Cascade Control

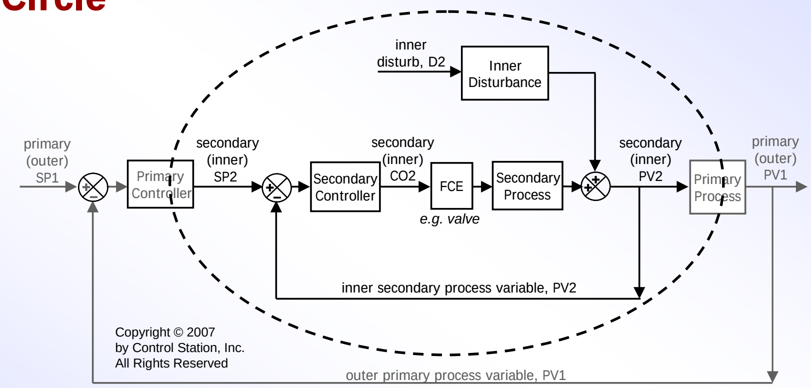
What We Will Learn in This Section

- The Cascade Control Architecture
- Benefits of a Cascade Strategy
- Design and Tuning a Cascade Controller
- Application to a Flash Drum Process
- Application to a Jacketed Reactor

Cascade Control

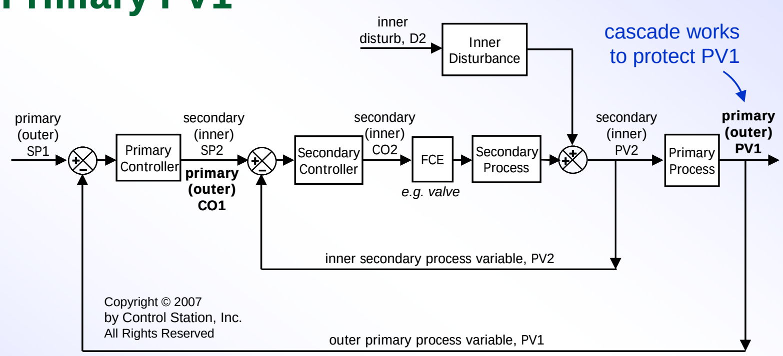
- Architectures for ____________ rejection
  - Feed Forward
  - Cascade
- Both require ____________ and engineering time in return for a controller better able to ____________
- Neither architecture benefits nor detracts from set point tracking performance

Traditional Feedback Loop is in the Dashed Circle



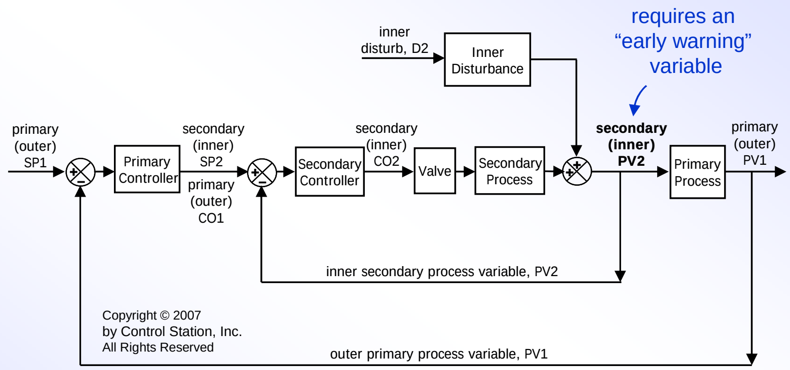
- A cascade is comprised of two ordinary PID controllers
- The inner secondary loop has a traditional ,
  and it is nested inside the outer primary loop

Nested Loops Work to Protect Outer Primary PV1



- Cascade architectures seek to improve the disturbance rejection performance of PV1

Early Warning is Basis for Cascade Success



- Success in a cascade design depends on the measurement and control of an "early warning" process variable PV2

