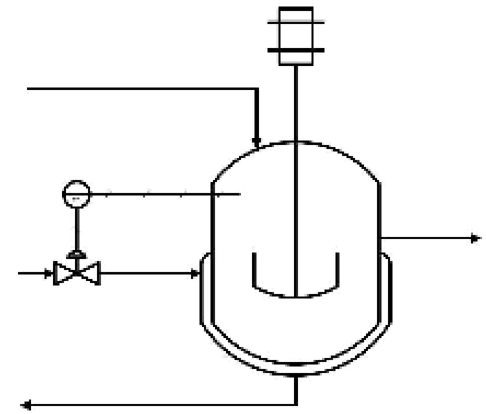


ChEN 403
Process Dynamics & Control

Introduction

Course Topics

- Math Modeling of Chemical Processes
- Solution of ODEs
  - » Laplace Transforms – ***Primary Emphasis***
  - » General Analytical Techniques
  - » Numerical Methods
- Transfer Functions
- Behavior of 1st, 2nd, & Higher Order Systems
- Fitting Model Parameters to Data
- Feedback Control - Behavior & Stability
- Design & Tuning of Controllers
- Advanced Control Schemes
- *Case Study*

Mathematical Nomenclature

- The nomenclature isn't what's important, it’s the concepts!
  - » Pretty much any symbols could be (and probably are) used
  - » Understand what's going on rather than memorizing symbols
- Will strive for consistency in the notes, homework, exams, etc.
  - » May be different from the text books, however

Typical Symbols

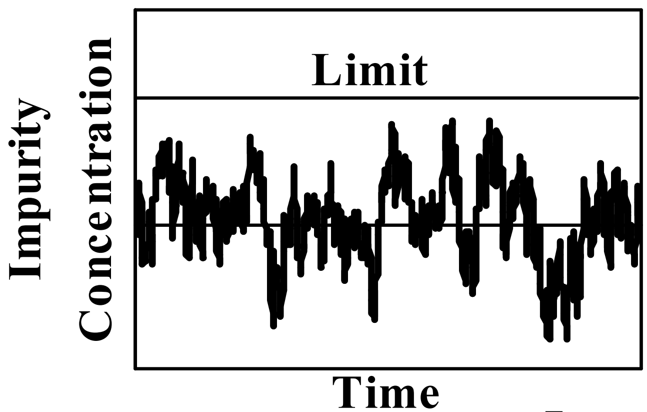
F	Volumetric flow rate
F'	Deviation variable
$\bar{F}'$	Laplace transform of deviation variable
F^*	Steady state value
$\hat{C}_p$	Heat capacity (mass basis)
$\tilde{C}_p$	Heat capacity (molar basis)
C_v	Valve coefficient

Importance of Process Control

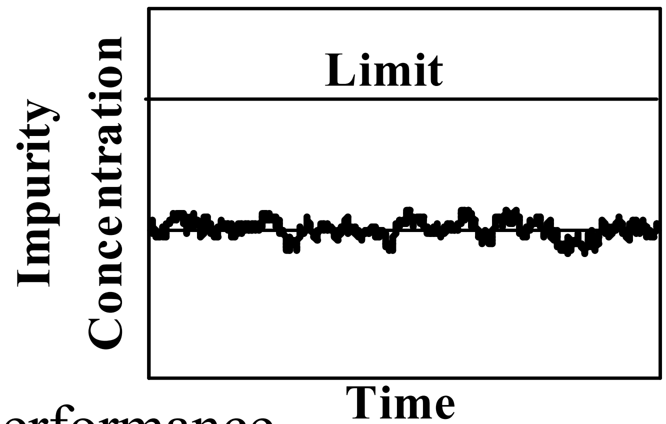
- Directly affects the safety and reliability of a process
  - » Control system must provide safe operation
  - » Control system must be able to "absorb" a variety of disturbances & keep the process in a good operating region
- Determines the quality of the products produced by a process
- Can affect how efficient a process is operated
- Bottom Line: process control has a major impact on the profitability of a company.

Benefits of Improved Control

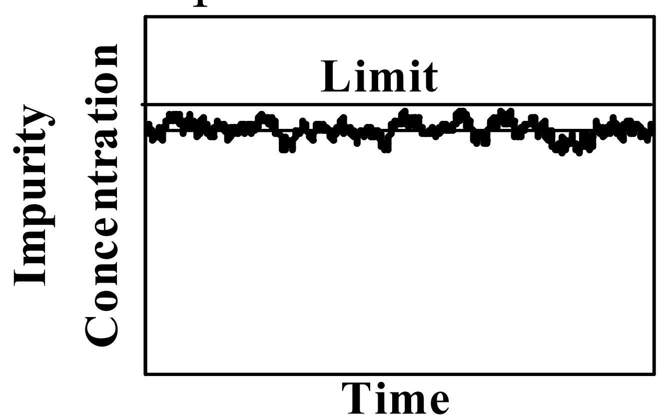
Old Controller



New Controller



Improved Performance



Let’s think about a simple household example

The Dynamics of the Household Shower

- What are the controlled or manipulated inputs?
  (What part of the system can be directly changed?)
- What are the set points?
  (What end result is desired?)
- What are the uncontrolled inputs?
  (What disturbances can happen outside of the shower stall?)
- Why might the set points change?
  (Do you want to run the shower the same way, morning or night, summer or winter, …?)
- What are the benefits of controlling this process?

