Date: ________________   Name: ___________________________________

LABORATORY EXERCISE 5
TEMPERATURE CONTROL LOOP CHARACTERISTICS

OBJECTIVE: To demonstrate typical characteristics of temperature control loops, primarily, the nonlinear effect of increasing load.

PREREQUISITES: Completion of the following:

Exercise 1	Process Dynamic Characteristics
Exercise 3	Valves and Positioners
Exercise 4	Characteristics of Flow Coops Loops

BACKGROUND: Temperature control loops often have a number of similar characteristics. These include:

Very limited amount of (or no) process measurement noise;
A relatively large time constant-to-dead time ratio;
If the primary load disturbance is a change in process throughput (for example, feed rate to a process heater), then the process characteristics change with throughput. Specifically, as the process throughput decreases, the process gain, time constant and dead time all tend to increase.

Due to this last characteristic, it is often beneficial to combine ratio and cascade control, where the Primary controllers output does not directly set the set point of the Secondary, but rather sets the required **ratio** of secondary PV to process flow. For example, a process heater outlet temperature controller may set the required fuel-to-feed ratio.

1. RUNNING THE PROGRAM

Start **Windows**.

Run **PC-ControLAB**.

2. PREPARATION

Confirm that FEEDBACK control strategy is being used. (See top line of the display.)

Select **Process I Select Model**. Highlight “Heater.mdl” and press **Open**.

Select **View I Variable Plot Selection**. Select “Yes” for PV-2. Leave all others the same. Press **Clear**.

The label above the controller, reading “Temperature (PV-1)”, should be highlighted in red. If it is not, click on It. Note the range of heater outlet temperature measurement. (Read scale at right of grid.)

From ________ DegF to ________ DegF.   Span: ________ DegF

Click on the label above the grid that reads “Feed Rate'”. Note the range of feed rate measurement.

From ________ GPM to ________ GPM Span: ________ GPM.

Click on the label above the grid that reads “Fuel Flo (PV-2)”. Note the range of fuel flow measurement.

From ________ KCFH to ________KCFH. Span: ________ KCFH.

Return to the “Temperature (PV-1)” label.

Note the type of valve characteristics and the pressure drop ratio. Press **Process I Change Parameters**.

Type of valve ____________________

Pressure drop ratio ____________________

For a gaseous fuel, a pressure regulator upstream of the valve would maintain a constant upstream pressure. The valve acts as a variable choked nozzle, hence the flow characteristics are as if there were a constant pressure drop *across the valve, even though the burner back pressure will very.*

3.0 TESTING THE PROCESS

What we will be doing:

We will test the process for process gain and dynamic characteristics at four different process flow rates. Our tests will always be such that the temperature remains in the vicinity of its normal operating region, 275 - 300 DegF. We will determine the process gain In two ways.

$$K_{P1} = \frac{\Delta \text{Temperature (\%)}}{\Delta \text{Signal to Valve (\%)}}$$ This is the process gain seen by the controller when a simple feedback control loop is used (that is, when the controller output goes directly to the valve).

$$K_{P2} = \frac{\Delta \text{Temperature (\%)}}{\Delta \text{Fuel Flow Rate (\%)}}$$ This is the process gain seen by the controller

when a cascade loop is used (that is, when the temperature controller output sets the set point of a fuel flow controller).

3.1 35% Process Flow.

With the controller in Manual, set the controller output at 10%.

Click **StepDecr** 8 times to decrease the feed rate to 140 GPM. (35%. You can read the scale on the LH side of the grid.)

At 35% process flow and 10% controller output, read and record in the table below the temperature (PV-1) and fuel flow rate (PV-2). (Use PAUSE to read the values.)

Then change the controller output to 13% and read and record the same variables. Also estimate and record the dead time and time constant due to the change in controller output.

Then calculate ΔTemp (%), ΔFuel Flow (%) and the two process gains listed above.

Process Flow	140 GPM		220 GPM		300 GPM		380 GPM	
Process Flow, %	35%		55%		75%		95%	
Controller Output	10%	13%	25%	28%	35%	38%	42%	45%
Δ Valve, %	3%		3%		3%		3%	
Fuel Flow, KCFH								
ΔFuel Flow, KCFH								
ΔFuel Flow, %								
Temperature, ^{0}F								
ΔTemperature, ^{0}F								
ΔTemperature, %								
$K_{P1}\left(\frac{\Delta \text{Temp},\%}{\Delta \text{Valve},\%}\right)$								
$K_{P2}\left(\frac{\Delta \text{Temp},\%}{\Delta \text{Fuel},\%}\right)$								
Dead Time, mins								
Time Const, mins								

3.2 55% Process Flow

Click **StepIncr** 4 times to increase the process flow to 220 GPM (55%).

Repeat the procedure above for the controller output at 25%, then at 28%.

