GX504

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NATIONAL UNIVERSITY OF IRELAND, GALWAY

SECOND SEMESTER EXAMINATIONS, 2000

B.E. DEGREE EXAMINATION

PLANT OPERATIONS

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Professor P. O'Donoghue;
Dr. M. Rodgers;
Professor P. Nolan;
Mr. R. Tobin B.E.

Time allowed: *two* hours.
Attempt *four* questions.

Access to a computer with the named MATLAB programs in Questions 1, 2, 3 and 4 will be provided for each candidate during the examination. Each candidate must hand up printouts of all relevant **program listings and graphs** with their answer books.

1. (i) A simple well-mixed buffer tank of constant volume has a variable inflow rate and a corresponding variable outflow rate. The inflow consists of a wastewater with a variable substrate concentration, which is not consumed in the buffer tank. Develop equations to facilitate the calculation of the responses of outflow rate and outflow substrate concentration to changes in the inflow rate and inflow substrate concentration.

   (ii) Using MATLAB programs Example_3_3.m and Simple Buffer Tank Outputs, plot the responses of outflow rate and outflow substrate concentration from a well-mixed buffer tank with a constant volume of 1.0 Ml for the following step changes in inflow rate and inflow substrate concentration:
   from zero hours up to 6 hours, the rate is 4 Ml/d and substrate is 200 mg/l;
   from 6 hours up to 12 hours, the rate is 6 Ml/d and substrate is 180 mg/l; and
   from 12 hours up to 24 hours, the rate is 8 Ml/d and substrate is 140 mg/l.
   Initially the substrate concentration in the tank is 200 mg/l. Assume that no consumption of substrate takes place in the buffer tank. Comment on the responses.

2. (i) The rate of oxygen transfer from air to water, r_a, in a simple well-mixed aerated buffer tank can be given by

   $$r_a = K_a q_a (S_{O,sat} - S_O)$$

   where K_a is a constant, q_a is the airflow rate, $S_{O,sat}$ is the saturated dissolved oxygen concentration and S_O is the dissolved oxygen concentration in the tank water. The simple buffer tank has a constant volume and a variable inflow and a corresponding variable outflow; the inflow can have a dissolved oxygen concentration. Develop an equation for the mass balance of oxygen so that its outflow concentration response to airflow rate changes can be calculated. Assume that there is no utilisation of oxygen in the tank.

(ii) Using MATLAB programs Example_3_4.m and Simple Aerated Tank Outputs, plot the responses of outflow dissolved oxygen concentration from a well-mixed aerated buffer tank with a constant volume of 1.0 Ml for the following step changes in airflow rate, q_a:

from zero hours up to 3 hours, the rate is 1.5 m^3/hr;

from 3 hours up to 12 hours, the rate is 6 m^3/hr; and

from 12 hours up to 24 hours, the rate is 8 m^3/hr .

The inflow rate is 5 Ml/d and its dissolved oxygen concentration is 0.2 mg/l. $S_{O,sat}$ is 10 mg/l and Ka is 2. Initially the dissolved oxygen concentration in the tank is 2.5 mg/l. Assume that no consumption of oxygen takes place in the buffer tank. Comment on the responses.

3. (i) A well-mixed simple flow-through reactor of constant volume, V, has an inflow, q_{in}, and an outflow, q_{out}. The inflow consists of a wastewater with a variable substrate concentration $S_{n,in}$ and biomass concentration $X_{b,in}$. It is assumed that the growth rate, r_X, of the biomass in the reactor is modelled by:

$$r_X = \mu_{max} . S_n . X_b / (S_n + K_n)$$

where μ_{max} is the maximum specific growth rate of the biomass, S_n is the substrate concentration in the reactor, K_n is the substrate saturation coefficient and X_b is the biomass concentration in the reactor. Develop mass balance equations for S_n and X_b that will facilitate the calculation of their response to changes in the inflow concentrations. Assume that dissolved oxygen is not limiting.

(ii) Using MATLAB programs Example_3_7.m and Simple Biological Reactor Outputs, plot the responses of outflow substrate concentration and biomass concentration from a well-mixed flow-through reactor with a constant volume of 1.2 Ml for the following step changes in inflow substrate concentration, $S_{n,in}$:
from zero up to 7 hours, the inflow substrate concentration is 380 mg/l; and
from 7 hours up to 24 hours, the inflow substrate concentration is 150 mg/l.

