Process Dynamics – CPN321

Sick Test

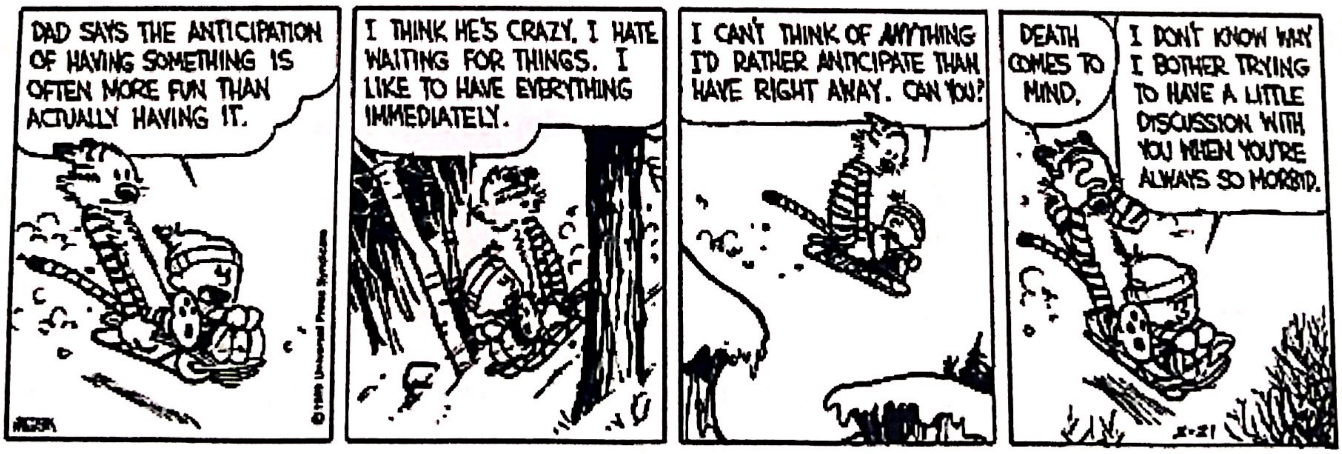
Chemical Engineering
Engineering and the Built Environment

Examiner: Carl Sandrock

November 2015 90 minutes

Instructions – Read carefully

• Answer all the questions. • This is a closed book test. All the information you may use is contained in the paper and the attached formula sheet. • Make sure that you motivate all your answers and write legibly. • You may use a computer.

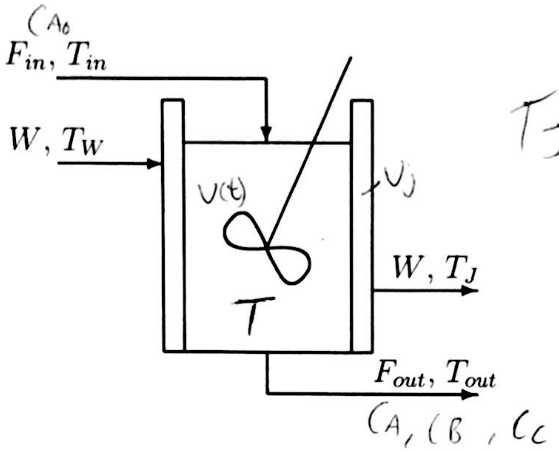


1 Cooled CSTR

The system shown in figure 1 is being used as a reactor for the the following reaction, which exhibits first-order kinetics and Arrhenius temperature dependence. $K = K_0 e^{-\frac{E}{RT}}$

$$A \longrightarrow B + 2C$$

The feed is pure A. You may assume that both the cooling jacket and the reactor contents are well mixed.



$T_J < T$

$R = K_0 e^{-\frac{E}{RT}}$
$= KVC_A$

Figure 1: A CSTR with a cooling jacket.

1. Identify input variables, parameters and output variables of this system. $\boxed{5}$
2. Develop a model of the time-dependant behaviour of the system. $\boxed{20}$.
3. Show that specifying the inputs and the parameters of your model completely specifies it. $\boxed{5}$
4. You probably assumed that the reactor contents, the jacket contents and the materials were each uniform in their properties (one temperature throughout, well-mixed). Explain how your model would change if this were not the case. Use diagrams to illustrate. $\boxed{5}$

$\boxed{35}$

2 Second order system

Consider the response of a second order system G_1 to a step change in u.

$$\frac{y}{u} = G_1(s) = \frac{1}{\tau^2 s^2 + 2\tau\zeta s + 1} \qquad (1)$$

$y\tau^2 s^2 + 2\tau\xi s y + y$.

1. Rewrite the system as a set of first order differential equations $\boxed{5}$
2. Assuming only $\tau > 0$ and $\zeta = 0.5$, obtain the analytic response of the system $y(t)$ to a unit step in u at time 0. $\boxed{5}$ underdamped.
3. Assuming that $\tau = 10$ and $\zeta = 0.5$, compare the analytic response $y_a(t)$ of the system to the solution obtained by Euler integration $y_e(t)$ by plotting a graph of the average absolute error ($1/T \int_0^T |y_a - y_e| dt$ where T is the simulation time) for step sizes between $\tau/10$ and 2τ. $\boxed{10}$

$\boxed{20}$

3 Multivariable systems

Consider the multivariable system described by

$$\mathbf{b} = G_2\mathbf{z} = E(s)F(s)\mathbf{z} \tag{2}$$

$\begin{matrix} b_1 \\ b_2 \end{matrix} = E(s)F(s) \begin{matrix} z_1 \\ z_2 \end{matrix}$

$$E(s) = \begin{bmatrix} G_3 & G_4 \\ G_5 & G_3 \end{bmatrix} \tag{3}$$

$$F(s) = \begin{bmatrix} G_6 & G_7 \\ 0 & G_6 \end{bmatrix} \tag{4}$$

1. Draw a block diagram showing each scalar transfer function, two inputs z_1 and z_2 and two outputs b_1 and b_2. $\boxed{7}$

2. Assuming $G_6 = \frac{1}{\tau_6 s+1}$, $G_7 = \frac{1}{\tau_7 s+1}$, convert $F(s)$ to a state space description $\boxed{8}$

$\boxed{15}$

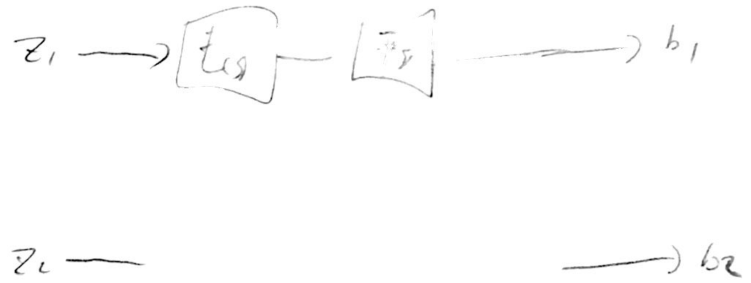
4 Approximation

$$G_8 = \frac{s+1}{s^3 + 2s^2 + 3s + 1} \tag{5}$$

1. Obtain a 1/1 Padé approximation of G_8. You may use SymPy, but remember to explain your method. $\boxed{10}$

2. Obtain a first order plus dead time approximation of G_8 $\boxed{10}$

$\boxed{20}$



Full Marks $\boxed{90}$