3.3 75% Process Flow

Click **StepIncr** 4 times to increase the process flow to 300 GPM (75%).

Repeat the procedure above for the controller output at 35%, then at 38%.

3.4 95% Process Flow

Click **StepIncr** 4 times to increase the process flow to 380 GPM (95%).

Repeat the procedure above for the controller output at 42%, then at 45%.

What you should have observed.

The process gain, as determined by the ratio of temperature change to change in fuel flow rate, decreases with increasing process flow rate, or conversely, increases with decreasing process flow rate. Thus, if a Cascade control loop were applied

(Temperature Controller setting the set point of a Flow Controller), and if the process is operated at widely varying flow rates, then there could be a problem with controller tuning. If the Temperature Controller were tuned properly for a high process flow rate, it would probably be overly aggressive at a low process flow rate. If it were tuned properly for a low rate, it would probably be too sluggish at a high process flow rate.

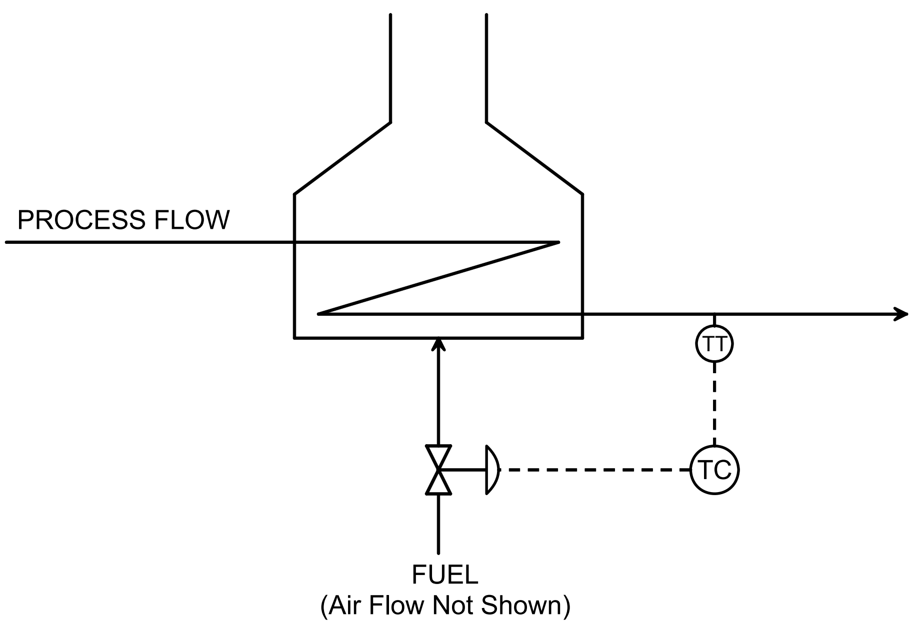
(Don't give up on Cascade control just yet, however. There are other reasons why it is beneficial. When we explore Ratio and Feedforward control, we will see how we can overcome the non-linearity problem.)

The process gain, as determined by the ratio of temperature change to valve position change, stayed relatively constant as the process load increased. This is due to the fact that we are using an equal percentage valve with a constant pressure drop. The inherent non-linear characteristics of the valve (see Exercise 2) offsets the non-linear characteristics of the process. If we had used a linear valve, rather than an equal percentage valve, then we would have seen the same type of decrease in process gain as the process flow rate increased.

You should also have observed the changing dynamics (decrease in dead time and time constant) as the process flow is increased. Since the ratio of these does not very nearly as widely as does the process gain, this is not of as serious of consequences as is the gain variation, however. It may still cause a different control loop response at high and low process flows.

4. CONFIRMATION OF OBSERVATIONS

This section pertains to a process heater with a simple temperature controller on the heater outlet. The following is a process and instrumentation diagram for sub-sections 4.1 and 4.2.



4.1 Feedback Control, Equal Percentage Valve

Set the following, which represents the “normal” operating point:

Process flow	300 GPM	(75%)
Temperature set point	275 DegF	
Controller output	35 %	

Enter the following controller tuning parameters:

Gain:	1.0
Reset:	15.0 minutestrepeat

Put the controller in Auto.

Change the set point to 300 DegF. Acceptable response? ________

Change the set point to 250 DegF. Acceptable response? ________

Increase the process flow to 380 GPM (95%).

When the loop settles out, change the set point to 300 DegF. Compare the response to the previous response when the load was 300 GPM:

About the same ________

A bit more sluggish ________

Much worse ________

Decrease the process flow to 220 GPM (55%).

When the loop settles out, change the set point to 250 DegF. Compare the response to the previous response when the load was 300 GPM:

About the same ________

A bit more sluggish ________

Much worse ________

Decrease the process flow to 140 GPM (35%).