Design Aspects of Process Control Systems

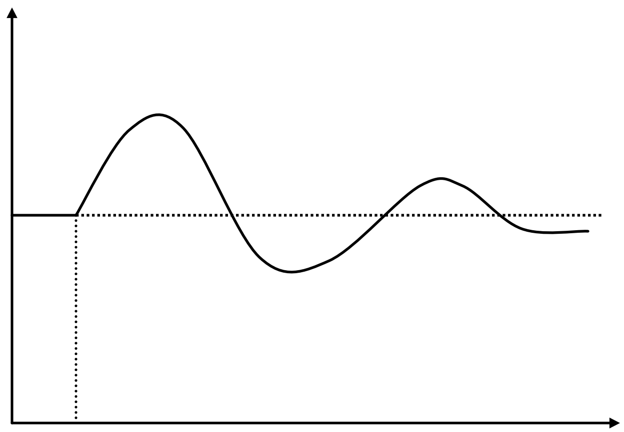
- *Manipulated variables*
  - » Variables that can be adjusted by the operator or controller
- *Disturbances*
  - » Uncontrolled changes, such as weather or feed composition
- *Measured variables*
  - » Values can be directly measured
- *Unmeasured variables*
  - » Values cannot be directly measured

Control Objectives

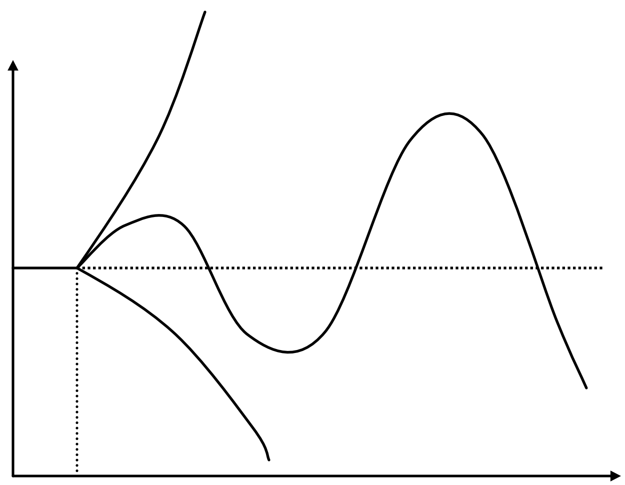
- Operational objectives
  - » Stability of process
  - » Suppress influence of disturbances
  - » Optimize performance of plant
- What variables should be measured?
- What variables should be manipulated?
- What is the best control configuration?
- How should measurements be used to adjust the manipulated variables?

Process Control Goals

- Suppress the influence of external disturbances
- Ensure the stability of a chemical process



