GX517

OLLSCOIL NA hÉIREANN, GAILLIMH

NATIONAL UNIVERSITY OF IRELAND, GALWAY

SECOND SEMESTER EXAMINATIONS, 2001

B.E. DEGREE EXAMINATION

PLANT OPERATIONS

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

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

Access to a computer with the named MATLAB programs in Questions 1, 2 and3 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. Axis legends must be inserted and the axis related to a plotted component should be indicated.

1. (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 (DO) concentration and S_O is the dissolved oxygen concentration in the tank water. The airflow rate is to be adjusted using a proportional plus integral (PI) algorithm that is based on the difference, e, between the actual dissolved oxygen concentration, S_O, and the setpoint value, y_d. Develop equations for the mass balance of oxygen and the airflow rate so that the airflow rate and the outflow dissolved oxygen concentration can be calculated in response to changes in inflow dissolved oxygen concentration. Assume the volume of the tank is constant and there is no utilisation of oxygen in the tank.

(ii) Using MATLAB programs Example_3_6.m and DO Controller Outputs, plot the responses of outflow dissolved oxygen concentration and airflow rate from a well-mixed aerated buffer tank with a constant volume of 1.0 Ml for the following step changes :
from 0 hours up to 6 hours, the set point is 4 mg/l and inflow DO is 0.1 mg/l;
from 6 hours up to 16 hours, the set point is 5 mg/l and inflow DO is 2 mg/l;
and from 16 hours up to 24 hours, the set point is 7 mg/l and inflow DO is 1.5 mg/l.
The inflow rate is 5 Ml/d, $S_{O,sat}$ is 10 mg/l and K_a is 2. The tunable controller gain K_c is 2 and the integral time τ_I is 0.01. Initially the DO in the tank is 3 mg/l. Assume that no consumption of oxygen takes place in the buffer tank. Comment on the responses. Explain the terms in the differential equation for dissolved oxygen in the appropriate MATLAB program.

2. (i) A well-mixed flow-through reactor of constant volume, V, has a flow q. The inflow consists of a wastewater with a variable organic carbon substrate concentration, oxygen concentration and heterotrophic biomass concentration. It is assumed that the growth rate of the biomass in the reactor is modelled by:

$$r_H = \mu h \max\left(\frac{Ss}{Ks + Ss}\right)\left(\frac{So}{Koh + So}\right)X_H - b_H X_H$$

the oxygen utilisation by:

$$ro = \frac{Y_H - 1}{Y_H}\mu h \max\left(\frac{Ss}{Ks + Ss}\right)\left(\frac{So}{Koh + So}\right)X_H$$

and the organic substrate utilisation by:

$$rs = -\frac{\mu h \max}{Y_H}\left(\frac{Ss}{Ks + Ss}\right)\left(\frac{So}{Koh + So}\right)X_H + (1 - fp)b_H X_H$$

where Ss, So and X_H are the concentrations of organic substrate, oxygen and biomass in the reactor, respectively. Explain each of the other terms in the above equations.

The rate of oxygen transfer from the air to the wastewater is given by:

ra =Ka.qa.(So,sat –So)

where Ka is a constant, qa is the airflow rate and So,sat is the saturated dissolved oxygen concentration in the wastewater.
Develop mass balance equations for Ss, So and X_H that will facilitate the calculation of their responses to changes in their inflow concentrations.

(ii) Using MATLAB programs Example_3_8 and Aerated_Biological_ Reactor_Outputs, plot the responses of substrate, oxygen and biomass concentrations in the outflow from a well-mixed flow-through aerated biological reactor with a constant volume of 1.4 Ml for the following step changes in the inflow organic substrate concentrations and airflow rates:
from 0 hours up to 5 hours, the organic substrate concentration is 300 mg/l and the airflow rate is 20 m^3/hr;
from 5 hours up to 12 hours, the organic substrate concentration is 200 mg/l and the airflow rate is 20 m^3/hr; and
from 12 hours up to 24 hours, the organic substrate concentration is 400 mg/l and the airflow rate is 5 m^3/hr.
The flow is 10 Ml/day, the inflow dissolved oxygen concentration is 1.5 mg/l and the concentration of heterotrophs in the inflow is 150 mg/l. The initial concentrations of organic substrate, oxygen and heterotrophs in the reactor are 25 mg/l, 1.5 mg/l and 350 mg/l, respectively. Use the parameters given in the program Example_3_8.
Comment on the behaviour of each of the graphed components. Explain the terms in the differential equation for biomass development in the appropriate MATLAB program.

3. (i) Illustrate the different phases of a sequencing batch reactor (SBR) for treating wastewater. Indicate how phosphorus removal and nitrogen removal could be carried out in a SBR. 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:

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

Use the following model parameters: μ_{max} = 6 /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 = 120 mg/l, the dissolved oxygen concentration, S_o = 1.0 mg/l and biomass concentration X_h = 800 mg/l; the volume of the reactor, V, during the react stage is 10 Ml. Comment on the behaviour of each of the graphed components during this react phase. Explain the terms in the differential equation for substrate utilisation in the appropriate MATLAB program. What is the dissolved oxygen setpoint used in this process? (Note: on the graph, X_h is scaled to $0.1*X_h$ and S_o to $10*S_o$)

4. (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.

5. (i) Briefly describe the state-space matrix representation for a linear dynamic system and how the state transition matrix defined from it can be used to determine the time response for a linear system.

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

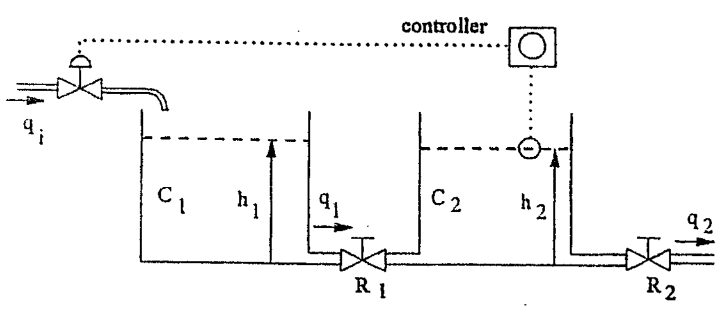

Figure 1 Two tank system

The capacitance of each tank, C1 and C2 is 5 m^2/s and the resistance values, R1 and R2 = 400 s/m^2.

The block diagram shown 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.

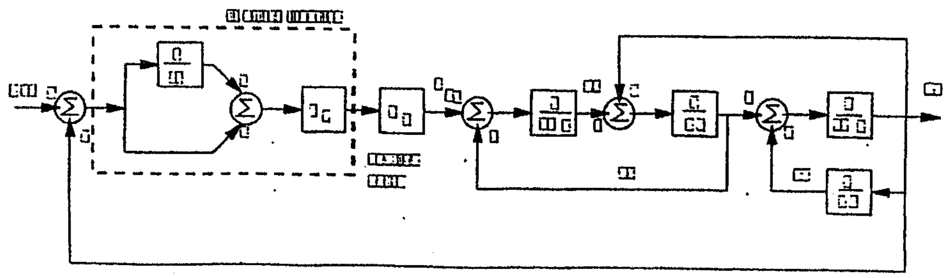

Figure 2 Block diagram for two tank system