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M.E. POWER ENGINEERING FIRST YEAR 2ND SEMESTER EXAMINATION, 2017

Subject : Combustion Technologies **Full Marks: 100** **Time : Three hours**

Answer any five questions. Use data from Table 1 and Table 2 for calculation.

1. (a) Define equivalence ratio. Derive its relationship with percentage excess air? (2+3)

   (b) Ethane (C_2H_6) is burnt in excess air so that complete combustion of the fuel takes place. If the product gas analysis on dry basis shows 85% nitrogen by volume, what is the percentage of excess air supplied? (5)

   (c) Dodecane ($C_{12}H_{26}$) enters an engine and burns with air to give products having volumetric analysis on dry basis as 12.1% CO_2, 3.4% CO, 0.5% O_2, 1.5% H_2 and rest nitrogen. Determine the air-fuel ratio of the reactant mixture on mass basis and the equivalence ratio. (10)

2. (a) How does the heating value at constant pressure differ from the heating value at constant volume? How much different are these values for methane fuel? Which of these two heating values is more relevant for (i) internal combustion engine, (ii) gas turbine combustor? (8)

   (b) A stoichiometric mixture of isooctane (C_8H_{18}) vapour and air is burned in a closed combustion chamber where a constant pressure of 1 atm. (100 kPa) is maintained. The initial volume and temperature of the reactant mixture in the chamber are 0.4 m^3 and 25°C. The mixture is ignited and heat is transferred from the chamber such that a final temperature of 727°C is reached. Assuming complete combustion determine the amount of heat transfer from the combustion chamber. What will be the final volume of the chamber? Consider all species to behave as ideal gas. (12)

3. (a) Methane-air mixture of equivalence ratio 1.1 enters a reactor at 1atm pressure and 25°C temperature. After the combustion of the fuel, the product mixture flows out of the reactor at 1200 K. The reactor operates at constant pressure, nitrogen behaves as inert gas. CO, CO_2, H_2 and H_2O in the product are in chemical equilibrium following the water gas shift reaction. Find the molar composition of the product gas coming out of the reactor. Given, at 1200 K $\frac{\bar{g}_i}{\bar{R}T}$ for CO, CO_2, H_2 and H_2O are −37.163, −68.577, −17.965, −49.689, respectively. (14)

   (b) Define specific reaction rate of a chemical reaction. Consider the reaction A + B → C, where the rate law is given as $\frac{d[X_A]}{dt} = -k[X_A]^2[X_B]^0$, with k = 0.1 m^3/kmol-s. In the initial mixture, the concentrations of A and B are 2 kmol/m^3 and 3.5 kmol/m^3, respectively with no C. What will be the concentrations of A, B and C after 5 secs. (6)

4. (a) Define laminar burning velocity of a premixed flame. Explain how the various factors affect the laminar burning velocity of a premixed fuel-air mixture. (2+6)

   (b) Derive an expression of burning velocity of a laminar premixed flame using a simplified analysis of one-dimensional and steady flame. Clearly state the assumptions considered for the derivation. (12)

5. (a) Derive an expression of critical kernel radius for spark ignition of a premixed reactant mixture in terms of laminar flame thickness. (8)

   (b) Explain why the charge inside the crevices of a spark ignition engine does not burn. (4)

   (c) In a stability test of laminar flame on a circular burner it is observed that the flame flashes back inside the burner as the supply of fuel-air mixture is turned off. However, such flash back does not happen when the equivalence ratio of the mixture goes below a certain value. – Justify the observations with proper explanation. (4)

(d) Why does a premixed methane-air flame appear blue while for propane flame the colour is greenish blue? (4)

6. (a) Why is the turbulent burning velocity much greater than the laminar burning velocity for a premixed flame? (4)

(b) Why does a flame in spark ignition engine propagate more rapidly at higher engine rpm? (4)

(c) Describe the structure of a co-flow, laminar, non-premixed flame using the temperature variations across the flame. How can the height of a non-premixed flame be obtained from the temperature distribution? (12)

7. (a) Define mixture fraction? Using the conservation equations of fuel and oxygen species, derive the conservation equation in mixture fraction for a non-premixed flame. Use 2-D Cartesian coordinates. (2+8)

(b) Consider a non-premixed flame of propane in co-flowing air. Assuming infinite rate of reaction, find the value of mixture fraction which would define the flame surface. (4)

(c) How does the height of a non-premixed flame change with the flow rate of fuel? Justify this variation using a phenomenological analysis. (6)

8. (a) What are the significance of viscosity and surface tension of liquid fuel on its atomization characteristics? (4)

(b) State the spray parameters which are important in the combustion of a liquid fuel. Which mean diameter of droplets is the most significant in combustion and why? (2+2)

(c) Consider spherico-symmetric evaporation model from the surface of a liquid fuel droplet. Derive an expression for temperature distribution in the gas phase around the droplet clearly stating the assumptions considered for the derivation. (12)

Table: 1 – Heat of formation and Heating Values

Species	Enthalpy of Formation (kJ/kmol)	Higher Heating Value (kJ/kg)	Lower Heating Value (kJ/kg)
CO_2	- 393520	-	
H_2O (v)	- 241820	-	
H_2O (l)	-285830	-	
CO	- 110530	-	
CH_4	- 74850	55510	50020
C_2H_6	- 84680	51870	47480
C_3H_8	- 103850	50350	46360
C_8H_{18}	- 220100	48119	44651

Table-2: $\Delta h = \left(h_T^0 - h_{298}^0\right)$ at different temperatures for species

Temperature (K)	$\Delta h = \left(h_T^0 - h_{298}^0\right)$ (kJ/kmol)				
	CO_2	CO	H_2O	O_2	N_2
298	0	0	0	0	0
500	8,301	5,943	6,947	6,097	5,920
1000	33,425	21,697	25,993	22,721	21,468
1200	44,488	28,440	34,518	29,775	28,118
1500	61,681	38,847	48,181	40,590	38,404
2000	91,420	56,737	72,805	59,169	56,130