Question 1: An oil engine operates in a *dual cycle* with compression (r_c) and expansion (r_e) ratios of 9 and 5, respectively. The initial pressure and temperature of the air are 1 bar and 30°C. The heat liberated at constant pressure is twice the heat liberated at constant volume, i.e.,

$$C_p\left(T_4 - T_3\right) = 2C_v\left(T_3 - T_2\right).$$

The isentropic expansion and compression strokes follow $PV^n =$ constant, with $n = 1.25$. The cylinder bore (diameter) is of 250 mm and the stroke length is of 400 mm.

(a) (8 Marks) Calculate pressures and temperatures at all strokes and fill up the table below

Stroke	P (bar)	T (K)
1	1.0	303.15
2		
3		
4		
5		

(b) (2 Marks) Sketch the *P-v* diagram for this cycle, indicating the swept (V_s) and TDC (V_c) volumes.

(c) (2 Marks) Calculate the Mean Effective Pressure (MEP) of the cycle (in bar) using the following expression:

$$MEP = \frac{1}{r_c - 1}\left[P_3\left(\rho - 1\right) + \frac{P_4\rho - P_5 r_c}{n - 1} - \frac{P_2 - P_1 r_c}{n - 1}\right]$$

(d) (2 Marks) Calculate *work done per cycle* (in kJ) and the *heat supplied per cycle* (in KJ), given

$$W_{\text{cycle}} = MEP \times V_s$$
$$Q_{\text{cycle}} = mQ_s = m\left[C_p\left(T_3 - T_2\right) + C_p\left(T_4 - T_3\right)\right] \quad \text{with } V_1 = V_s + V_c = \frac{r_c}{r_c - 1}V_s$$

(e) (6 Marks) Sketch *T-S* and *P-V* diagrams for the Otto and Diesel cycles.

Also given:

$$C_p = 1.0\frac{\text{kJ}}{\text{kg.K}}\,,\quad C_v = 0.71\frac{\text{kJ}}{\text{kg.K}}\,,\quad MW = 29\frac{\text{g}}{\text{gmol}}\ \text{(molecular weight)},$$
$$R = 8.3144621 \times 10^{-5}\frac{\text{m}^3\text{.bar}}{\text{K.gmol}}\ \text{(gas constant)},\quad \rho = \frac{r_c}{r_e}$$

Question 2:

(a) (8 marks) A biodiesel manufacturing plant takes animal fats as feedstock and also spent cooking oil for refining. The output of the plant is 75000 tonnes per year of biodiesel. Assigning this a calorific value of 37 $MJ.kg^{-1}$, calculate the amount of fossil fuel derived carbon dioxide eliminated by its use in preference to mineral diesel of calorific value 43 $MJ.kg^{-1}$. Given, atomic weights/$g.mol^{-1}$: C: 12 and H: 1.

(b) (2 Marks) By what chemical process can the performance of a bio-diesel be improved?

(c) (2 Marks) What is one major benefit of having natural gas in its liquefied form?

(d) (8 marks) Natural gas is supplied in liquefied form to a particular terminal as LNG (liquefied natural gas, heat of combustion 55 $MJ.kg^{-1}$) in a quantity of 1.2 million tonnes per annum where it is converted back to gas and used to generate electricity. At what rate will it so generate if the efficiency is 35%?

Question 3:

(a) The steady flow energy conservation can be written in the form:

$$\frac{\dot{Q} - \dot{W}_s}{\dot{m}} = \left(h_{out} + \frac{u_{out}^2}{2} + gz_{out}\right) - \left(h_{in} + \frac{u_{in}^2}{2} + gz_{in}\right)$$

(i) (3 Marks) Explain the meaning of the symbols and terms in this equation.

(ii) (3 Marks) What assumptions are used to derive this expression?

(b) (3 Marks) The equation given above is valid for steady flow devices with one inlet and one outlet. State a modified version of this formula that is valid of steady flow devices with two inlets (whose properties are labelled 1 and 2) and one outlet (labelled 3). Give an equation representing steady mass conservation in this case.

