Several Control Systems For Five CSTR Cascade Under The Effect of Step, Sinus And Ramp Inputs

by

MUSTAFA ALPBAZ
CENGİZ ÖZKAN

Faculté des Sciences de l'Université d'Ankara
Ankara, Turquie
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MUSTAFA ALPBAZ
CENGİZ ÖZKAN

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University of Ankara, Faculty of Science
Chemical Engineering Dept. Ankara, Turkey
University of Firat, Faculty of Engineering,
Chemical Engineering Dept. Elazığ, Turkey

SUMMARY

In this research, the feedback and feed forward control, cascade control and interacting control mechanisms which were under the effect of step, sinus and ramp inputs given to the feed flow rate of the five continuous flow stirred tank reactors (CSTR) having exothermic first order irreversible reaction were studied. The variations of output variables with respect to time under the effects of step, sinus and ramp inputs with three control mechanisms were calculated by digital computer. The effectivenesses of the control mechanisms were compared and investigated.

INTRODUCTION

Alpbaz (1) has investigated the dynamics of the five CSTR cascade and effectiveness of the feedback and feedforward control mechanisms under the step change given to the feed flow rate for the same system.

Alpbaz and Selek (2) have examined the dynamic properties and the effectiveness of the combined feedback and feedforward control of the five CSTR cascade under the sinus change of the various frequencies given to the feed flow rate and change of the output variables with respect to the time.

Alpbaz and Kaytakoğlu (3), have calculated the effect of continuous and discontinuous ramp input given to the feed flow rate to the output variables as an dynamic work, after than with introducing the feedback and feedforward control, the change of output variables with respect to time was investigated.

The mathematical form of the step change is shown below,

\[ t = 0 \quad f(t) = 0 \]
\[ t = t \quad f(t) = A \]

(1)
The sinus input which has amplitude, A, frequency, ω,

\[ t = 0 \quad f(t) = 0 \]
\[ t = t \quad f(t) = A \sin(\omega t) \quad (2) \]

The continuous ramp input with tangent B,

\[ t = 0 \quad f(t) = 0 \]
\[ t = t \quad f(t) = Bt \quad (3) \]

There is much reported work on the theoretical study of the combined and separate feedback and feedforward control systems. Their applications on to the five CSTR cascade are given in literature (1,2,3). Combined feedback and feedforward control of the five CSTR cascade is shown in Fig. 1.

In chemical engineering, for some purposes, cascade control system can be used instead of feedback and feedforward control. In cascade control system, the measurements are made from two different output variables which can be output tank temperature and cooling temperature. This type of control system could have three term two conventional controllers. Basically, first controller detect the fifth tank output temperature by a measuring element and compares with the desired value to produce error and then the output of the controller in response to this error is fed to the second controller. The second controller detect, the cooling water temperature and compares with the first controller output to produce new error and then the output of the second controller related with new error adjust the control valve to produce corrective action to the process which can be cooling flow rate. This type of control system is shown in Fig. 2.

In the case of interacting control system, two different feedback controller are used. The output temperature and concentration are detected separately and then these measuring signals are sent to the related controllers. Each controller compares related signal with desired value to produce error and than the output of the each controllers are sent to the two different control valves. While one control valve adjust the cooling flow rate and other manipulate the feed flow rate. The interacting control system is shown in Fig. 3.

The mathematical model having mass and energy balance related with the five CSTR cascade and cooling energy balance were given on
Fig. 1. Feedforward and feedback control of the five CSTR cascade
Fig. 2. Cascade control of the five CSTR cascade
Fig. 3. Interacting control of the five CSTR cascade
the work of Albpaz and Selek (2). The related computer solution and range of parameters were given in that work (2).

RESULTS

Steady-state cascade model was solved with input conditions given in Table 1. The result obtained from computer solution is shown in Fig. 4.

<table>
<thead>
<tr>
<th>$V_1$</th>
<th>$V_2$</th>
<th>$C_0$</th>
<th>$\theta_0$</th>
<th>$T_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>lt/min</td>
<td>lt/min</td>
<td>mol/lt</td>
<td>$^\circ$C</td>
<td>$^\circ$C</td>
</tr>
<tr>
<td>1.0</td>
<td>6.0</td>
<td>0.5</td>
<td>5.0</td>
<td>23.0</td>
</tr>
</tbody>
</table>

Table 1. The operating steady-state conditions for the five CSTR cascade.

In the case of cascade control, the location points to detect the cooling water temperature are very important. For this reason cooling water temperature could be measured in five different location points. The effects of the location points on the behaviour of control system were shown with the results obtained from computer solution. When the system was in the steady-state condition given in Fig. 4, the step change was given to the feed flow rate. The time response of the temperature, $T_5$, related with detecting points of cooling water temperature are shown in Fig. 5. As it is shown from Fig. 5 that the detecting point from last tank was found to give the better control from other points. In this type of control, the effect of the step change given to the set point on the output temperature, $T_5$, was examined. When the initial value of the set point was SPNT (1) = 7.805 $^\circ$C, step change increase in set point SPNT (2) = 8.805 $^\circ$C and decrease in set point SPNT (2) = 7.00 $^\circ$C in set point were given separetly. The time response of the output temperature, $T_5$, is shown in Fig. 6. The effect of the cascade control on the time response of the output variables of five CSTR cascade under the effect of the sinus change given to the feed flow rate ($w = 2 \pi t / 360$) was investigated. In Fig. 7 comparison have been made between the combination of feedback and feedforward control and cascade control. For phase-plane analysis, the related diagrams for output concentration and temperature effected with similar sinus input are given in Fig. 8. From the direction of the arrows it can be seen that the output variables show stability. The continuous
ramp input having the target value ($B = 1.0$) was given to the feed flow rate of the same cascade operating at similar steady-state. In Fig. 9, the comparison have been made between the combination of feedback and feedforward control and cascade control. The output tempera-
Fig. 5. Cascade control of the fifth tank of the five CSTR cascade under the effect of step change in throughput

