

054402 Design and Analysis

LECTURE 11: PLANTWIDE CONTROL SYSTEM DESIGN

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Refs: Seider, Seader and Lewin (2004), Chapter 20
Luyben, Tyreus and Luyben (1999).

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Objectives

At the end of this section, you should be able to:

- ☆ Be capable of proposing a workable plantwide control system, given control objectives.
- ☆ Be able to apply the plantwide control system design method of Luyben and coworkers, to reliably design plantwide control systems.
- ☆ Be able to organize the control system design in such a way that the objectives are achieved in order of importance.

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Plantwide Control Design Method

Luyben et al. (1999) suggest a method for the conceptual design of plant-wide control systems, which consists of the following steps:

Step 1: *Establish the control objectives.*

Step 2: *Determine the control degrees of freedom.*

Simply stated – the number of control valves – with additions if necessary.

Step 3: *Establish the energy management system.*

Regulation of exothermic or endothermic reactors, and placement of controllers to attenuate temperature disturbances.

Step 4: *Set the production rate.*

Step 5: *Control the product quality and handle safety, environmental, and operational constraints.*

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Plantwide Control Design Method

Step 6: *Fix a flow rate in every recycle loop and control vapor and liquid inventories (vessel pressures and levels).*

Step 7: *Check component balances.* Establish control to prevent the accumulation of individual chemical species in the process.

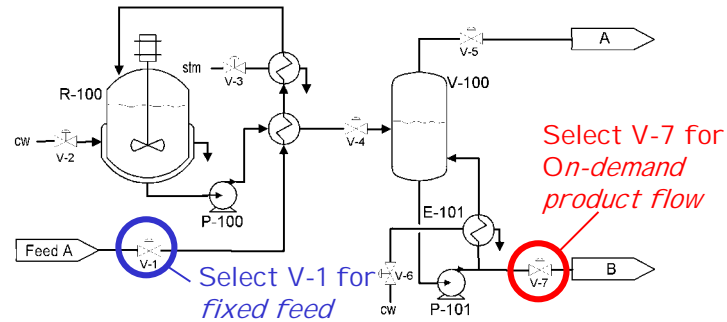
Step 8: *Control the individual process units.* Use remaining DOFs to improve local control, but only after resolving more important plant-wide issues.

Step 9: *Optimize economics and improve dynamic controllability.* Add nice-to-have options with any remaining DOFs.

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Example 1: Acyclic Process



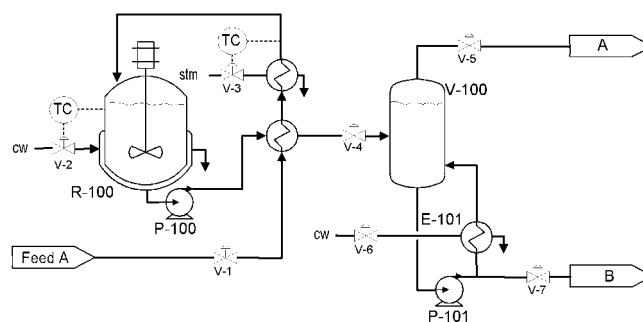
Steps 1 & 2: Establish the control objectives and DOFs:

- ★ Maintain a constant production rate
- ★ Achieve constant composition in the liquid effluent from the flash drum.
- ★ Keep the conversion of the plant at its highest permissible value.

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Example 1: Acyclic Process (Cont'd)



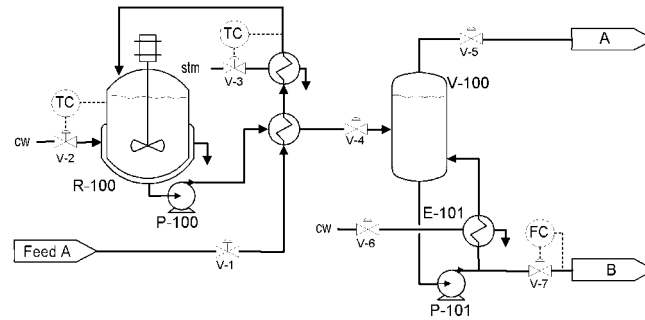
Step 3: Establish energy management system.

- ★ Need to control reactor temperature: Use V-2.
- ★ Need to control reactor feed temperature: Use V-3.

