Fermentation Homework

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Problem 1

The air supply to a fermenter was turned off for a short period of time and then restarted. A value for C* of 7.3 mg/l has been determiend for the operating conditions. Use the tabular measurements of dissolved oxygen (DO) values to estimate the oxygen uptake rate and kLa of this system.

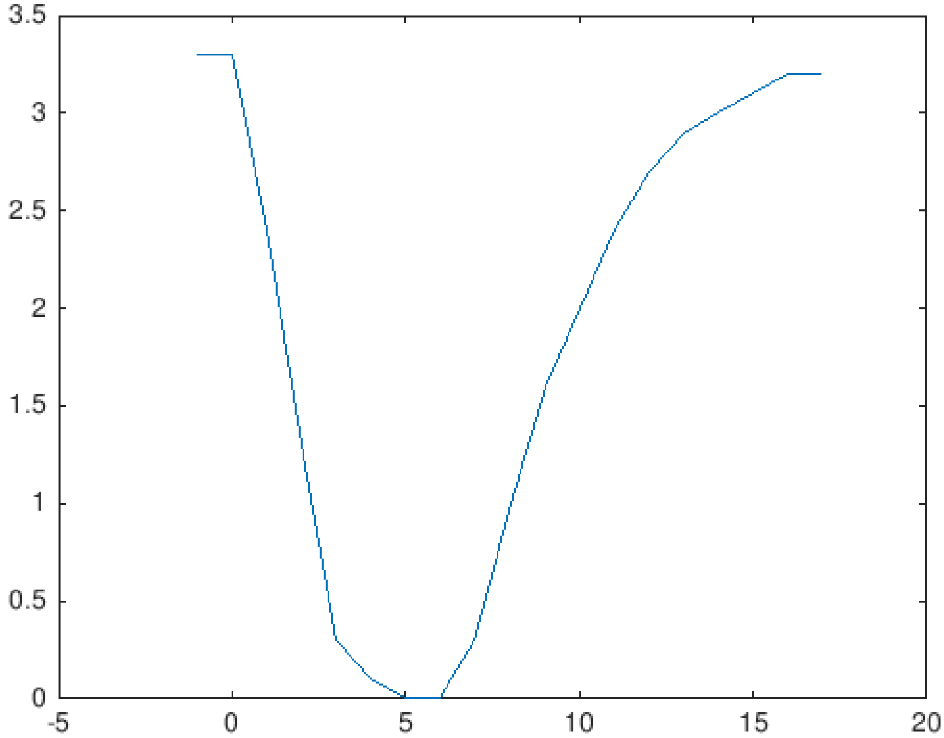
```
time = -1:1:17; % units = minutes
DO = [3.3, 3.3, 2.4, 1.3, 0.3, 0.1, 0.0, 0.0, 0.3, 1.0, 1.6, 2.0, 2.4,
 2.7, 2.9, 3.0, 3.1, 3.2, 3.2]; % units = mg/l
c_star = 7.3; % units = mg/l
```

Equations:

- dcl/dt = OTR - OUR
- OTR = kla * (c_star - cl)
- OUR = qo2 * X

Plot DO vs. time

```
plot(time, DO)
```



The negative slope of the curve represents the OUR (oxygen uptake rate). Slope from t = 0 to t = 3 minutes used to calculate OUR.

```
OUR = (DO(5) - DO(2)) / (time(5) - time(2)) * -1; % units = mg/l-min
fprintf('The oxygen uptake rate is %.2f mg/l-min.\n',OUR);
```

The oxygen uptake rate is 1.00 mg/l-min.

The positive slope of the curve represents the OTR - OUR. Substituting the OTR equation into the dcl/dt equation and solving for kla gives:

- kla = (dcl/dt + OUR) / (c_star - cl)

To solve for kla, I will assume a constant positive slope between the times t = 10 to t = 12 minutes and use the cl from t = 11 minutes.

```
dcldt = (DO(14) - DO(12)) / (time(14) - time(12)); % units = mg/l-min
cl = DO(13); % units = mg/l
kla = (dcldt + OUR) / (c_star - cl); % units = min^-1
```

Converting the units of kla from min^-1 to hour^-1

```
kla = kla * 60; % units = min^-1 * min/hour = hour^-1
fprintf('The kla is %.2f h^-1.\n',kla);
```

The kla is 16.53 h^-1.

Problem 2

A value of kla = 30 h^-1 has been determined for a fermenter at its maximum practical agitator rotational speed and with air being sparged at 0.5 l gas/l reactor volume-min. *E. coli* with a qO2 of 10 mmol O2/g-dry wt-h are to be cultured. The critical dissolved oxygen concentration is 0.2 mg/l. The solubility of oxygen from air in the fermentation broth is 7.3 mg/l at 30 deg C.