Fig. 6. Cascade control of the fifth tank of the five CSTR cascade under the effect of the step change in set point
Fig. 7. Comparison with combined feedback and feedforward control (2) and cascade control of the fifth tank under the effect of the sinus change ($w = 2 \pi t/360$)

ture could not come to the desired value with both control systems. Figs. 9, 10 show the test for comparison between similar control systems with a discontinuous ramp input having the tangent values ($B = 0.5, 1.0$) and ceasing time ($t = 2$ min). The output temperature came to the desired value.

In interacting control system, in order to control the output variables, the feed and input cooling water were manipulated. It can easily be seen that the sinus and ramp inputs were destroyed with manipulation of feed flow rate and than it is not possible to examine the effect of these inputs. Only the effect of the step input can be considered.
The result obtained from computer solution are shown in Figs. 12, 13. It was observed that the value of the control valve adjusting the feed flow rate helped the output temperature to reach the desired value in a shorter time. Fig. 12, 13 show the effect of the several valve constant on the output temperature. \( \text{KVC} = 0.5 \) was chosen to be most suitable value.

CONCLUSION

The conclusion obtained from present work is shown below.

In cascade control, the location points to detect the cooling water temperature are very important. It was found from result of the digital computer solution that the measurement of the cooling water temperature of the fifth stage was very efficient to control the cascade. The output temperature under the effect of the continuous ramp input could not come to desired value. With discontinuous ramp input, the out-
Fig. 9. Comparison with combined feedback and feedforward control (b) and cascade control of the fifth tank of the five CSTR cascade under the effect of the continuous ramp input (B = 1.0).
Fig. 10. Comparison with combined feedback and feedforward control and cascade control of the fifth tank under the effect of the discontinuous ramp input \((B = 0.5, t = 2 \text{ min})\)

Fig. 11. Comparison with combined feedback and feedforward control and cascade control of the fifth tank under the effect of the discontinuous ramp input \((B = 1.0, t = 2 \text{ min})\)
Fig. 12. The interacting control of the output temperature of the fifth tank

Fig. 13. The interacting control of the output concentration of the fifth tank
put temperature reach to the desired value. The combined feedback and feedforward control system is better than the cascade control when the step, ramp and sinus inputs disturb the cascade.

In interacting control system, it is not possible to examine to the effect of sinus and ramp inputs. Only the effect of the step change were considered. It was found that the valve constant for feed flow rate was very efficient to control the system.

NOMENCLATURE

A Value of step input, Amplitude
B Tangent of ramp input
C₀ Initial input concentration (mol/lt)
Cₙ Concentration of n’th tank (mol/lt)
KC Proportional acting factor for feedback control of output temperature
KCCN Proportional acting factor for first and second controller of cascade control
KCF Proportional acting factor for feedforward control
KCI Proportional acting factor for interacting control
KV Valve constant of interacting control
 t Time
SPNT Set Point
T₀ Input temperature of reactor (°C)
Tₙ Temperature of n’th stage of reactor (°C)
TD Derivative action time for feedback control of output temperature
TDCI Derivative action time for interacting control of output concentration
TDCN Derivative action time for first and second controllers of cascade control
TDF Derivative action time for feedforward control
SEVERAL CONTROL SYSTEMS

TR Reset time for feedback control of output temperature
TRCI Reset time for interacting control of output concentration
TRCN Reset time for first and second controllers of cascade control

\[ V_1 \quad \text{Feed flow rate} \]
\[ V_2 \quad \text{Coolant flow rate} \]
\[ \theta_0 \quad \text{Initial temperature of input coolant (°C)} \]
\[ \theta_n \quad \text{Temperature of coolant in n'th tank (°C)} \]
\[ w \quad \text{Frequency} \]
\[ w\phi_n \quad \text{Measuring point n} \]

REFERENCES


ÖZET

Bu araştırmada, birinci mertebeden tek yönlü ekzotermik bir reaksiyonu içeren beş tam karıştırımdaki akım reaktörlerinin besleme akış hızına verilen kademe, sinüs ve ramp etkileri altında iken geri ve ileri, kaskat ve birbirine etki eden kontrol sistemlerinin davranışları incelenmiştir. Kademe, sinüs ve ramp etkilerinde üç kontrol mekanizmaları ile çıktık değişkenlerinin zamana göre değişimleri sayısal bilgisayar ile hesaplanmıştır. Kontrol mekanizmalarının etkinlikleri araştırılmıştır.