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Example 1: Acyclic Process (Cont'd)



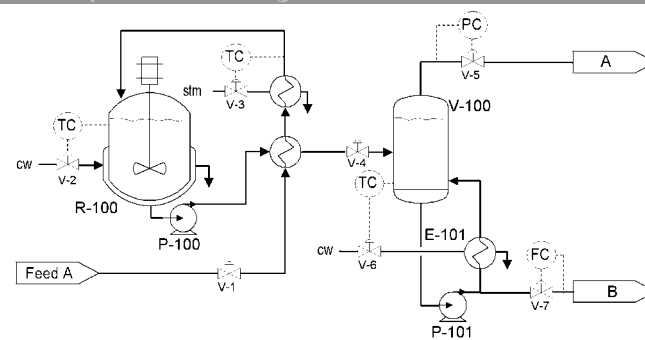
Step 4: Set the production rate.

- ★ For on-demand product: Use V-7.

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Example 1: Acyclic Process (Cont'd)



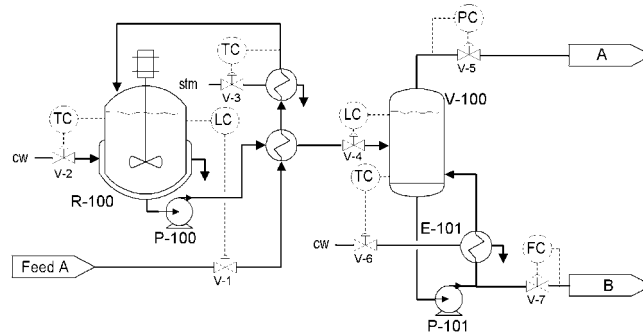
Step 5: Control product quality, and meet safety, environmental, and operational constraints.

- ★ To regulate V-100 pressure: Use V-5
- ★ To regulate V-100 temperature: Use V-6

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Example 1: Acyclic Process (Cont'd)



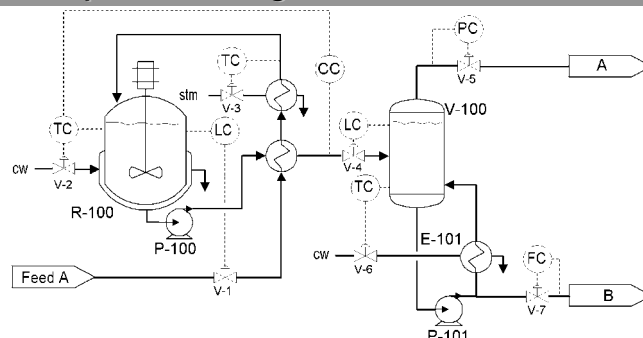
Step 6: Fix recycle flow rates and vapor and liquid inventories

- ★ Need to control vapor inventory in V-100: Use V-5 (already installed)
- ★ Need to control liquid inventory in V-100: Use V-4
- ★ Need to control liquid inventory in R-100: Use V-1

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Example 1: Acyclic Process (Cont'd)



Step 7: Check component balances. (N/A)

Step 8: Control the individual process units (N/A)

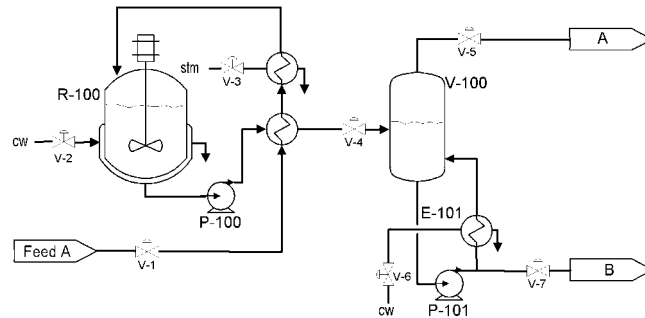
Step 9: Optimization

- ★ Install composition controller, cascaded with TC of reactor.

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Example 1 (Class): Acyclic Process



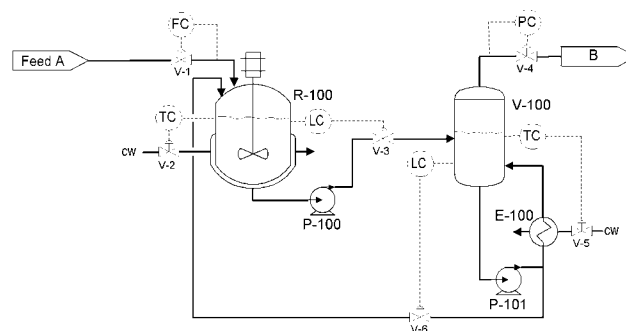
Try your hand at designing a plant-wide control system for fixed feed rate.