When the loop settles out, change the set point to 300 DegF. Compare the response to the previous response when the load was 300 GPM:

About the same ________

A bit more sluggish ________

Much worse ________

What you should have observed:

Due to changing dynamics at lower process flow rates, the control loop becomes slightly more aggressive. However, we can probably live with it at all flow rates.

4.2 Feedback Control, Linear Valve

Put the controller in Manual

Set the following:

Process flow	300 GPM (75%)
Set Point	275 DegF
Controller Output	35%

Select **Process I Change Parameters** and change the following:

Valve Cv-Max	From	129.85	to	22.36
Valve Type: 0=EqPct; 1=Lin	From	0.0	to	1.0

Enter the following tuning parameters:

Gain	1.2
Reset	12.00 minutestrepeat

Put the controller in Auto and change the set point to 300 DegF.

Acceptable response? _________

Change the set point to 250 DegF? Acceptable response? _________

Put the controller in Manual

Set the following:

Process flow	140 GPM (35%)
Set Point	275 DegF
Controller Output	16.31%

Put the controller in Auto and change the set point to 300 DegF.

Acceptable response? _________

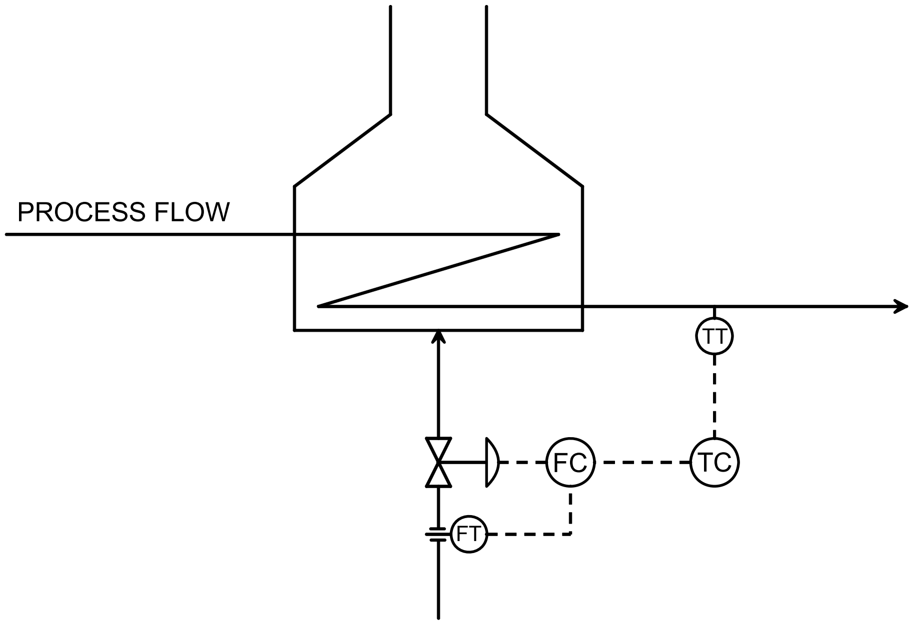
What is happening to the control loop? ____

What you should have observed:

With the linear valve and an effective constant pressure across the valve, the non-linearity of the process unit dominates and causes the loop to become unstable at low process flow rates.

4.3 Cascade Control

The following is a process and instrumentation diagram for sections 4.3 and 4.4:



Click on **Control | Select Strategy I Cascade**

Select the Fuel Flow controller and enter the following tuning parameters:

Gain	0.5
Reset	0.15 minutes/repeat

Select the Temperature controller and enter the following tuning parameters:

Gain	1.0
Reset	15 minutes/repeat

Put the Fuel Flow controller in the cascade mode (press **Casc**) and the Temperature controller in the Automatic mode (press **Auto**).

With the Temperature controller selected, make a series of set point changes:

From 275	to	300 DegF
From 300	to	250 DegF
From 250	to	275 DegF

Acceptable response? _________

With the Temperature controller selected, press **StepIncr** 4 times to increase the process flow to 380 GPM (95%). When the loop settles out, make the same series of set point changes as above.

Acceptable response? _________

How does the response compare with the response when the process flow was 300 GPM (75%)?

About the same: ________

Slightly more sluggish: ________

With the Temperature controller selected, press **StepDecr** one step at a time to reduce the process flow rate, eventually to 140 GPM (35%). Let the control system settle out between each step. What happens to the response as the process load is decreased?

Becomes increasingly more aggressive ________

Becomes increasingly more sluggish ________

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What you should have observed:

Due to the increasing process gain (K_{P2} in section 3) at lower process flows, the Cascade control becomes increasingly more aggressive, and eventually becomes unstable, as the process flow is decreased.

But don't give up on Cascade yet; there are other reasons to use it. And when we look at Ratio and Feedforward control (Exercises 14, 16 and 17) we will see what can be done to overcome the non-linearity