time



time

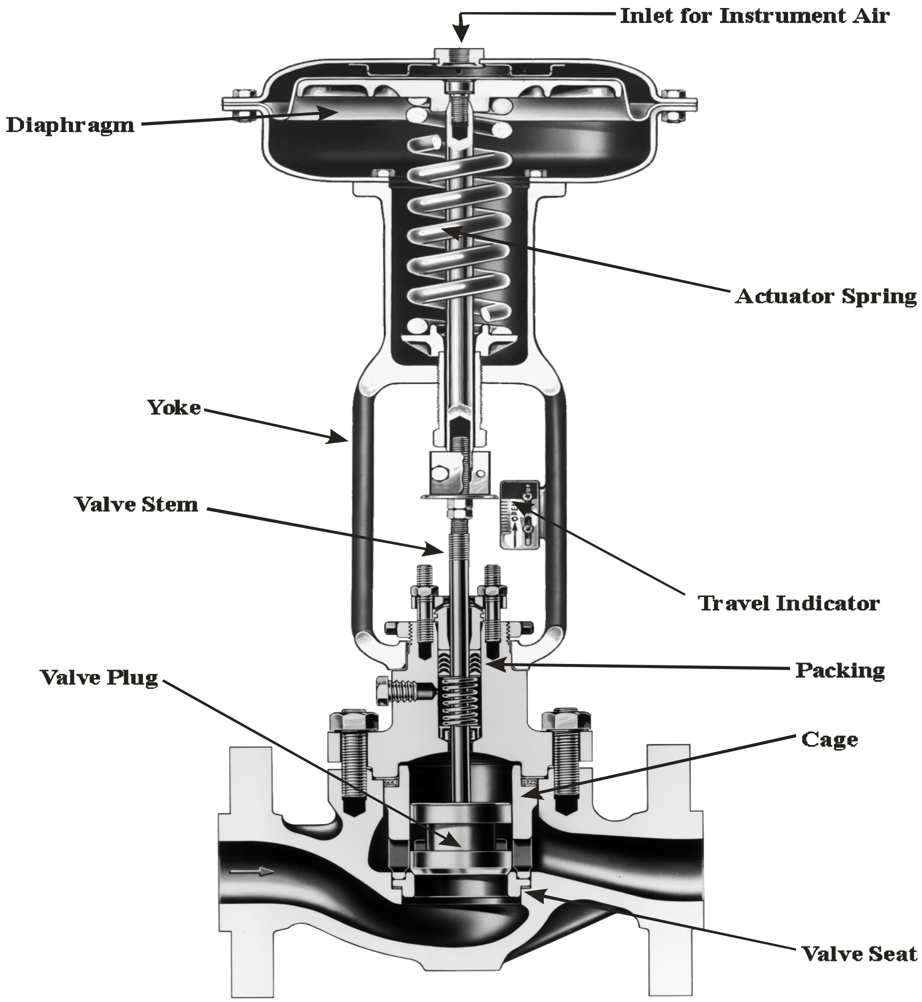
Process Control & Optimization

- Control & optimization are terms that are many times erroneously interchanged
  - » Control: adjusting manipulated variables to maintain the controlled variables of the process at specified setpoints
  - » Optimization: chooses the values for key setpoints such that the process operates at the "best" economic conditions

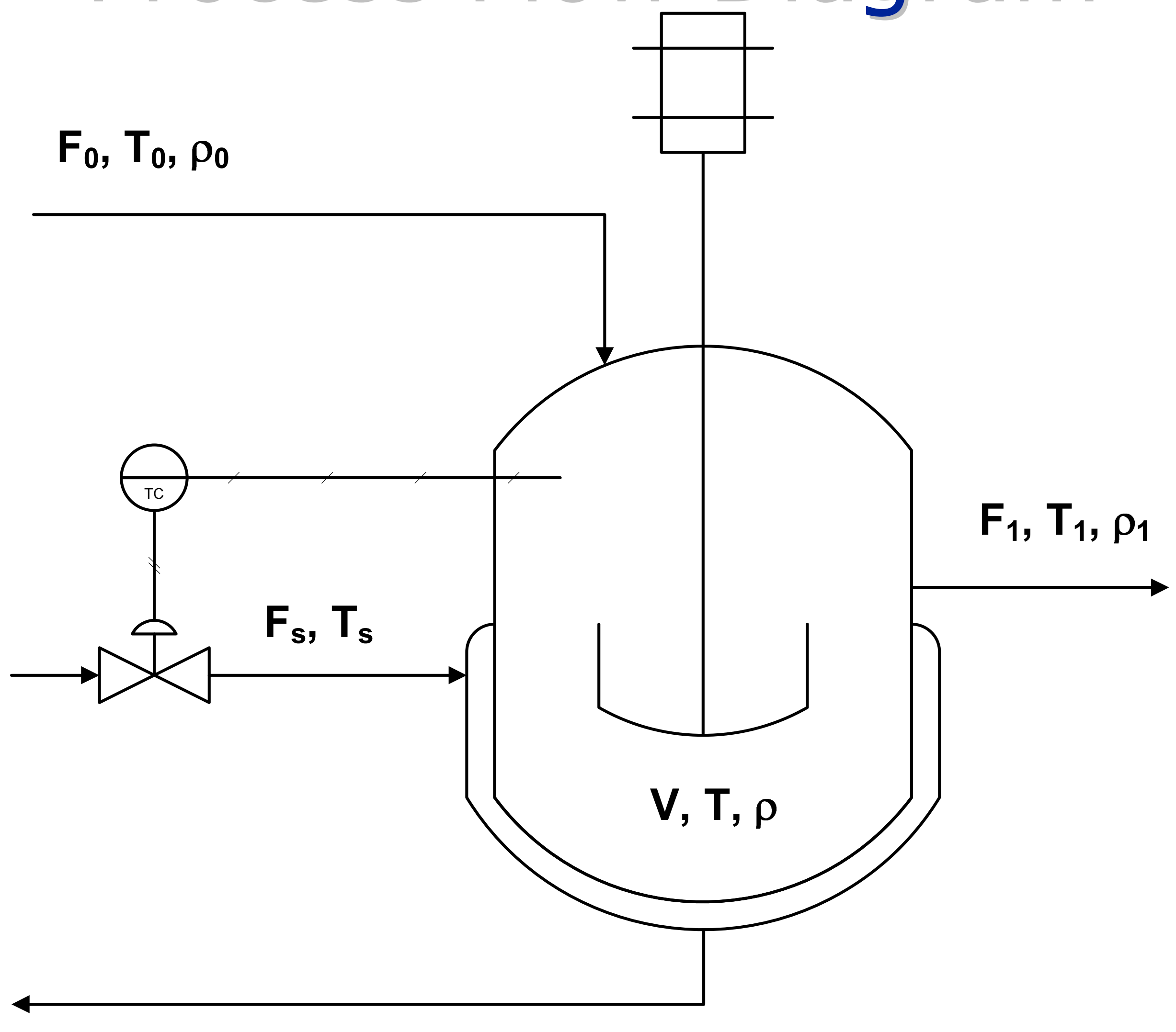
Process Control Hardware

- Measurement element
  - » Orifice meter
  - » Thermocouple
- Transmitter
- Control Valve (with actuator, positioner, & I/P)
- DCS Controller & I/O cards
- DCS Communication Network (a LAN)
- DCS Operator Console
- Advanced Control Computer

