Ref. No.: Ex/PG/BPE/T/123A/2024

M.E. BIO-PROCESS ENGINEERING FIRST YEAR SECOND SEMESTER 2024

Bioenergy Engineering

Answer any five questions

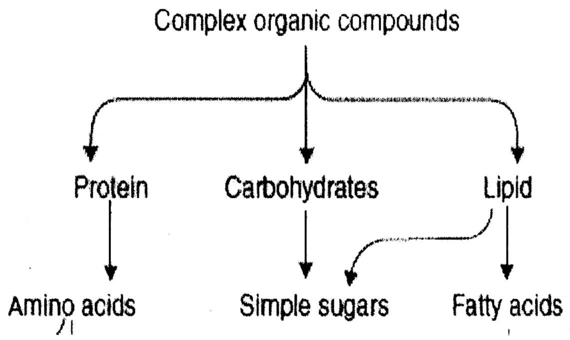
Full Marks 100

Assume any missing data

All symbols have usual significance

Time: 3 Hours

1.A) The following figure represents the hydrolysis process, namely, the first step in the biogas generation process.



Which stepswill follow the hydrolysis to generate biogas from a bio-waste? Describe all with the relevant microbes involved in these steps. **10**

1.B) From the following reaction stoichiometry, one should be able to produce **12 moles** of hydrogen from **one mole** of glucose. Is it possible in reality? Justify your answer. **10**

$$C_6H_{12}O_6 + 6H_2O \rightarrow 6CO_2 + 12H_2$$

The Gibbs free energy change for oxidation of glucose and hydrogen is as follows:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O \qquad \Delta G^{o'} = -2872\ kJ/reaction$$

$$12H_2 + 6O_2 \rightarrow 12H_2O \qquad \Delta G^{o'} = -2846\ kJ/reaction$$

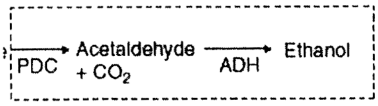
2(A) In a biogas plant, 20 m^3 cow dung (1ton/m^3) and 1m^3 kitchen waste slurry (0.8t/m^3) are anaerobically digested daily. The dry matter (DM) contents of cow dung and kitchen waste slurry are 10% (w/w) and 45% (w/w) respectively. The organic matter (OM) contents of cow dung and kitchen waste slurry are 80% (w/w) and 90% (w/w) of DM respectively. The volumetric yields of biogas from cow dung and kitchen slurry are 450m^3/ton OM and 600m^3/ton OM respectively, and overall methane content is 80% (v/v). What are the daily production rates (m^3/d) of biogas and methane from the unit? **10**

2B) In which biofuel generation process is the following reaction involved?

$$TAG + 3CH_2CH_3\,(OC(O)CH_3) \leftrightarrow 3RCOOCH_2CH_3 + C_3H_5(OC(O)CH_3)_3$$

Naming the enzyme involved in the process, describe the process along with advantages and challenges. **10**

[Turn over

3(A)	*E.coli* is genetically modified by the insertion of PET operon represented by the following.Describe overall strategy with the pathway for the production of ethanol using genetically modified *E.coli* strains. 	10	
3B)	When the bacterium *Methylotrophicum*is used to produce acetic and butyric acid from CO the following reaction occurs: $$CO + xO_2 + yN_2 + zH_2O \rightarrow 0.52CO_2 + 0.42CH_2O + 0.024CH_2O_{0.5} + 0.036 \text{ C-mole cells}$$ The biomass has an elemental composition of $CH_{1.8}O_{0.5}N_{0.2}$. How many moles of oxygen, nitrogen and water are consumed per mole of CO? How many moles of butyric acid and acetic are produced per mole of CO?	10	
4A)	Discuss on different routes of production of bio-hydrogen.	10	
4B)	A considerable amount of methane is produced in Norway from its North Sea oil and gas wells. Some of this methane is converted to methanol by partial oxidation and then is biochemically converted to biomass that is used as animal feed. The reported stoichiometry of the biochemical reaction is $$CH_3OH + 0.731O_2 + 0.146\ NH_3 \rightarrow 0.269CO_2 + 0.731C - mol\ biomass$$ What is the atomic composition of biomass produced? How much heat is produced per mole of methanol consumed? What fraction of Gibbs free energy of reactants is present in the biomass? Assume the validity of energy regularity approximation ($\Delta_c G = 112\xi\ and\ \Delta_c H = 110.9\xi$).	10	
5A)	You have been asked to produce electricity from wastewater containing organic waste and the COD value is **0.64g/L**. Which bioprocess would you recommend. Describe the process with its typical arrangement, microbe specificity, calculation of efficiency and challenges.	13	
5B)	Describe the role of algae in CO_2 capture and generation of biochemicals.	7	
6A)	What do you mean by "Energy transition" and "Biorefinery" concept?	2+ 3	
6B)	A single chambered MFC equipped with PEM and an air cathode is run using glucose at a concentration of **1g/L**. The available anode surface area is $5 \times 10^{-4} m^2$and the anode volume is **0.025L**.The average voltage has been determined to be **0.3V** over **10h** operation when a **500Ω** resistor is used. Determine the average power density on the basis of surface area and the coulombic efficiency of the cell. [**F=96485C/mol** e^- ***available***]	10	
6C)	A bioprocess uses substrate, S, NH_3 as nitrogen source along with oxygen and water to generate biomass, B, and a product, P along with CO_2. Defining $Y_{Q/S}$, correlate $Y_{Q/S}$ with $Y_{B/S}, Y_{P/S}, Y_{N/S}, \xi_B, \xi_P, \xi_N$ and ξ_S.	5	

