Ex/ChE/T/322/2018

BACHELOR OF ENGINEERING IN CHEMICAL ENGINEERING EXAMINATION, 2018

(3rd Year, 2nd Semester)

PROCESS DYNAMICS AND CONTROL

Time : Three hours Full Marks : 100

Answer any FOUR questions. All questions carry equal marks

(Table of [1] Laplace Transforms and [2] Table of Ziegler-Nichols and Cohen-Coon optimum controller settings may be used).

1. In a constant-volume isothermal CSTR ($V=2.1$ m^3), a 1st-order liquid-phase reaction A → products ($k=0.04$ min^{-1}) is taking place. The inflow rate remains constant at 0.085 m^3/min. The steady inlet concentration of A is 0.925 mol/m^3. An alarm sounds if and when the reactant concentration in the reactor reaches 0.83 mol/m^3 and beyond the level of 0.85 mol/m^3, there is a risk of explosion. Your job, as operator, is to intervene immediately on hearing the alarm. Somebody has suddenly doubled the reactant inlet concentration. (a) On hearing the alarm, what should you do so as to avoid a disaster and bring back the reactor to its earlier steady state? (b) How much time earlier (from the alarm ringing) was the steady-state changed? (c) How much time, from your intervention, will it take for the reactant concentration in the reactor, to enter a band of ±2% about its earlier steady value?

2. You are required to estimate the volumetric flow rate, q (L min^{-1}), through a constant-volume mixing tank ($V = 1000$ L) in which an aqueous solution, containing a certain solute, is mixed. You can measure only the solute concentrations C_i (in inflow) and C (in outflow). Somebody suggests that you momentarily increase C_i (and then instantaneously bring it back to its earlier steady value) and observe how C changes subsequently:

t (min)	0	2	4	8	12	16	20	30	40
$C-C_s$ (g/L)	1	0.8187	0.6703	0.4493	0.3012	0.2019	0.1353	0.0498	0.0183

Based on the above data (where C_S is the steady value) estimate, if possible, 'q'.

3. (a) What is the basis of Direct Synthesis methods for Controller Tuning? (answer in one sentence).
For a FOPDT process (K_p, θ_D, τ_p), if it is desired that the controlled response should also be in the form of a FOPDT with same dead time as the process, i.e. $\bar{y}_m(s)/\bar{y}_{sp}(s) = e^{-\theta_D s}/(1+\lambda s)$,
Then show that (using a truncated Taylor series expansion for the exponential), this would result in a PI control strategy.
(b) However, if a 1st-order Pade approximation is used instead for the exponential, (and assuming $\theta_D << \lambda$) then show that Direct Synthesis results in PID control.

4. Compare Ziegler-Nichols optimum controller settings (based on the Bode stability criterion and Frequency Response) and the Cohen-Coon settings (based on the Process Reaction Curve approximated by a FOPDT model $G_{PRC} = Ke^{-\lambda s}/(1+\tau s)$) for a P-only controller used in a control system where $G_p = 10/[1+5s]$; $G_v = 0.5/[1+1.5s]$ and $G_m = 2\,e^{-0.2s}/[1+0.5s]$.
For a P-only controller, Z-N settings give $K_C=0.5K_{C,max}$ whereas C-C settings give $K_C = (1/K)(\tau/\lambda)(1+[\lambda/3\tau])$.
State all necessary assumptions.
In the above problem, what is the frequency of limit cycle oscillations? Can you recalculate it by another exact controller tuning technique in order to reconfirm.

5. Consider a first order chemical reactor (transfer function $G_P=K_P/(1+\tau s)$) with recycle (transfer function of recycle element G_F). Show that (a) whereas the reactor without any recycle is inherently stable, the very introduction of recycle even with very fast dynamics, (i.e. $G_F=1$) makes the process potentially unstable. Specifically consider the cases $K_P<1$, $K_P=1$ and $K_P>1$ separately and comment.
(b) Now if G_F is first order, comment on the poles and zeroes of the overall transfer function of the reactor with recycle, and thereby deduce the condition for stability.

6. Consider a control system where $G_p = 10/[1+5s]$; $G_v = 0.5/[1+1.5s]$ and a sensor-transmission combine is present. Obtain the optimum range of values of the gain for a P controller for each of the following cases regarding the dynamics of the sensor-transmission combine, separately by Routh Analysis and Frequency Response.

a) Zero-order element: $G_m = 2$.
b) First-order element $G_m = 2/[1+0.5s]$
c) First-order element with dead time: $G_m = 2\,e^{-0.2s}/[1+0.5s]$