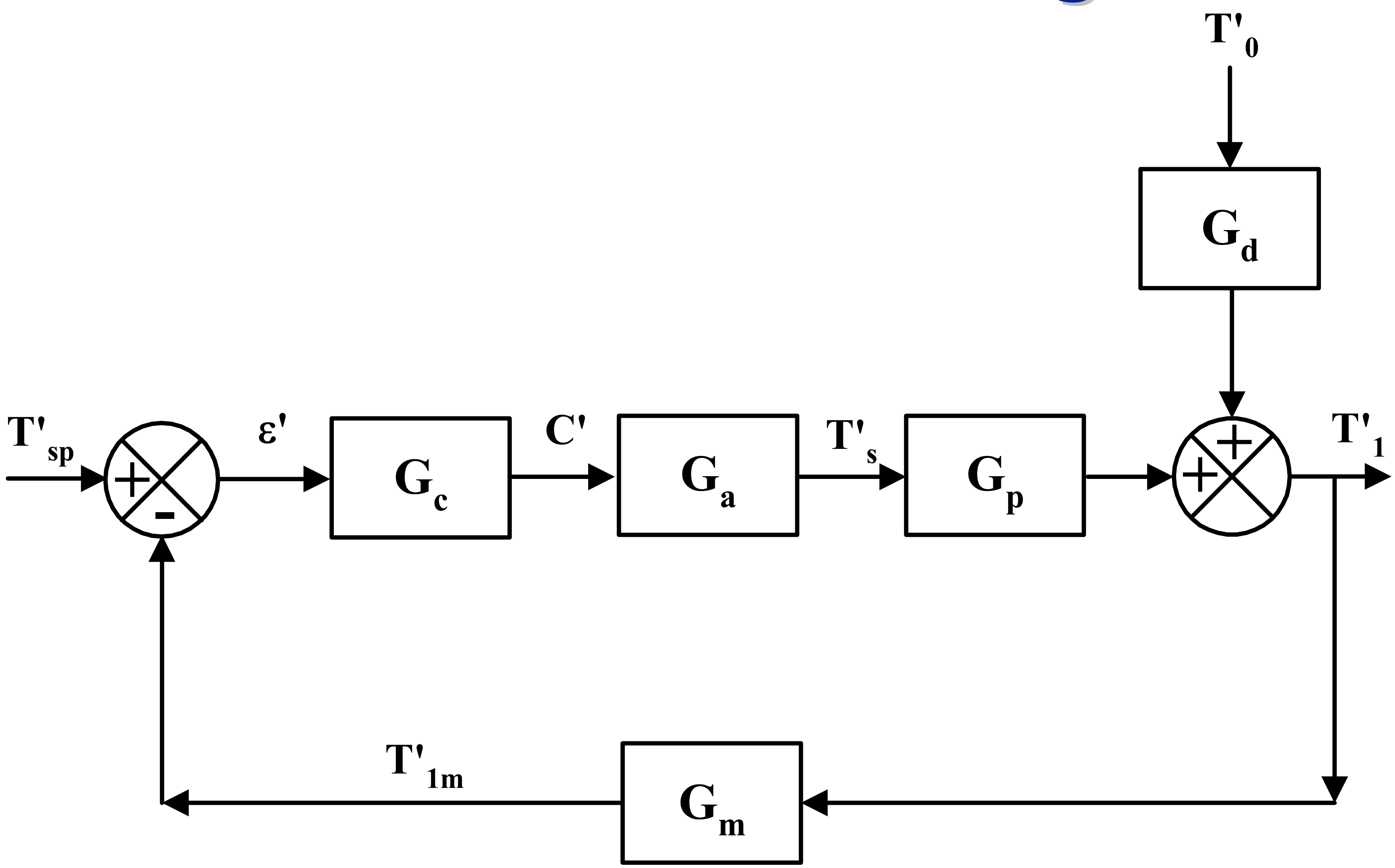
Cross-section of a Globe Valve



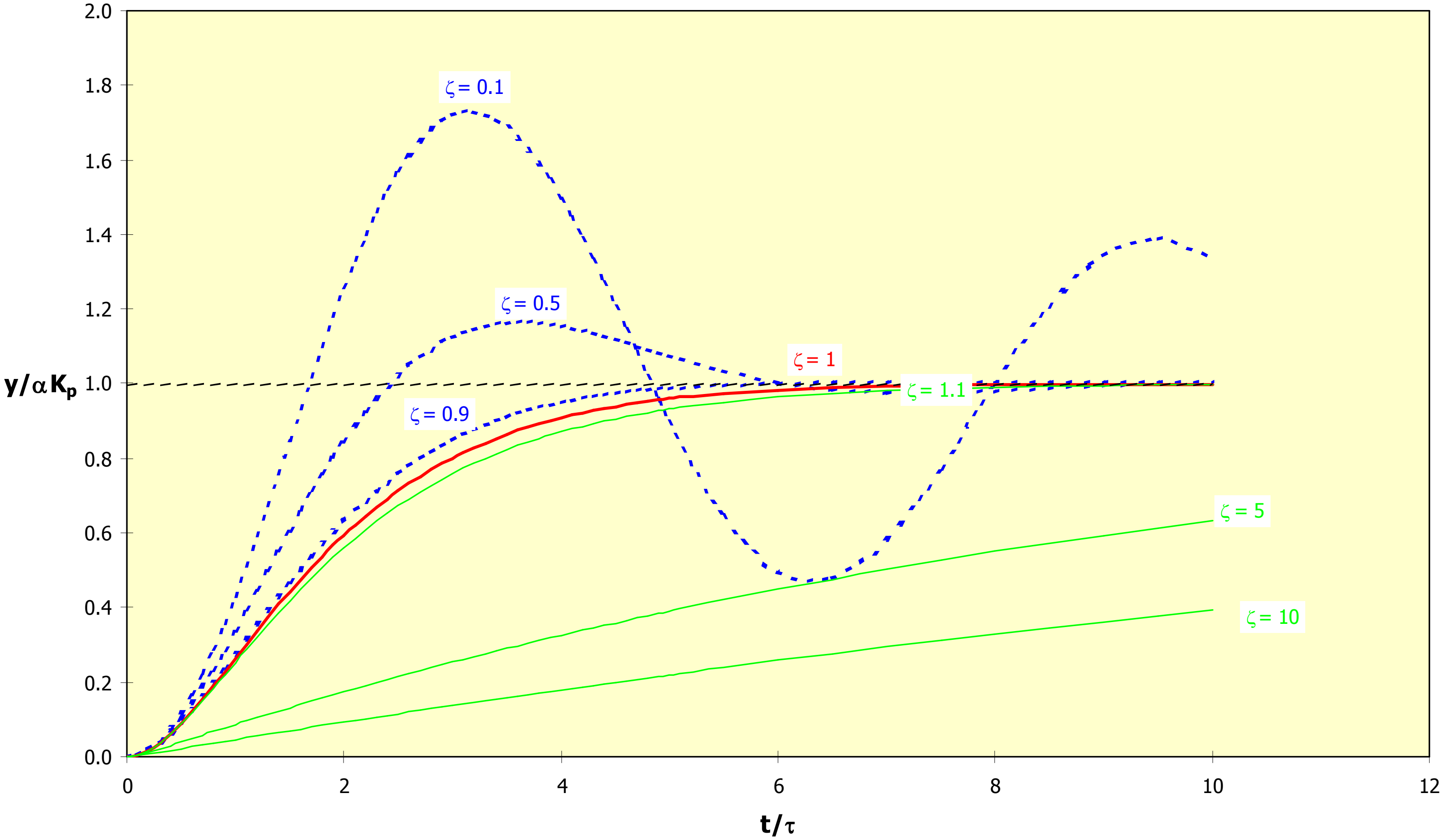
Process Flow Diagram



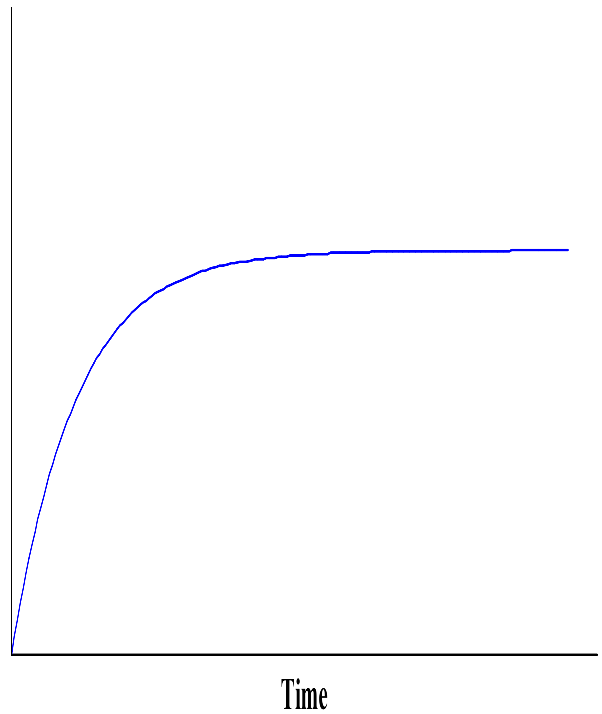
Information Flow Diagram

