CVEN 5534 Wastewater Treatment
Assignment 3
Due: Tuesday, Sept. 28

1. A municipal wastewater treatment plant receives 70 m^3/min of medium strength wastewater (see attached characterization). Approximately 95% of the COD is removed before discharge. Of the fraction removed, 65% of the influent COD is oxidized by bacteria to CO_2 and 35% is incorporated into bacterial biomass.

a. What is the mass flow rate of oxygen (kg/day) that must be supplied?
b. What is the biomass generation rate (kg/year) if the chemical for bacterial cells is $C_5H_7NO_2$?

2. Show by means of comparing the oxidation of a simple carbohydrate, CH_2O, that the oxygen equivalence of nitrate when nitrate is the electron acceptor in respiration = 2.86 g-O_2/g-NO_3-N.

3. The maximum growth yield for a culture of bacteria growing on soluble COD = 0.4 g-cells (as COD)/g-substrate COD. However, it was observed in a batch growth test using soluble COD as the growth substrate that the observed yield was only 0.32 g-cells (as COD)/g-substrate COD.

a. If 30% of the cells were lysed during the growth experiment, calculate the fraction of the COD from the cells that was available as substrate.
b. What fraction of the solids are inert (debris)?

4. A municipal treatment plant receives an average wastewater flow of 50,000 m^3/d. The influent COD is 300 g/m^3, and the observed growth yield for the population of bacteria in the plant is 0.45 g-cells/g-COD.

    a. Calculate the observed yield on a COD basis.
    b. Write the COD-based stoichiometry for oxidation of the influent organic matter (COD).
    c. Calculate the mass of oxygen required per day to stabilize the waste.
    d. What is the rate at which viable cells are grown (in terms of mass COD/day).

5. Methane production by a strain of *Archaea* growing on acetate follows this molar stoichiometry when cell yield is considered:

$$1CH_3COO^- + 0.03CO_2 + 0.02NH_4^+ + 0.92H_2O \rightarrow 0.95CH_4 + 0.02C_5H_7NO_2 + 0.98HCO_3^-$$

a) Write the mass-basis stoichiometry for methane production and show that mass conservation is satisfied.
b) Write the COD-basis stoichiometry for methane production and show that COD is conserved.

c) If acetate is consumed in an anaerobic digester at a rate of 500 kg-CH_3COO^-/d, at a temperature of 35 ^oC and a pressure of 1 atm, what is the rate of methane (CH_4) production in m^3/day, assuming the stoichiometry given above?

d) What is the rate of volatile suspended solids generation (kg-VSS/day) assuming 1 g $C_5H_7NO_2$ = 1 g VSS (volatile suspended solids)?

6. For the following concurrent reactions and rate expressions,

a. develop a tableau formulation for the reactions and components by populating the cells in the table below. Leave cells blank when there is no appropriate coefficient

b. (next page)

Reaction 1: heterotrophic bacteria growth and aerobic mineralization of soluble COD

$$-\frac{1}{Y_H}S_S - \frac{(1-Y_H)}{Y_H}S_O + 1^* X_{BH} = 0$$

Reaction 1a: synthesis uptake of ammonia nitrogen by heterotrophic bacteria

$$-i_{NXB}S_{NH} + i_{NXB}X_{NB} = 0$$

Reaction 2: autotrophic bacteria growth on ammonia and energy production, neglect synthesis uptake of ammonia for autotrophs

$$-\frac{1}{Y_{YA}}S_{NH} - \frac{(4.57-Y_A)}{Y_A}S_O + 1^* X_{BA} = 0$$

Reaction 3: death, lysis and decay of heterotrophic bacteria and formation of debris and soluble substrate COD

$$(-1)X_B + (1-f_D)S_S + f_D X_D = 0$$

Where components and stoichiometric coefficients are

X_{BH} = heterotrophic bacteria cells (g-COD/m^3)
X_{BA} = autotrophic bacteria cells (g-COD/m^3)
X_D = nonbiodegradable cell debris (g-COD/m^3)
X_{NB} = nitrogen stored in cells (g-N/m^3)
S_S = substrate soluble COD (g-COD/m^3)
S_{NH} = soluble ammonia nitrogen (g-N/ m^3)
S_O = oxygen (g-O_2/ m^3)
i_{NXB} = g-N/g-cell-COD and i_{NXD} = g-N/g-debris-COD
Y_H = g-heterotroph cell-COD/g-COD consumed
Y_A = g-autotroph cell-COD/g-NH4-N consumed
f_D = g debris-COD produced/g biomass-COD decayed

COD AND NITROGEN STOICHIOMETRIC AND KINETIC MATRIX FOR GROWTH AND DECAY

	Components							**Rates**
Process	Soluble COD S_S (mg/L COD)	Soluble NH_4-N S_{NH} (mg/L N)	Dissolved O_2, S_O (mg/L O_2)	Heterotrophic biomass, X_{BH} (mg/L COD)	Autotrophic (Nitrifying) Biomass, X_{BA} (mg/L COD)	Debris, X_D (mg/L COD)	Ammonia N in cells X_{NB} (mg/L N)	$\mathbf{r_j}$
Aerobic Heterotrophic Growth								**1 and 1a** $\mu_H X_{BH}$
Aerobic Growth of Autotrophs (Nitrification)								2 $\mu_A X_{BA}$
Decay and Lysis of Heterotrophs								**3** $b_H X_{BH}$

And reaction rates are
$\mu_H * X_{BH}$ = growth rate for heterotrophs (d^{-1})
$\mu_A * X_{BA}$ = growth rate for autotrophs (d^{-1})
$b_H * X_{BH}$ = decay rate for heterotrophs (d^{-1})

c. Give the total rate expressions for ammonia nitrogen, heterotrophic bacteria, autotrophic bacteria, debris, soluble COD, and oxygen considering the reactions 1, 1a, 2, and 3