The inflow rate is 5 Ml/d and its biomass concentration is 120 mg/l. μ_{max} is 5/d, K_n is 20 mg/l and the biomass yield coefficient, Y_b is 0.67. Initially the substrate (S_n) and biomass (X_b) concentrations in the tank are 29.5 mg/l and 349 mg/l respectively. Comment on the response of the biomass relative to the substrate.

4. (i) Illustrate the different phases of a sequencing batch reactor for treating wastewater. Develop differential equations to model the behaviour of a biodegradable substrate during (a) the fill phase and (b) the react phase.

(ii) Using MATLAB programs Example_4_9.m and Batch Reactor, plot graphs of the biomass, dissolved oxygen, substrate and airflow rate during the 2 hour react phase of a sequencing batch reactor. The airflow rate, qa, is controlled as follows:

$$q_a = -25*(So - 2.0); \text{ if } q_a > 25, q_a = 25.$$

Use the following model parameters: μ_{max} = 3.733/d; saturation coefficents for substrate and oxygen, K_s = 20 mg/l and K_{oh} = 0.2 mg/l, respectively; yield coefficient = 0.6; decay rate, b_h = 0.4/d; inert fraction, f_p=0.1; airflow rate parameters, a=166/d and b=16 m^3/min; and $S_{O,sat}$ =10 mg/l. At the start of the react stage, the substrate concentration, S_s = 90 mg/l, the dissolved oxygen concentration, S_o = 2.0 mg/l and biomass concentration X_h = 900 mg/l; the volume of the reactor, V, during the react stage is 12.5 Ml. Comment on the behaviour of each of the graphed components during this react phase.
(Note: on the graph, X_h is scaled to $0.1*X_h$ and S_o to $10*S_o$)

5. (i) Discuss and, where relevant, illustrate using simple diagrams each of the following:
   (a) closed loop control
   (b) cascade control
   (c) feed forward control
   (d) programmable logic controller
   (e) control philosophy

   (ii) List and describe the instrumentation used in controlling a modern wastewater treatment system.

6 (i) Briefly describe the linear state space representation for modelling dynamic systems. In particular describe the terms:

   (a) system order
   (b) state variable
   (c) input variable
   (d) output variable

Explain what is meant by the term, eigenvalue, and state (without proof) the general expression for the time response of such a system.

(ii) Using the usual modelling assumptions, determine the state space matrix model for the two tank liquid level control system (Figure 1) when it is operated in open loop mode (i.e. input is q_i and no feedback).

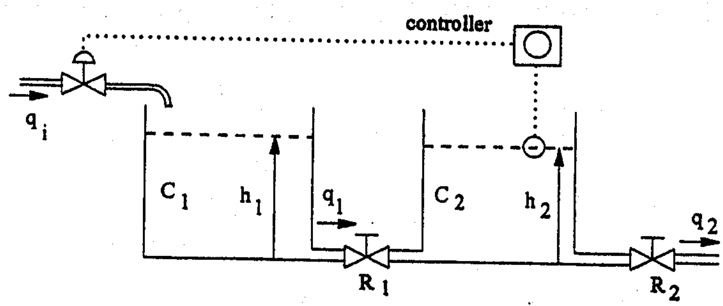

Figure 1 Two tank system

The capacitance of each tank, C1 and C2 is 4 m^2/s and the resistance values, R1 and R2 = 500 s/m^2.
Using your state space "A" matrix (or otherwise) determine the characteristics (e.g. natural frequency, damping ratio or time constants of the system).

(iii) The block diagram in Figure 2 describes the above system when a PI (Proportional + Integral or two term) controller is used. Using the IMC or Ziegler-Nichols rules, determine controller settings. Show, also, how your state space representation would be modified to include the PI controller.

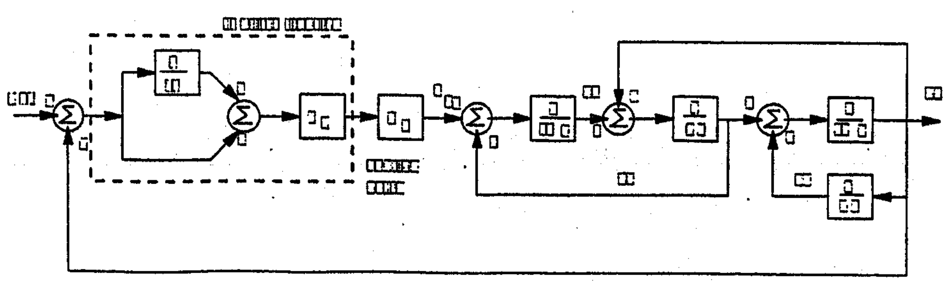

Figure 2 Block diagram for two tank system