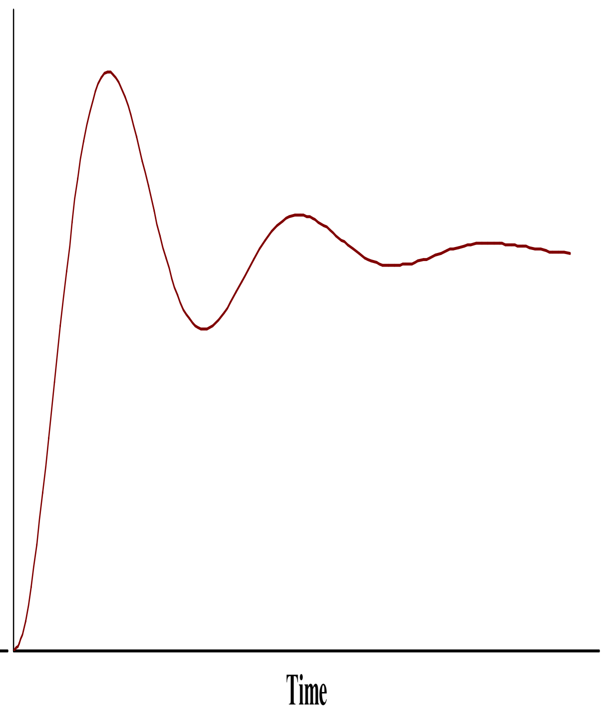


Recognize Standard Forms



Recognize Standard Forms





Rate of Mass & Energy Accumulation

- Material Balance Equation

$$\frac{d(\rho V)}{dt} = \rho_0 F_0 - \rho F_1 \quad \Rightarrow \quad F_0 = F_1$$