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Example 2: Cyclic Process



The above control system for (fixed feed) has an inherent problem?

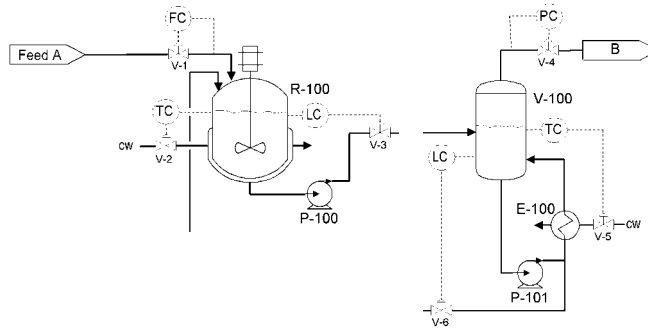
Can you see what it is?

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Example 2: Cyclic Process (Cont'd)



The above control system for (fixed feed) has an inherent problem?

Can you see what it is?

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Example 2: Cyclic Process (Cont'd)

Combined molar feed to the CSTR: $F_0 + B$

Molar material balance around the flash vessel: $F_0 + B = D + B$

Overall molar material balance: $F_0 = D$

Molar balance on CSTR:

$$-\frac{1}{V_R} \frac{dn_A}{dt} = kx_A c_{total} \Rightarrow (1 - x_A)(F_0 + B) = kx_A c_{total} V_R$$

$$c_{total} V_R = n_T$$

$$(1 - x_A)(F_0 + B) = kx_A c_{total} V_R \Rightarrow (1 - x_A)(F_0 + B) = kx_A n_T$$

$$\text{Rearranging: } B = \frac{x_A(F_0 + kn_T) - F_0}{1 - x_A}$$

Balance on A for perfect separation: $F_0 = kx_A n_T$

$$\rightarrow B = \frac{F_0^2}{kn_T - F_0}$$

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Example 2: Cyclic Process (Cont'd)

$$B = \frac{F_0^2}{kn_T - F_0}$$

"Snowball" effect

e.g., suppose $kn_T = 200$:

F_0	B
50	16.7
75	45
100	100
125	208
150	450

A more general result uses the dimensionless, Damköhler number: $Da = kn_T/F_0$ giving:

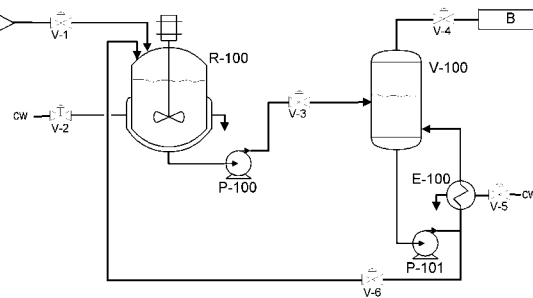
$$B = \frac{F_0}{Da - 1} \quad \text{"Snowball" effect for } Da \rightarrow 1$$

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Example 2: Cyclic Process (Cont'd)



Steps 1 & 2: Establish the control objectives and DOFs:

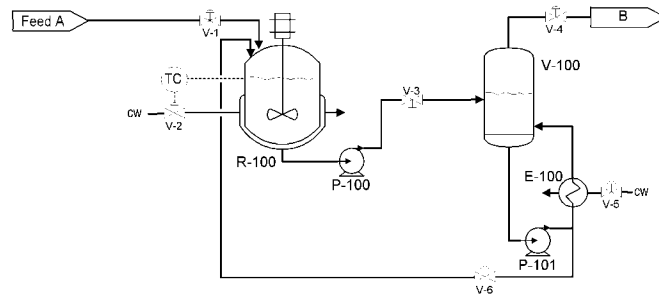
- ☆ Maintain the production rate at a specified level.
- ☆ Keep the conversion of the plant at its highest permissible value.