Cascade Design

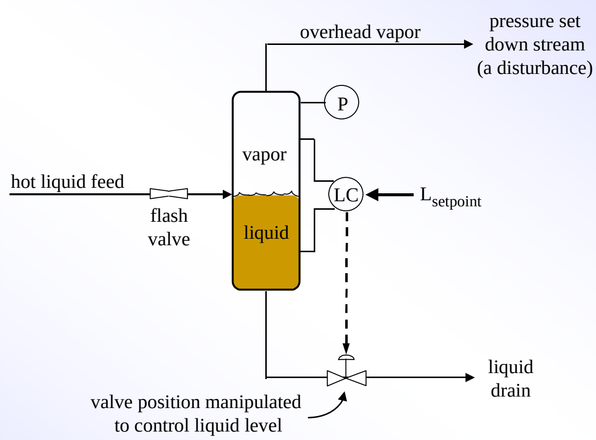
- Characteristics for selecting early warning PV2 include:
  - it must be measurable
  - the same used to manipulate PV1 also manipulates PV2
  - the same disturbances that are of concern for PV1 also disrupt PV2
  - PV2 responds to disturbances of concern and to FCE manipulations

Cascade Design

- A cascade design requires:
  - ____ sensors
  - ____ controllers
  - ____ final control element (FCE)
- The output of the outer primary controller, rather than going to a valve, becomes the ____ of the inner secondary controller
- Because of this nested architecture:

Success requires that
the ____ of the inner secondary inner loop
is significantly faster
than that of the outer primary outer loop

Example: Flash Drum Process

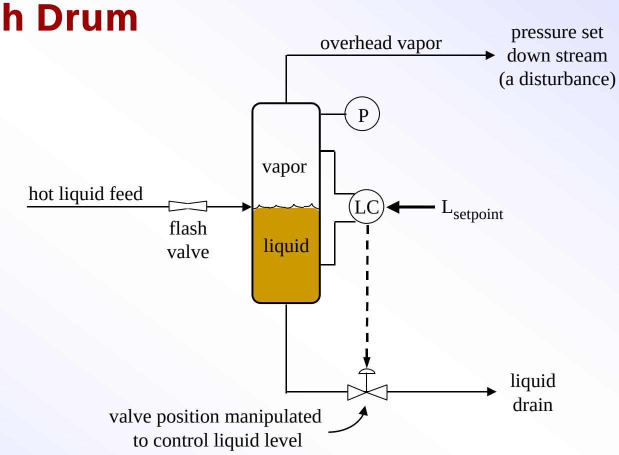


- Level must never fall so low that vapor is sent down liquid drain nor rise so high that liquid enters the vapor line

Flash Drum – Single Loop Architecture

- Design Objective → control liquid level in the drum
- Choose valve position as manipulated variable
  - If level too high, open valve
  - If level too low, close valve
- Concern is that drain flow rate changes as a function of
  - valve position
  - hydrostatic head (height of the liquid)
  - (a disturbance)

Flash Drum



- If pressure of vapor phase is constant, then as drain valve opens and closes, the liquid drain flow rate increases and decreases in predictable fashion
- would then be satisfactory

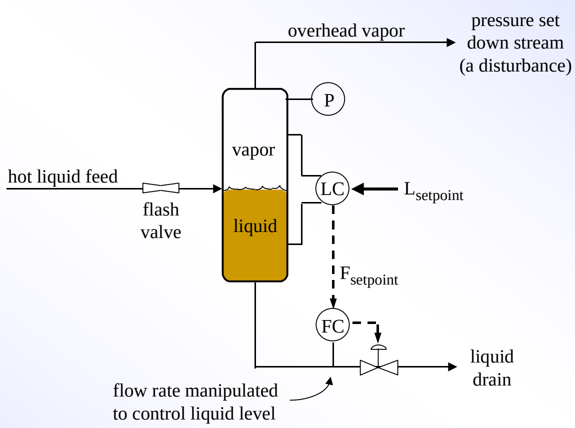
Flash Drum – Single Loop Architecture

- Suppose the vapor phase pressure starts decreasing:
  - This disturbance causes pressure pushing down on the liquid interface to decrease
  - If the valve position were to remain constant, the liquid drain _____ would similarly decrease
  - Consider that if a pressure decrease occurs quickly enough, the controller can be _____ the valve yet the liquid drain flow rate can continue to decrease
  - If pressure increases suddenly, the controller may be opening the valve while the liquid drain flow rate _____

  This contradictory outcome can confound the controller

- Observation → It is liquid drain flow rate, not valve position, that must be adjusted for high performance disturbance rejection

Solution: Flash Drum Cascade Architecture



- Two controllers (level control; drain flow rate control)
- Two sensors (measuring liquid level; liquid drain flow rate)
- One final control element (valve in the liquid drain stream)