- Heat Balance Equation

$$\frac{d\left(\rho V \hat{H}\right)}{dt} = \rho_0 F_0 \hat{H}_0 - \rho_1 F_1 \hat{H}_1 + UA\left(T_s - T\right) \quad \Rightarrow$$

$$\left(\rho V \hat{C}_p\right)\frac{dT_1}{dt} + \left(\rho F_0 \hat{C}_p + UA\right)T_1 = \left(\rho F_0 \hat{C}_p\right)T_0 + \left(UA\right)T_s$$

Transfer Functions

- Laplace transforms create a *transfer function*

$$\left(\rho V\hat{C}_p\right)\frac{dT_1'}{dt}+\left(\rho F_0\hat{C}_p+UA\right)T_1'=\left(\rho F_0\hat{C}_p\right)T_0'+\left(UA\right)T_s'$$

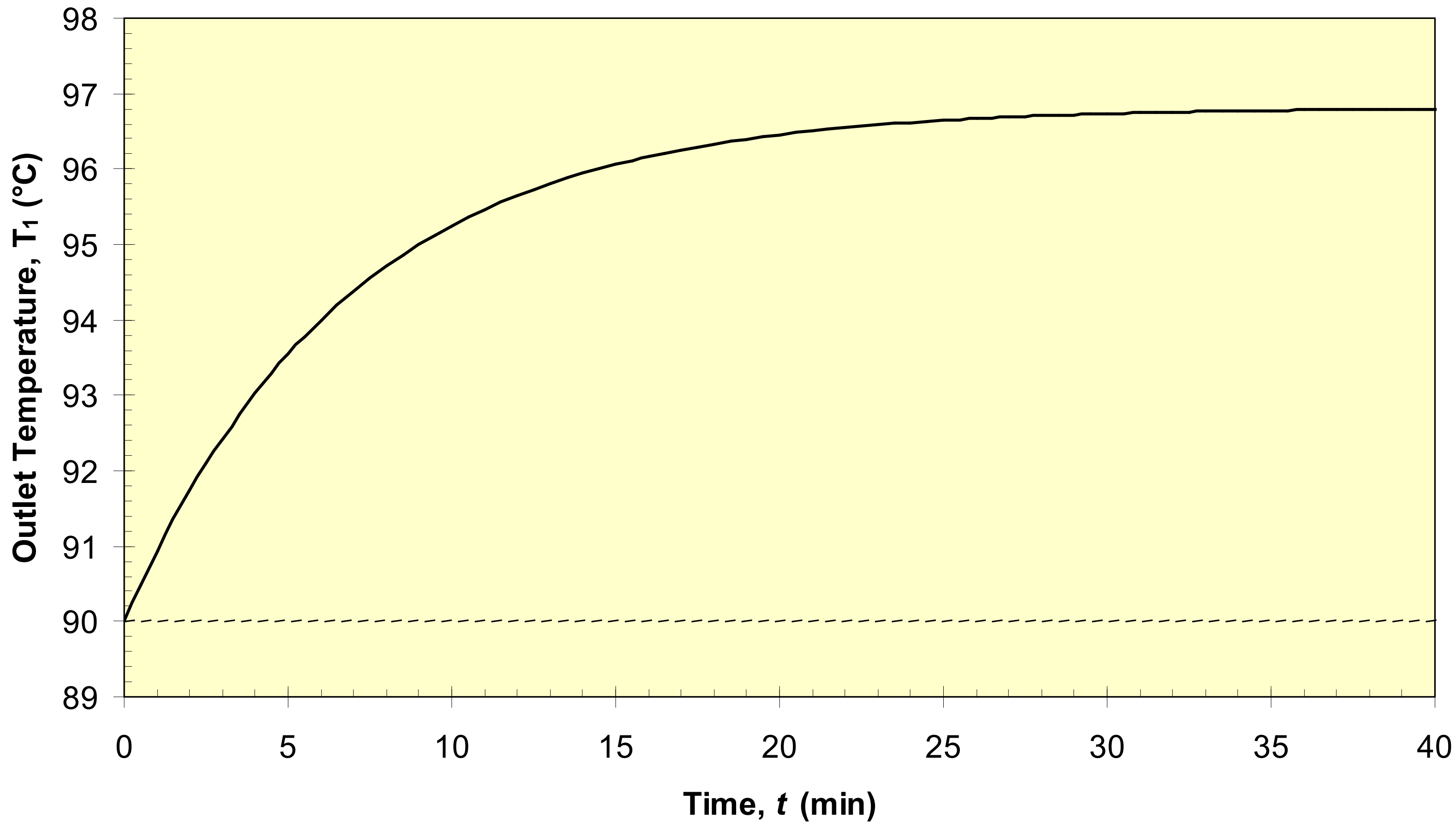
$$\left(\frac{\rho V\hat{C}_p}{\rho F_0\hat{C}_p+UA}\right)\frac{dT_1'}{dt}+T_1'=\left(\frac{\rho F_0\hat{C}_p}{\rho F_0\hat{C}_p+UA}\right)T_0'+\left(\frac{UA}{\rho F_0\hat{C}_p+UA}\right)T_s'$$