- Part a: What maximum concentration of *E. coli* can be sustained in this fermenter under aerobic conditions?
- Part b: What concentration could be maintained if pure oxygen was used to sparge the reactor?

```
kla = 30; % units = h^-1
air = 0.5; % units = l gas / l reactor volume-min
qo2 = 10; % units = mmol O2 / g-dry wt-h
crit = 0.2; % units = mg/l
o2sol = 7.3; % units = mg/l
t = 30; % units = deg C
```

Part a

Equations:

- OUR = qo2 * X = kla * (c_star - cl)

Qo2 and kla are given. C_star is the solubility of oxygen and the cl is the critical oxygen concentration. Rearranging to solve for X:

- X = kla * (c_star - cl) / qo2

Substituting in given values:

- X = kla * (o2sol - crit) / qo2

convert qo2 to use mg oxygen instead of mmol oxygen

```
qo2 = qo2 * 15.999; % units = mg O2 / g-dry wt-h
X = kla * (o2sol - crit) / qo2; % units = mg oxygen * g-dry wt E. coli
 * h / h * mg oxygen * l = g-dry wt E. coli/l
fprintf('The maximum concentration of E. coli using air is %.2f g-dry
 wt E. coli / l.\n',X);
```

```
The maximum concentration of E. coli using air is 1.33 g-dry wt E.
 coli / l.
```

Part b

Equations:

Air is 21% oxygen, so using pure oxygen would increase the partial pressure of oxygen from 0.21 * total pressure to 1 * total pressure. Assuming the pressure of the sparged gas is 1 atm, the new c_star is:

```
c_star = o2sol * 1 / 0.21; % units = mg/l * atm / atm = mg/l
X = kla * (c_star - crit) / qo2; % units = mg oxygen * g-dry wt E.
 coli * h / h * mg oxygen * l = g-dry wt E. coli/l
```

```
fprintf('The maximum concentration of E. coli using pure oxygen is
 %.2f g-dry wt E. coli / l.\n',X);
```

```
The maximum concentration of E. coli using pure oxygen is 6.48 g-dry
 wt E. coli / l.
```

Problem 3

- Part a: Estimate the required cooling-water flow rate for a 100,000-l fermenter with an 80,000-l working volume when the rate of oxygen consumption is 100 mmol O2/l-h. The desired operating temperature is 35 deg C. A cooling coil is to be used. The minimum allowable temperature differential between the cooling water and the broth is 5 deg C. Cooling water is available at 15 deg C. The heat capacities of the broth and the cooling water are roughly equal.

- Part b: Estimate the required length of the cooling coil if the coil has a 2.5-cm diameter and the overall heat transfer coefficient is 1420 J/s-m^2-deg C.

```
vol = 100000; % units = l
work_vol = 80000; % units = l
qo2 = 100; % units = mmol O2/l-h.
t_desired = 35; % units = deg C
min_deltat = 5; % units = deg C
t_water = 15; % units = deg C
c_water = 1.0; % units = Kcal/kg-deg C
c_broth = c_water; % assumption from part a
d = 2.5; % units = cm
h = 1420; % units = J/s-m^2-deg C
```

Part a

Equations:

- Q = 0.12 * qo2 (Equation 6.29 from text)

```
Q = 0.12 * qo2; % units = Kcal/l-h
```

Multiply by working volume of the tank to get the heat produced by the entire tank, not just 1 L.

```
Q = Q * work_vol; % units = Kcal/h
```

- Q = m * cp * deltaT

Rearranging to solve for mass flow rate:

- m = Q / (cp * deltaT)

Find the delta T of the water:

- deltaT = tfinal - tinitial

- tfinal = tbroth - mindeltat

```
deltaT = (t_desired - min_deltat) - t_water; % units = deg C
```

Solve for mass flow rate:

```
m = Q / (c_water  * deltaT); % units = Kcal * kg * deg C / h * Kcal *
 deg C = kg water / h
fprintf('The required flow rate of cooling water is %.2f kg/h.\n',m);
```

The required flow rate of cooling water is 64000.00 kg/h.

Part b

Equations:

- Q = U * A * deltaTlm (where deltaTlm is the log mean difference of the temperature)
- deltaTlm = (deltat1 - deltat2) / log(deltat1 / deltat2)
- deltat1 = desired fermenter temperature - initial water temperature
- deltat2 = desired fermenter temperature - final water temperature

Rearranging to solve for the surface area of the pipe:

- A = Q / (U * deltaTlm)

Here U is the given h value.

```
deltat1 = t_desired - t_water; % units = deg C
deltat2 = min_deltat; % units = deg C
deltaTlm = (deltat1 - deltat2) / log(deltat1 / deltat2); % units = deg
 C
```

Convert Q to units J/s to use the above equation

```
Q = Q / 3600; % units = Kcal/h * h / s = Kcal/s
Q = Q * 4184; % units = Kcal/h * J/Kcal = J/h
A = Q / (h * deltaTlm); % units =  * s * m^2 * deg C / J * s * deg C =
 m^2
```

- A = pi * d * l

Rearranging the surface area equation for the length of the pipe:

- l = A / (pi * d)

Convert d from cm to m

```
d = d / 100; % units = cm * m/cm
l = A / (pi * d); % units = m^2 / m = m
fprintf('The required pipe length to cool the fermentation broth is
 %.2f m.\n',l);
```

The required pipe length to cool the fermentation broth is 924.58 m.

