operating air-fuel ratio of 21:1. Calculate:

i. the required mass air flow rate (kg/sec) into the engine;

ii. brake specific fuel consumption (g/kW·hr);

iii. the mass flow rate (kg/hr) of the exhaust gas; and

iv. brake output per displacement (kW/litre).

(18 marks)

Q2 (a) Explain why an electric dynamometer is considered to be better than a hydraulic dynamometer?

(4 marks)

(b) Spark ignition (S.I.) engines produce high amount of carbon monoxide (CO) and unburned hydrocarbon (HC) emissions during operation. Explain the causes for those emissions.

(6 marks)

(c) Compression ignition (C.I.) engine operation can be approximated by the ideal Air-Standard Diesel Cycle.

i. Justify the assumptions of isentropic compression stroke and the constant-pressure heat addition process used for this idealised cycle;

ii. Sketch this ideal Air-Standard Diesel Cycle on a *P-V* diagram; and

iii. Derive the expression for Diesel Cycle thermal efficiency, based on its temperature values of T_1, T_2, T_3 and T_4.

(10 marks)

Q3 (a) Referring to the exhaust gas aftertreatment process for an S.I. engine, describe the roles of a three-way catalyst (TWC) system that is normally installed inside the exhaust pipeline of the S.I. engine.

(6 marks)

(b) Gasoline used for spark ignition engine has a typical chemical formula of C_8H_{18}. During combustion this fuel will react exothermically with oxygen using this reaction route:

$$\mathbf{C_8H_{18} + O_2 \rightarrow CO_2 + H_2O} \quad \textit{(Equation 1)}$$

i. Rewrite Equation 1 in its chemically balanced form; and
ii. Calculate the mass of water that will be produced, assuming complete combustion process is taken place.

(14 marks)

Q4 A V6 research engine with capacity of 3000cc operates on a 4-stroke cycle at 3600 RPM. The compression ratio is 9.49 and the length of the connecting rods is 17.1 cm. Its bore is equivalent with the stroke. At the given engine speed, the combustion terminates at 20 $^{\circ}$C after-top-dead-centre (aTDC). Calculate:

i. the cylinder bore and stroke length;
ii. average piston speed;
iii. the clearance volume of each cylinder; and
iv. piston speed at the end of combustion.

(20 marks)

Q5 A five-cylinder, four-stroke cycle S.I. engine has a compression ratio r_c = 11:1, bore = 5.52 cm, stroke = 5.72 cm, and connecting rod length = 11.00 cm. Cylinder inlet conditions are 63°C and 92 kPa. The intake valve closes at 41° after-bottom-dead-centre (aBDC) and the spark plug is fired at 1.5° before-bottom-dead-centre (bTDC). Calculate:

i. temperature (K) and pressure (kPa) in the cylinder at ignition, assuming Otto cycle analysis (i.e., assume the intake valve closes at BDC and ignition is at TDC);

ii. effective compression ratio (i.e. actual compression of the air-fuel mixture before ignition); and

iii. actual temperature (K) and pressure (kPa) in the cylinder at ignition.

(20 marks)

Q6 During a combustion process inside a spark ignition (S.I.) engine, the flame front stops before it reached the walls of the combustion chamber. Consider the unburned boundary layer as a volume of 0.1 mm thick along the entire combustion chamber surface, with the piston having a 3.0 cm hemisphere bowl in its face. Calculate the percentage of fuel that does not get burned due to being trapped in the surface boundary layer. Provide your assumptions and justifications.

(20 marks)

END OF QUESTIONS

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The distance between the crank axis and wrist pin axis or piston position is given by, s:

$$s = a\cos\theta + \sqrt{r^2 - a^2\sin^2\theta}$$

Where a = crankshaft offset, r = connecting rod length and θ = crank angle, measured from the centerline and it is zero when the piston is at TDC

For an engine with N_c cylinders, displacement volume, V_d:

$$V_d = V_{BDC} - V_{TDC} \qquad V_d = N_c\left(\frac{\pi}{4}\right)B^2S$$

Where B = cylinder bore, S = stroke, S = 2a

Compression ratio, r_c is defined as: $r_c = V_{BDC}/V_{TDC}$

The cylinder volume at any crank angle is given by: $V = V_c + \left(\frac{\pi B^2}{4}\right)(r + a - s)$

Where V_c = clearance volume

Brake work of one revolution, W_b: $W_b = 2\pi T$; $W_b = \frac{V_d(bmep)}{n}$

Where T = engine torque, bmep = brake mean effective pressure, n = number of revolutions per cycle

Mean effective pressure: $mep = \frac{\dot{W}n}{V_dN}$

Engine torque, T, for 2-stroke and 4-stroke cycles:

$$T_{2-stroke} = \frac{V_d(bmep)}{2\pi} \qquad T_{4-stroke} = \frac{V_d(bmep)}{4\pi}$$

Engine power,

$$\dot{W} = \frac{WN}{n} \qquad \dot{W} = 2\pi NT$$

N = engine speed

Specific fuel consumption $sfc = \dot{m}_f/\dot{W}$

Instantaneous volume, V at any crank angle, θ:

$$\frac{V}{V_c} = 1 + \frac{1}{2}(r_c - 1)\left[R + 1 - \cos\theta - \sqrt{R^2 - \sin^2\theta}\right]$$

V_c = clearance volume, R = r/a,

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Volumetric efficiency,

$$\eta_v = \frac{m_a}{\rho_a V_d}$$

$$\eta_v = \frac{n\dot{m}_a}{\rho_a V_d N}$$

where

m_a = mass of air into the engine for one cycle

$\dot{m}_a$ = steady - state flow of air into the engine

ρ_a = air density evaluated at atmospheric conditions

V_d = displacement volume

N = engine speed

n = number of revolutions per cycle

$$\rho_{air} = 1.181 \, {kg}/{m^3}$$

For a generator, power output is the product of voltage and current.

Average piston speed is U_p=2SN

The ratio of instantaneous piston speed divided by the average piston speed is:

$$\frac{U_p}{\overline{U}_p} = \left(\frac{\pi}{2}\right)\sin\theta\left[1 + \left(\frac{\cos\theta}{\sqrt{R^2 - \sin^2\theta}}\right)\right]$$

where

$$R = {r}/{a}$$

Compound/Element	**Molecular weight**	**Compound/Element**	**Molecular weight**
Air	28.966	Nitric Oxide, NO	30.006
Carbon Dioxide, CO_2	44.01	Nitrogen, N_2	28.0134
Carbon Monoxide, CO	28.011	Nitrous Oxide, N_2O	44.0133
Isooctane, C_8H_{18}	114.23	Nitrogen dioxide, NO_2	46.0065
Methane, CH_4	16.04	Oxygen, O_2	31.9998
Hydrogen, H_2	2.016	Water Vapor - Steam, H_2O	18.02
Gasoline, C_8H_{15}	111.00	Light diesel, $C_{12.3}H_{22.2}$	170.00
		Heavy diesel, $C_{14.6}H_{24.8}$	200.00