$$\tau\frac{dT_1'}{dt}+T_1'=K_0\cdot T_0'+K_s\cdot T_s'$$

$$\tau s\bar{T}_1'+\bar{T}_1'=K_0\cdot\bar{T}_0'+K_s\cdot\bar{T}_s'$$

$$\bar{T}_1'=\frac{K_0}{\tau s+1}\cdot\bar{T}_0'+\frac{K_s}{\tau s+1}\cdot\bar{T}_s'$$

Uncontrolled Tank Temperature



Control Loop Transfer Functions

- Uncontrolled response to disturbance

$$\bar{T}_1' = \left[\frac{K_0}{\tau s + 1}\right]\bar{T}_0' + \left[\frac{K_s}{\tau s + 1}\right]\bar{T}_s' \quad \Rightarrow \quad T_1' = T_0' K_0 \left[1 - \exp\left(-\frac{t}{\tau}\right)\right]$$

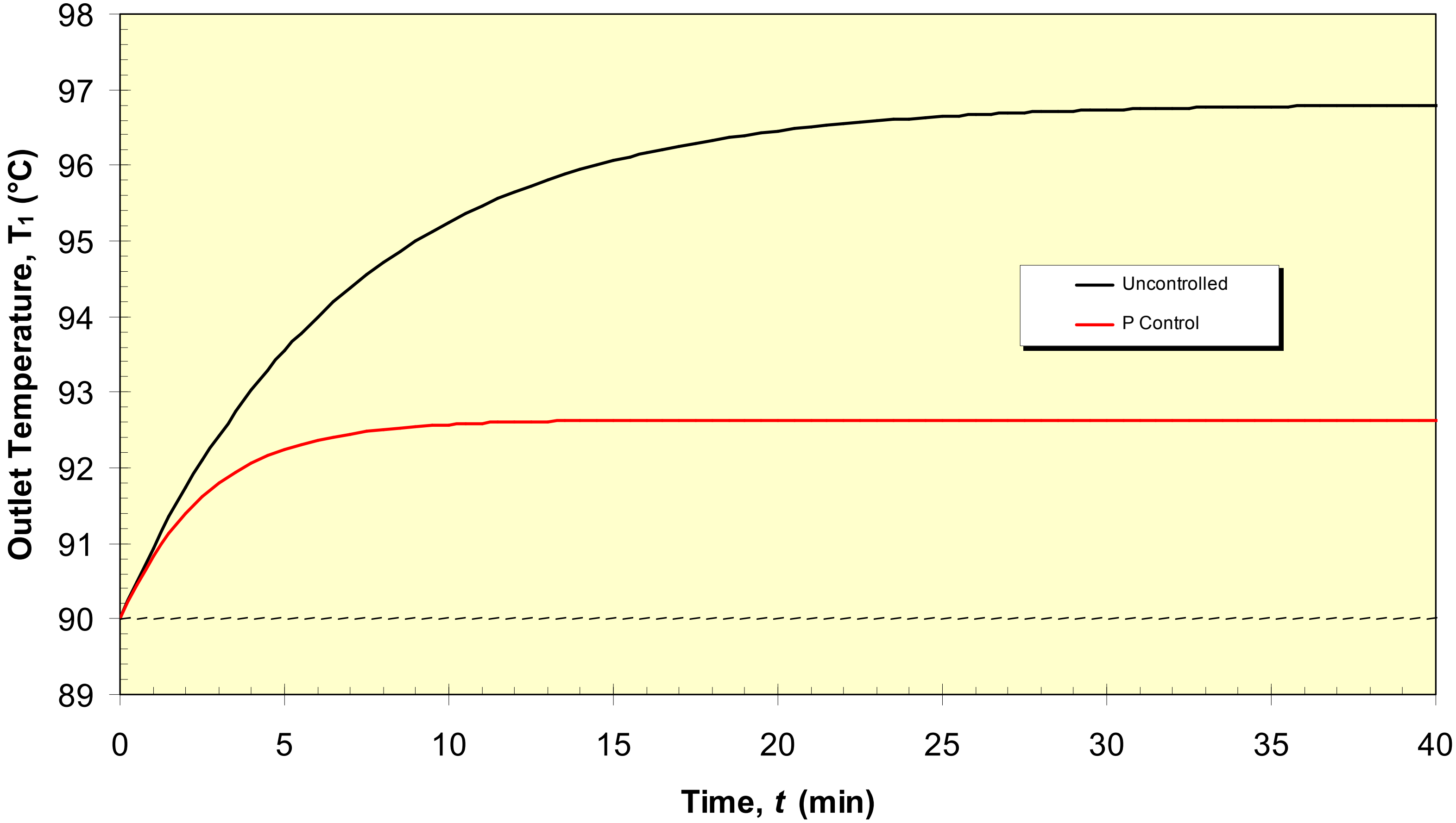
- Closed loop response

$$\frac{\bar{T}_1'}{\bar{T}_0'} = \frac{G_d}{1 + G_c G_a G_p G_m} = \frac{K_0}{\tau s + 1 + G_c K_0}$$