(c) A steady flow device with two inlets and one outlet does work on the fluid at a rate of 80 kW. The remaining known inlet and outlet properties are given by:

Property	**Inlet 1**	**Inlet 2**	**Outlet 3**	**Units**
Cross-sectional area, A	0.03	0.1	0.5	m^2
Inlet/outlet height, z	0.2	1.2	0.5	m
Volume flux, q	1.8	0.5	20	m^3/s
Temperature, T	80	70	30	°C
Pressure, p	200		110	kPa

Assuming the fluid behaves as an ideal gas with $R = 0.3$ kJ/(kg.K) and $C_p = 800$ kJ/(kg.K), calculate:

(i) (2 Marks) the fluid velocity through each inlet and outlet;

(ii) (6 Marks) the pressure p_2;

(iii) (2 Marks) the rate is heat added to gas.

(d) (1 Mark) Comment on whether the gas transfers heat to the surroundings or whether the steady flow device heats the gas.

Question 4: A vapour-compression refrigeration system circuates Refrigerant 134a at a rate of 6 kg/min. The refrigerant enters the compressor at -10°C, 1.4 bar and exits at 7 bar. The isentropic compressor efficiency is 67%. There are no appreciable pressure drops as the refrigerant flows through the condenser and evaporator. The refrigerant leaves the condenser at 7 bar, 24°C. Ignoring heat transfer between the compressor and its surroundings, determine:

(a) (8 Marks) H_i, $i \in \{1, 2, 3, 4\}$;

(b) (3 Marks) Coefficient of performance, β;

$$\beta = \frac{H_1 - H_4}{H_2 - H_1}$$

(c) (3 Marks) Refrigeration capacity, $\dot{Q}_{\text{in}}$ (in ton),

$$\dot{Q}_{\text{in}} = \dot{m}\left(H_1 - H_4\right)$$

(d) (6 Marks) Sketch the schematics of the process and *T-S* diagram for this cycle.

In the expressions above for β and $\dot{Q}_{\text{in}}$, assume that subscripts 1, 2, 3 and 4 represent the flows:

- 1: evaporator ⇒ compressor;
- 2: compressor ⇒ condenser;
- 3: Condenser ⇒ Expansion Valve and;
- 4: Expansion Valve ⇒ Evaporator.

Question 5:

(a) (5 Marks) Define the specific humidity ω, the saturation pressure of water vapour $p_{\text{v,sat}}$, and relative humidity φ. Assuming that dry air and water vapour behave like ideal gases show that

$$\omega = \frac{R_a \varphi p_{\text{v,sat}}}{R_v\left(p - \varphi p_{\text{g,v,sat}}\right)},$$

where R_a and R_v are the specific gas constants of dry air and water vapour, respectively.

(b) (7 Marks) Air leaving an air-conditioning system in a building is mixed adiabatically with air from outside in a steady process. If the inlets to the mixing chamber are labelled 1 and 2 and the outlet is labelled 3, then state equations corresponding to the mass conservation of dry air, the mass conservation of water vapour and the conservation of energy. Hence show that

$$\frac{\dot{m}_{a2}}{\dot{m}_{a1}} = \frac{\omega - \omega_1}{\omega_2 - \omega_3} = \frac{h_3 - h_1}{h_2 - h_3}$$

where $\dot{m}_a$ is a mass flux of dry air and h is an enthalpy.

(c) Saturated air at 16°C leaves the cooling section of an air-conditioning system in a building at a rate of 1 m^3/s. This air is mixed adiabatically at a constant pressure of 100 kPa, with air from outside that has temperature 30°C and specific humidity 0.0182 kg H_2O/kg dry air. If the mass flux of dry air after mixing is 1.8 kg/s, then:

(i) (3 Marks) Determine the mass flux through both inlets;

(ii) (1 Mark) Calculate the specific humidity of the air leaving the cooling section of the air-conditioning system;

(iii) (4 Marks) Calculate the specific humidity of the mixed air.

You may assume the saturation pressure of water vapour at 16°C is 1818.747 Pa and that the specific gas constants $R_a = 287.1$ J/(kg.K) and $R_v = 461.5$ J/(kg.K), respectively.