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Example 2: Cyclic Process (Cont'd)



Step 3: *Establish energy management system.*

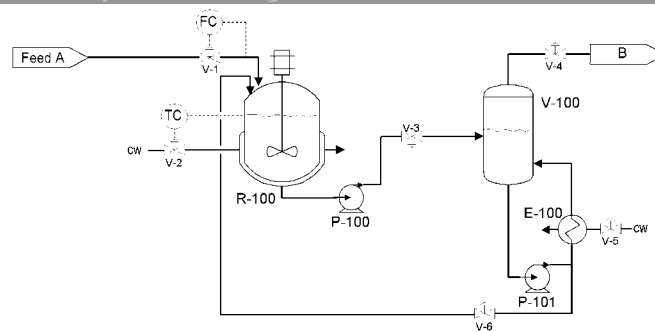
- ★ Need to control reactor temperature: Use V-2.

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Example 2: Cyclic Process (Cont'd)



Step 4: *Set the production rate.*

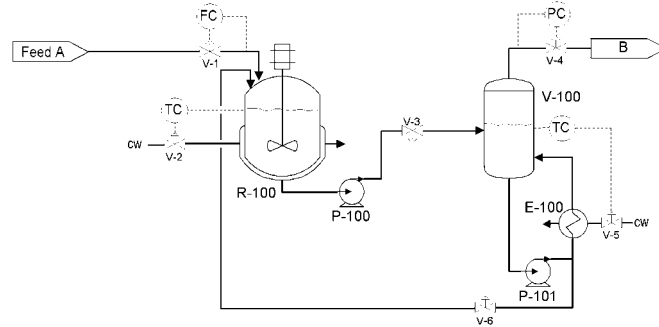
- ★ For on-demand product: Use V-7.

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Example 2: Cyclic Process (Cont'd)



Step 5: Control product quality, and meet safety, environmental, and operational constraints.

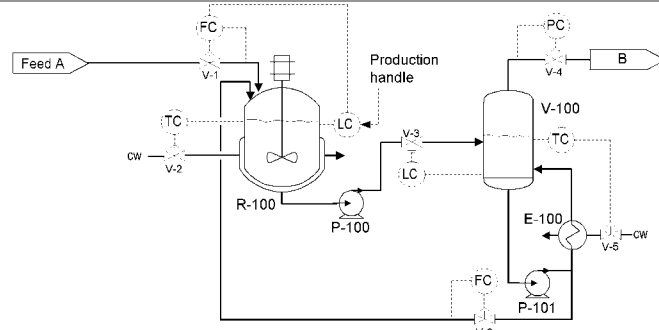
- ★ To regulate V-100 pressure: Use V-4
- ★ To regulate V-100 temperature: Use V-5

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Example 2: Cyclic Process (Cont'd)



Step 6: Fix recycle flow rates and vapor and liquid inventories

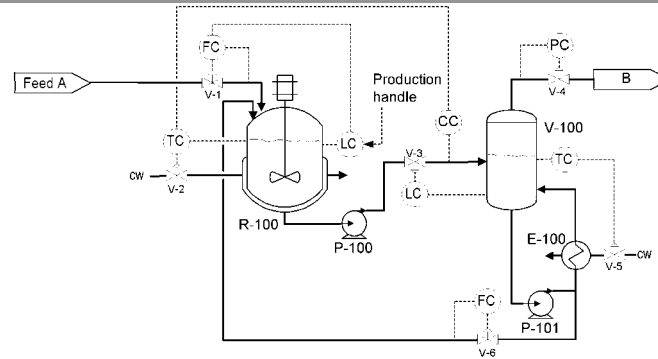
- ★ Need to control recycle flow rate: Use V-6
- ★ Need to control vapor inventory in V-100: Use V-4 (already installed)
- ★ Need to control liquid inventory in V-100: Use V-3
- ★ Need to control liquid inventory in R-100: Cascade to FC on V-1.

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Example 2: Cyclic Process (Cont'd)



Steps 7, 8 and 9: Improvements

- ★ Install composition controller, cascaded with TC of reactor.

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Summary

- ★ Provided motivation for handling flowsheet controllability and resiliency as an integral part of the design process
- ★ Outlined qualitative approach for unit-by-unit control structure selection
- ★ Introduced the P&ID and provided recommendations for single unit control configuration
- ★ Outlined qualitative approach for plantwide control structure selection

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Summary

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- ☆ Be able to apply the plantwide control system design method of Luyben and coworkers, to reliably design plantwide control systems.
- ☆ Be able to organize the control system design in such a way that the objectives are achieved in order of importance.

Note that the above objectives are equivalent!