1. Purging a reactor tank of a potentially hazardous chemical (28 points)

While it is fairly rare in a well-run company, sometimes processes are just "abandoned" at some point and not properly shut down and cleaned up. This is the case for this problem.

A partially-filled stirred tank reactor containing 100,000 liters of liquid was found in a far corner of ACME chemicals plant (located, of course about 20 miles south of where the Roadrunner cartoons are set.)

The liquid is mostly water ($\rho = 1 \text{ kg/liter}$) but is suspected to be contaminated with 10% by weight of phenol. You may have personal familiarity with "phenol" in Chloraseptic throat spray. While it won't kill you in small concentrations, phenol does take its toll on the bacteria (it is also used as a disinfectant) that live in the waste treatment ponds at ACME. So to keep from significantly reducing the bacteria population in the pond, some limits on the amount of phenol dumped into the treatment pond in a given time are necessary.

a. The engineer who runs that facility tells you that you can send no more than 0.01 kg/s of phenol to waste treatment. At what rate can you drain the tank if the liquid is going directly to the treatment facility?

b. At this rate, how long will it take to dump all of the liquid from this tank?

You decide that this is too long to wait and further explore the "killing bacteria" issue with the waste treatment supervising engineer (this is the "people" part of engineering.) The further discussion reveals that it is not just the total amount/time of entering phenol that is dangerous to the bacteria, but if the local concentration of phenol at the entrance of the pond gets too large, then the bacteria will be killed. The treatment engineer gave you the 0.01 kg/s limit just to safe for any inlet concentration. She tells you that the limit of 0.01 kg/s of phenol could be relaxed to 10 kg/s (of entering phenol) if the concentration of the phenol stream was reduced to 0.05 wt%

You envision two options. (1) Add water to the tank to dilute the phenol solution to the new limit (stop adding water) and then drain the water at the maximum rate. (2) Add a diluting water stream after the drain from the tank to dilute the stream.

c. Analyze case (1). What size tank would be needed for this option to work?

d. Also case (1). How long would it take for the tank to be completely drained if we don't count the time necessary to add pure water to the tank?

e. Would you expect to encounter any difficulty in keeping the flowrate constant?
f. Analyze case (2). What water flowrate do you need to add in the diluent stream to allow tank draining at the maximum rate allowed by the treatment plant.

g. Also case (2). How long does this option take?

Note that for this problem where the answers are numerical, it is advisable to write in words what you are doing for each step and use equation with symbols to do intermediate algebra.

**Suggested notation**

\[ q = \text{volumetric flowrate, liters/s (you may have several of these)} \]
\[ V = \text{volume, liters} \]
\[ x = \text{mass fraction (mass phenol/mass solution)} \]
2. Short questions (24 points)

a. The *Weber* number is defined as \((u^2 D \rho)/\sigma\). It is the ratio of inertia forces to surface tension forces and hence tells us if, say, raindrops would be deformed from a spherical shape as they fall. From this expression write down the *dimensions* of the surface tension coefficient, \(\sigma\). The term \(D\) is the diameter, which is of course a length, the density \(\rho\) has dimensions of mass/length\(^3\), and \(u\) is the velocity, length/time.

b. Using the mixing correlation plot, if the mixing Reynolds number is 10,000, what is the blend time, \(t_b\)? For your problem the fluid is water so that \(\rho/\mu\) is \(10^6\), the impeller diameter, \(D\) is 0.1 m, the revolution rate, \(N\) is 1/s and the tank diameter, \(T\) is 0.3 m.

c. If the rotation rate is increased so that the Reynolds number is multiplied by 5, now what is the blend time? (Note the axes. This is a plot of the Logarithms of the dimensionless numbers on the ordinate and abscissa)

d. For the mixing conditions of part c, would the tank be well-mixed if the tank volume was .4 m\(^3\) and the inflow and outflow rates were equal at 0.1 m\(^3\)/s. (Explain why)

e. Use the Antoine Equation

\[
\log p = A - \frac{B}{T + C}
\]

to find the normal boiling point of n-hexane to within 5 C. The constants are:

\text{n-Hexane: } A = 7.00270, B = 1171.530, C = 224.366. \text{ T is in C and p is in mbar. Note that a bar is just about 1 ATM.}

f. Approximately 1600 people per hour can ride the *Millennium Force* rollercoaster at Cedar Point. There are 3 trains with 36 people per train at various locations on the track circuit at one time. How long is the average "total ride experience", that is the time from when they let you start to sit down on the ride until you have exited the ride?

**g. extra credit, (4 points)**, if the Weber number is increased, does this mean that drops would be more likely or less likely to remain spherical as they fall.
3. Your apartment in New Orleans. (48 points)

You were intrigued with the apartment in Amsterdam -- not for the glamorous reasons of European cosmopolitan life, but because you figured that there would be steady work for a chemical engineer any place where the much of the land was below sea level or the level of other large bodies of water. So you take a job in New Orleans.

Your apartment was carefully chosen in a solid building on the 4th floor so that you expect to be above floodwater even if a serious hurricane hits. However, you soon realize that some sort of indoor air pollutants are present. (Your cat's hair is falling out.)

Since you are chemical engineer, you feel inclined to model the expected concentration of contaminant substances and realize (sensibly) that your cat is probably sensitive to only sufficiently high concentrations. You would like to know: (1) how the pollutant concentration varies with time while you are not home and the windows are not open and (2) how much higher is the maximum concentration than the steady state concentration that occurs when you have the windows open and the fan on.

You can assume your apartment is well mixed. (But perhaps not well-decorated.)

Your apartment is a sprawling 800 ft² and the ceiling height is 9 ft so that \( V = 7200 \) ft³. During the 18 hrs/day that you are at work (or on Bourbon Street) your apartment has an air infiltration rate of \( q_1 = 1200 \) ft³/hr. You expect that whatever the pollutant is, it is coming from the newly-painted walls as this is the only surface in the apartment that appears to be less than 20 years old. Your estimate of the total newly-painted wall area is \( WA = \text{wall perimeter} \times \text{wall height} = 3200 \) ft². The rate of release of the pollutant is constant at \( A = .003 \) mg/(hr ft²) * \( WA \) and the rate of disappearance, \( D \) (from the cat breathing and the plants absorbing) is 2 mg/hr.

a. Find the steady state concentration of the pollutant in the air, \( c_{\text{open}} \), if the windows are open and the fan is on, so that the flowrates, in and out, are steady at 14400 ft³/hr,

b. Find the steady state concentration of the pollutant in the air, \( c_{\text{closed}} \), if the windows are closed so that the flowrates, in and out, are steady at 1200 ft³/hr.

c. Find an algebraic relation for the concentration of the pollutant in the air, \( c_i \) as a function of time once the window are shut, starting with the "open window" steady concentration, \( c_{\text{open}} \).

d. How long does it take for the steady closed-window concentration to be reached (in hours)?

e. If you wished to make sure that the concentration never gets larger than 1/2 of its maximum value, how long could you stay away before you would need to return to open the windows.

f. Suppose that you could change the height of the walls (and hence \( V \) and \( WA \)). Would increasing or decreasing the height of the wall change the value of \( c_{\text{closed}} \)? Please answer this with reference to an algebraic relation.