P Control:

$$\frac{\bar{T}_1'}{\bar{T}_0'} = \frac{K_0}{\tau s + 1 + K_c K_0} \quad \Rightarrow \quad T_1' = T_0' \frac{K_0}{1 + K_c K_0}\left[1 - \exp\left(-\frac{1 + K_c K_0}{\tau} t\right)\right]$$

Tank Temperature Under P Control



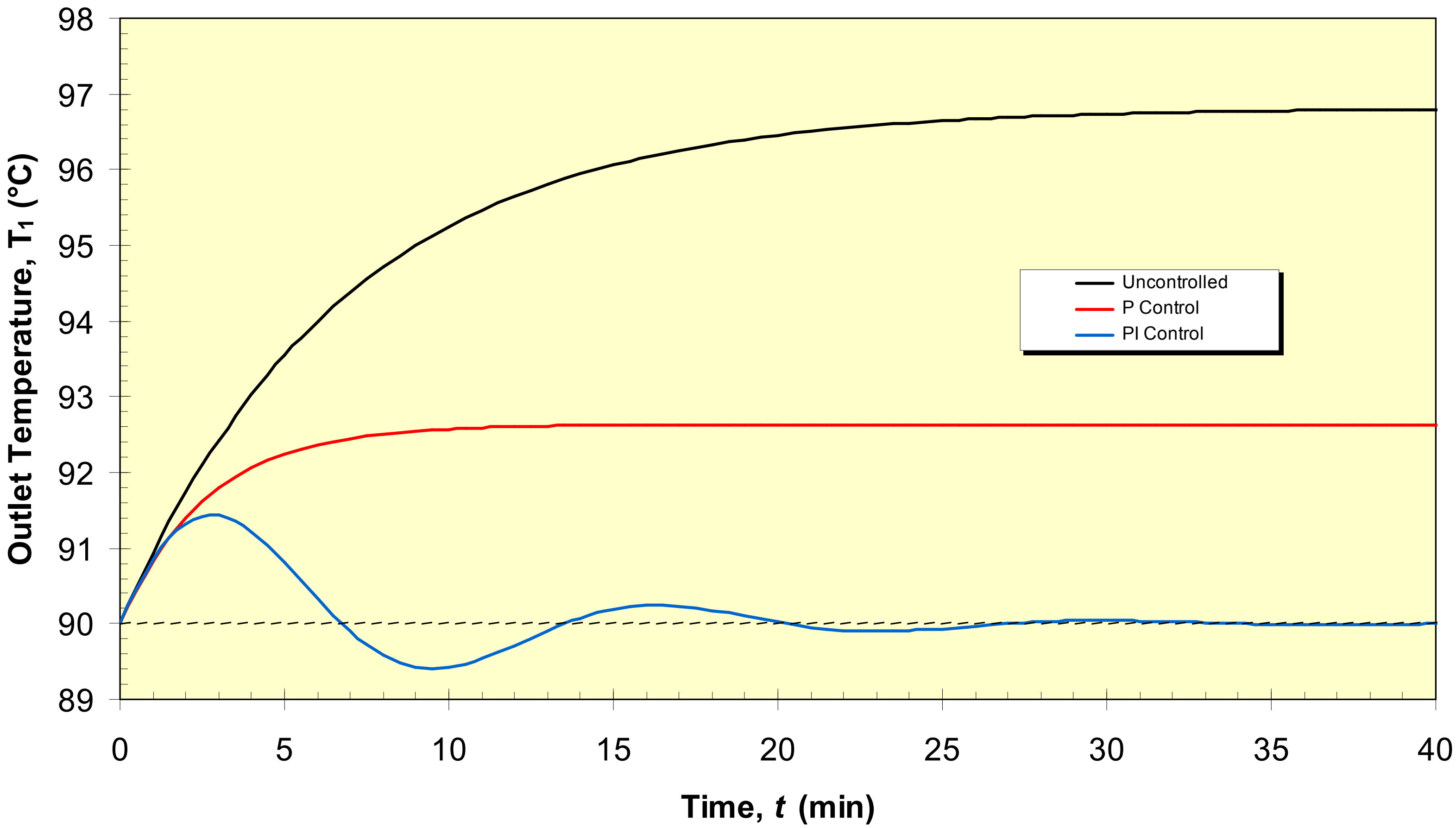
Control Loop Transfer Functions

- Closed loop response
  PI Control:

$$\frac{\bar{\bar{T}}_1'}{\bar{\bar{T}}_0'} = \frac{K_0}{\tau s + 1 + K_c\left(1 + \frac{1}{\tau_I s}\right)K_0}$$

$$= \frac{\left(\frac{\tau_I}{K_c}\right)s}{\left(\frac{\tau\tau_I}{K_0 K_c}\right)s^2 + \tau_I\left(\frac{1}{K_0 K_c} + 1\right)s + 1}$$

Tank Temperature Under PI Control



In Summary…

- Introduction to the course material
  - » Why is process control important?
  - » Some typical control problems
  - » Process & information flow diagrams