Problem 10

E. coli have a maximum respiration rate, qo2max, of about 240-mg O2/g-dry wt-h. It is desired to achieve a cell mass of 20 g dry wt/l. The kla is 120 h^-1 in a 1000-l reactor (800 l working volume). A gas stream enriched in oxygen is used (i.e., 80% O2) which gives a value of C* = 28 mg/l. If oxygen becomes limiting, growth and respiration slow; for example, qo2 = (qo2max * cl)/(0.2 mg/l + cl), where cl is the dissolved oxygen concentration in the fermenter. What is cl when the cell mass is at 20 g/l?

```
qo2max = 240; % units = mg O2/g-dry wt-h
cell_mass = 20; % units = g dry wt/l
kla = 120; % units = h^-1
vol = 1000; % units = l
working_vol = 800; % units = l
o2_gas = 0.8; % units = %
c_star = 28; % units = mg/l
```

Equations:

- qo2 * X = kla * (c_star - cl)
- qo2 = (qo2max * cl) / (0.2 + cl)

Substitute the second equation into the first.

- (qo2max * cl * X) = kla * (c_star - cl) * (0.2 + cl)

Use MATLAB solver to find the value of cl

```
eqn = @(cl) ((qo2max * cl * cell_mass) - kla * (c_star - cl) * (0.2 +
 cl));
initial_guess = rand();
sol = fzero(eqn, initial_guess);
fprintf('The cl value is %.2f mg/l.\n',sol);
```

The cl value is 0.44 mg/l.

Problem 14

A stirred-tank reactor is to be scaled down from 10 m^3 to 0.1 m^3. The dimensions of the large tank are dt = 2m; di = 0.5 m; n = 100 rpm.

- Part a: Determine the dimensions of the small tank (dt, di, h) by using geometric similarity.
- Part b: What would be the required rotational speed of the impeller in the small tank if the following criteria were used?

```
          # Constant tip speed
          # Constant impeller Re number
```

```
vol_large = 10; % units = m^3
vol_small = 0.1; % units = m^3
dt_large = 2; % units = m
di_large = 0.5; % units = m
n_large = 100; % units = rpm
```

Part a

Equations:

- V = pi * (dt/2)^2 * h

Rearranging to solve for h:

- V / (pi * (dt/2)^2) = h

h/dt must remain constant between the large and small reactors: h_large / dt_large = h_small / dt_small = h_to_dt dt/di must remain constant between the large and small reactors: dt_large / di_large = dt_small / di_small = dt_to_di

```
h_large = vol_large / (pi * (dt_large/2) ^ 2); % units = m^3 / m^2 = m
h_to_dt = h_large / dt_large;
dt_to_di = dt_large / di_large;
```

Substitute the ratio of height to diameter into the volume equation solved for small height and solve for the new diameter.

- h_small = h_to_dt * dt_small
- vol_small = pi * (dt_small/2)^2 * h_to_dt * dt_small
- vol_small = pi * dt_small^3 * h_to_dt / 4
- dt_small = ((vol_small * 4) / (pi * h_to_dt))^(1/3)

```
dt_small = ((vol_small * 4) / (pi * h_to_dt)) ^ (1/3); % units =
 m^3^1/3 = m
h_small = h_to_dt * dt_small; % units = m
di_small = dt_small / dt_to_di; % units = m
fprintf('The height of the small reactor is %.2f m, the tank diameter
 of the small reactor is %.2f m, and the impeller diameter of the
 small reactor is %.2f m.\n',h_small,dt_small,di_small);
```

```
The height of the small reactor is 0.69 m, the tank diameter of the
 small reactor is 0.43 m, and the impeller diameter of the small
 reactor is 0.11 m.
```

Part b

Part 1 Equations:

- N * Di must stay constant
- n_large * di_large = n_small * di_small

Rearranging to solve for n_small:

- n_small = n_large * di_large / di_small

```
n_small = n_large * di_large / di_small; % units = rpm
fprintf('The new speed of the impellor is %.2f rpm.\n',n_small);
```

```
The new speed of the impellor is 464.16 rpm.
```

Part 2 Equations:

- N * Di^2 * rho / mu must stay constant
- n_large * di_large ^2 * rho / mu = n_small * di_small^2 * rho / mu

Cancelling rho and mu as they are consstants and solving for n_msall:

- n_small = n_large * di_large^2 / di_small^2

```
n_small = n_large * di_large^2 / (di_small^2); % units = rpm
fprintf('The new speed of the impellor is %.2f rpm.\n',n_small);
```

```
The new speed of the impellor is 2154.43 rpm.
```

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