A Cascade Control Solution

- Liquid level is the outer primary PV1 and controlling it remains the main objective
- For inner secondary PV2 choose liquid drain flow rate:
  - liquid drain flow rate is ____
  - the same valve used to ____ liquid level (PV1) also manipulates the liquid drain flow rate (PV2)
  - changes in vapor phase pressure that ____ PV1 also impact PV2
  - drain flow rate is *inside* the liquid level in that it responds well ____ liquid level to changes in valve position and changes in vapor phase pressure

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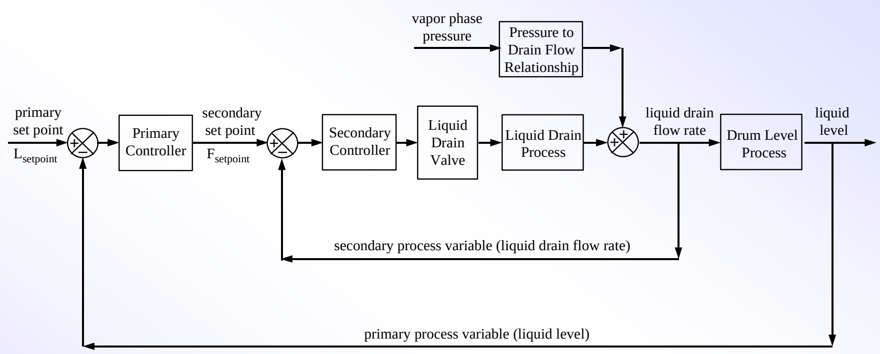
Flash Drum Cascade Architecture



- ____ (main objective) is outer primary loop
- ____ is inner secondary loop
- ____ is set point of secondary controller
- Flow control dynamics are much ____ than level control dynamics so this is consistent with design criteria

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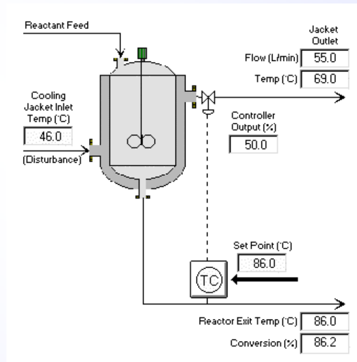
Flash Drum Cascade Architecture

- If liquid level is too high, the primary level controller now calls for an increased liquid drain flow rate rather than simply an increase in valve opening
- The flow controller then decides whether this means opening or closing the valve and by how much
- Thus, a vapor phase pressure disturbance gets addressed quickly by the secondary flow controller and this improves ________ performance

Tuning a Cascade Implementation

- Cascade loop tuning uses our existing skills:
  - Begin with both controllers in ________
  - Select ________ controller for the inner secondary loop (integral action increases settling time and offset is rarely an issue for the secondary process variable)
  - Tune the secondary P-Only controller for ________ and test it to ensure satisfactory performance
  - Leave secondary controller in automatic; it is now part of the primary process. Select a ________ controller for the primary loop, tune it for ________ and test it
  - With both controllers in automatic, tuning is complete

Exploring the Jacketed Reactor Process



- Well mixed vessel with exothermic (heat producing) reaction
- Residence time is constant so conversion of feed to product can be inferred from the reactor exit stream temperature
- Objective → maintain constant measured reactor exit stream ______ in spite of jacket inlet temperature disturbances

The Jacketed Reactor

- To control reactor exit stream temperature, the vessel is enclosed with a cooling jacket
- If the exit stream temperature (and thus conversion) is high, the controller opens a valve to increase cooling liquid flow rate
- This cools the reactor, slowing the heat producing reaction
- The disturbance variable of concern is ______ temperature

Disturbances and the Jacketed Reactor

- Consider scenario where the temperature of the cooling liquid entering the jacket fluctuates, changing the ability of the cooling jacket to remove heat
- If the cooling liquid temperature becomes colder just as the reactor temperature starts to fall, the controller can lower the cooling liquid flow rate yet be removing more heat than before
- Again, a contradictory result can ______ the controller and impact ______ performance

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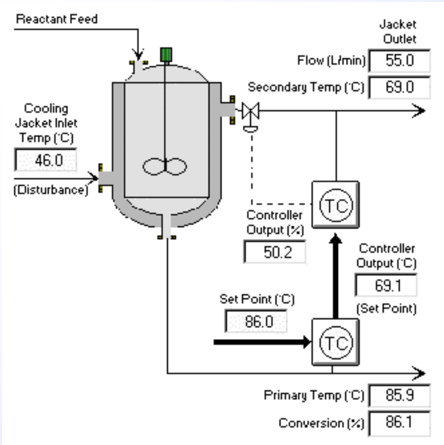
Cascade Architecture for the Jacketed Reactor