7A)	A 1L CSTBR with **80%** (v/v) liquid and **20%** (v/v) overhead gas space is operated to generate hydrogen using hyperthermophilic bacterial strain *T. maritima* at optimum temperature, **70°C.** The dilution rate is $0.84h^{-1}$ and the feed concentration of glucose is 5g/L. The overhead gas pressure (gauge) measured under steady state is **175kPa** (atmospheric pressure=**101.3kPa**). Gas phase concentration of hydrogen, in terms of $mole\ fraction\ (or\ volume\ fraction) of\ hydrogen\ gas\ in\ the\ overhead, (y_{H_2})$,is usually determined using gas chromatograph (GC). Liquid phase concentration is determined applying Henry's law. It is known that mass of hydrogen generated (m_{H_2})at any time can be correlated with the total overhead pressure (P_T) with the following equation: $m_{H_2} = y_{H_2} * P_T \left(\frac{V_{overhead}}{RT} + K_{H_2} * V_{Liquid}\right) * (MW_{H_2}) \quad (i)$ where, $MW_{H_2} = molecular\ weight\ of\ hydrogen.$ $K_{H_2} = Henry's\ law\ constant;$ Henry'slaw:$C_{H_{2(l)}} = K_{H_2} p_{H_2}$ $C_{H_{2(l)}} = liquid\ phase\ concentration\ of\ hydrogen\ in\ equilibrium\ with\ the\ overhead\ gas;$ $p_{H_2} = \mathbf{partial\ pressure\ of\ hydrogen\ in\ overhead\ gas\ phase} = y_{H_2} * P_T$ The growth is uninhibited and follows Monod kinetics. There is no hydrogen present in the system initially. Generation of hydrogen is growth associated and from the perspective of growth under steady state, equation (ii) gives the mass of hydrogen generated as follows: $m_{H_2} = Y_{H_2/X} * C_{XS} * V_{Liquid} \quad (ii)$ Where, $C_{XS} = biomass\ concentration\ under\ steady\ state$ Somehow, the laboratory GC is temporarily not in operation. Considering the validity of both equations (i) and (ii), determine the hydrogen concentration in the overhead in terms of y_{H_2}. Data: $\mu_{max} = 0.94h^{-1}$; $K_s = \frac{0.57g}{L}$; $Y_{x/s} = 0.248\frac{g\ biomass}{g\ substrate}$; $Y_{H_2/X} = 0.19\frac{g\ H_2}{g\ biomass}$; $R = 8.314\ \mathrm{L.kPa/mol.K}$; $K_{H_2} = 7.21X10^{-6}$**M/kPa at 70°C.**	13	
7B)	The growth of hydrogen generating microorganism is usually inhibited at high hydrogen partial pressure. Write down a representative growth rate equation under such situation.	2	
8	Discuss on (i) Ethanol production through ED pathway (ii) Role of nitrogenase and hydrogenase in hydrogen production (iii) Algal lipid and Strategy for enhancement of Production (iv) Limit of 2nd law of thermodynamics on a bioprocess from the following case study: **Per C-mole** of a substrate, **0.451C-mole** of a product and **0.235C-mole** of biomass are produced and **0.0399 mole** of nitrogen source is consumed.	5x 4 = 20	

Parameter	S (Substrate)	N (Nitrogen source)	B (Biomass)	P (Product)
$\Delta_c G$ **kJ/mol**	**478.7**	**391.9**	**524.2**	**659.5**