M.E. MECHANICAL ENGINEERING - FIRST YEAR - SECOND SEMESTER EXAMINATION, 2025

COMBUSTION ENGINEERING

Time: Three hours **Full Marks 100**

	All parts of the same question must be answered together. Assume any unfurnished data suitably **Use of Thermodynamic Tables and Charts permitted**	
	PART I (50 Marks)	
	Group A **Answer any TWO parts:**	10
1. (a)	Define adiabatic flame temperature for an isobaric reaction and derive the equation for determining the adiabatic flame temperature for stoichiometric combustion of methane if the reactants enter at 298 K. Will its value change if excess air is used?	5
(b)	Consider the reaction: $CO + 0.5O_2 = CO_2 - 283005\ kJ/kmol$. Explain whether increase of pressure and increase of temperature would favour the forward or the backward reaction.	5
(c)	Define flame propagation speed and flame displacement speed. If reactants are coming out from a flat flame burner at 40 cm/s and the flame is stabilized on the burner, what are the values of flame propagation speed and flame displacement speed?	5
	Group B **Answer any TWO parts:**	40
2. (a)	Consider combustion of LPG (40% C_3H_8+ 60% C_4H_{10} by volume) burning with 25% excess air at constant volume. The fuel enters at 298 K while the air enters at 400 K. The products leave at 1400 K. Calculate heat transfer between the combustor and the surroundings. Neglect dissociation effects	20
(b)	Consider the combustion of methane in 25% excess air. If the reactants enter at 298.15 K and final temperature of the products is 2000 K, calculate the heat transferred from the combustor considering and neglecting the dissociation of CO_2.	20
(c)	A premixed laminar flame is stabilized in a shear layer where the horizontal velocity of the reactant mixture varies linearly from 0.9 m/s to 1.4 m/s over a distance of 30 mm. If the flame speed for the mixture is 0.36 m/s, determine the flame shape	20

	PART II (50 Marks)	
	Group A **Answer any ONE questions:**	20
1. (a)	In a high-temperature cracking process, the decomposition of ethane follows the reaction: $C_2H_6 \rightarrow 2CH_3$ This reaction follows the Arrhenius rate law: $\boldsymbol{k(T) = A \cdot exp\,(-E_a / RT)}$ Pre-exponential factor: A = 1.2 × 10^{14} s^{-1}, Activation energy: E_a = 280,000 J/mol, Gas constant: R = 8.314 J/mol·K At T_1 = 1000 K, the rate constant is $k_1 = 2.5 \times 10^4$ s^{-1}. At what temperature will the rate constant become one-fifth of its value at 1000 K?	20
(b)	Consider the following three-step mechanism for the formation of species B: 1. $A + C \overset{k_1}{\rightleftharpoons} D$ 2. $D \overset{k_2}{\rightarrow} B + C$ 3. $B \rightarrow$ Products Assume: • Species D is in steady state • Species C and D are intermediates • Step 1 is in partial equilibrium with equilibrium constant K_{eq} (a) Express the concentration of intermediate D in terms of concentrations of A, C, and K_{eq} (b) Express the net formation rate of B as a global step involving [A], [C], k_2 and K_{eq}	20
	Group B **Answer any TWO questions:**	15 x 2 = 30
2. (a)	A gas-phase reaction $A \rightarrow n\,Products$ occurs in a constant-volume, adiabatic, and perfectly mixed batch reactor. The reaction is first-order with rate $r = k[A]$, Assume ideal gas behavior and constant heat capacity.	15

	Derive expressions for: (a) Species concentration [A](t) (b) Pressure P(t) (c) Temperature T(t)	
2 (b)	Consider a Perfectly Stirred Reactor (PSR) operating at steady state and constant temperature. The reactor volume is $V = 4.0\ L$, and the following first-order irreversible reaction occurs within the reactor: $CO \rightarrow CO_2$ The rate of reaction is given by: $r = k[CO]$, with $k = 0.20\ s^{-1}$ The inlet concentration of CO is $[CO]_{in}$=2.0 mol/L. Derive value of the outlet concentration $[CO]_{out}$ for volume flow rates changes at volume flow rate of 1L/s.	15
2(c)	In high-temperature hydrogen combustion, the following reversible elementary reaction is important: $H_2O + M \rightleftharpoons H + OH + M$ This reaction represents the thermal dissociation of water, assisted by a third body M. At a temperature of $T = 1800K$, the reverse rate coefficient is given as: $k_r = 2.0 \times 10^{-10}\ cm^6/mol^2 \cdot s$ The equilibrium constant for the reaction at this temperature is: $K_{eq} = 1.5 \times 10^{-4}$ This equilibrium constant is based on a standard reference pressure of 1 atm (101325 Pa). Use the ideal gas constant $R = 8.314 J/molK$ Determine the forward rate coefficient k_f at $T = 1800K$.	15