- Outer primary variable remains ______
- Inner secondary variable is ______

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The Reactor Cascade Architecture

- Cooling jacket outlet temp is a proper secondary variable
  - it is measurable with a sensor
  - valve used to manipulate reactor exit stream temperature (PV1) also manipulates cooling jacket outlet temp (PV2)
  - changes in cooling jacket inlet temperature that disturb reactor exit stream temp also disturb the cooling jacket outlet temp
  - the cooling jacket outlet temp is *inside* the reactor exit temp in that it responds first to changes in valve position and changes in the cooling jacket inlet temperature

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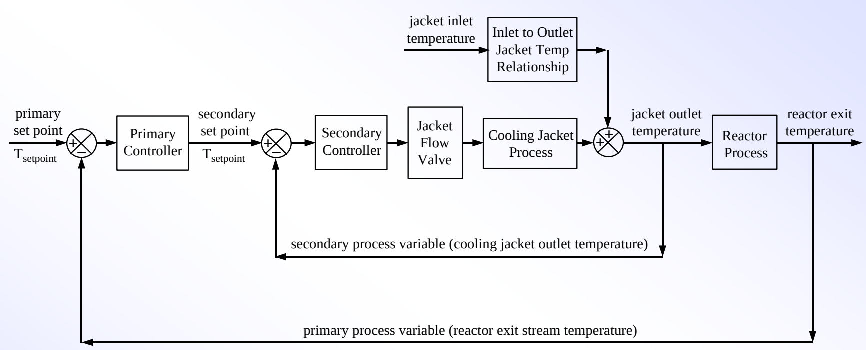
The Reactor Cascade Architecture



- Outer primary process (PV1) is reactor exit temperature
  - measured variable is reactor exit stream temperature
  - controller output is set point of secondary controller
- Inner secondary process (PV2) is the cooling jacket
  - measured variable is the cooling jacket outlet temperature
  - manipulated variable is the cooling jacket liquid flow rate

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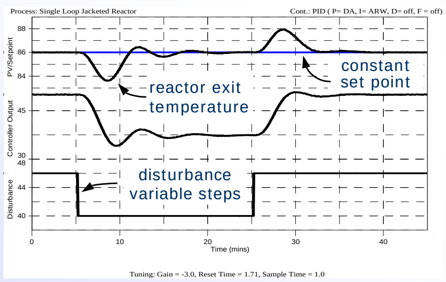
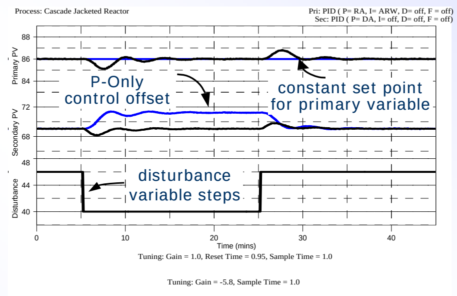
Disturbance Rejection Comparison

Disturbance Rejection Performance of Single Loop PI Controller

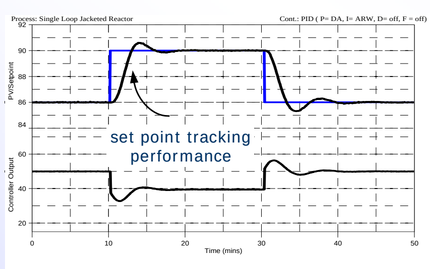


Disturbance Rejection Performance of Cascade Architecture

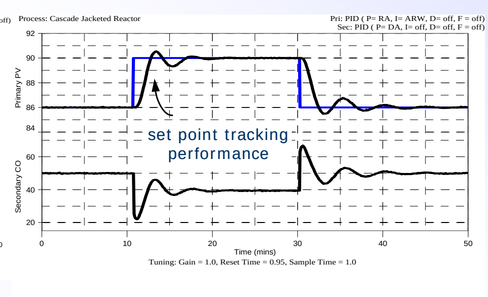


Set Point Tracking Comparison

Set Point Tracking Performance Under PI Control



Set Point Tracking Performance Under Cascade Control



- Cascade does not provide benefit in tracking set point changes

Answer These Questions to a Friend

- Why use cascade control?
- What process characteristics are advantageous for cascade control?
- What types of controllers should be used?
- How are cascade controllers tuned and operated?