Date: ________________ Name: ___________________________________

LABORATORY EXERCISE 2
CONTROL VALVE CHARACTERISTICS

OBJECTIVE: To demonstrate the relation between valve stem position and the fluid flow through a control valve, for both linear and equal percentage valves. Also, to demonstrate the difference between manufactured and installed valve characteristics.

PREREQUISITES: Completion of Exercise 1, Process Dynamic Characteristics.

BACKGROUND: A control valve is the most common type of final control element for process control loops. The position of the valve stem (typically somewhere between 0 and 100% open) sets the flow rate of fluid through the valve. The response is typically non-linear, however; an incremental change in valve position will produce a different change in fluid flow, depending upon the initial position of the valve. Two factors which cause the non-linear response are the type of valve (i.e., the valve characteristics) and the effect of the rest of the process piping network on the pressure drop through the valve.

Two common forms of valve characteristics are **equal percentage** and **linear**. These characteristics are determined by the physical shaping of the valve internals by the valve manufacturer; hence they are termed the **manufactured characteristics.** If the pressure drop across the valve were constant at all valve positions, then the flow rate would vary with valve position according to the manufactured characteristics. However, in most practical applications, as the flow rate increases other portions of the process piping begin to take some of the available system pressure drop; hence the pressure drop across the valve will decrease. This gives rise to the term **installed characteristics**, which describes how the flow rate varies with valve position in a particular installation.

The variation in pressure drop across the valve can be characterized by a factor termed the “pressure drop ratio” (PDR), where

$$\text{PDR} = \frac{\text{Minimum pressure drop across valve}}{\text{Maximum pressure drop across valve}}$$

$$= \frac{\text{Pressure drop with valve wide open}}{\text{Pressure drop with valve closed}}$$

A PDR of 1.0 indicates that the valve takes all of the available pressure drop at all valve positions; the balance of the components in the piping network take none of the pressure drop. In other words, this indicates that there is a relatively small valve in a very large line. If the PDR becomes smaller (approaching but never reaching zero), then the indication is that the line is smaller relative to the size of the valve. The usual practice is to size the valve and the other components in the piping network so that the valve will take 25% to 50% of the available system pressure drop when it is wide open. This corresponds to a PDR of 0.25 and 0.5, respectively.

1. STARTING THE PROGRAM

Start **Windows**.

Run **PC-ControLAB**.

2. PREPARATION

Confirm that the **Feedback** control strategy is being used.

Select **View | Horizontal Grid Scale | Seconds**. (Note that the grid now displays the last 60 seconds of operation, not the last 60 minutes.) Most flow loops are very fast, so it is better to run the chart on a fast time scale for this exercise.

Select **Process | Select Model**. Highlight "flow.mdl" and press **Open**.

This process exhibits flow measurement noise, which is typical of many real flow processes. For this exercise, however, we will use a noise-free measurement. Therefore, select **Process | Change Parameters.** Then highlight "Meas Noise: 0=Off; 1=On". Enter a new value of 0.0, then press **OK** then **Clear**.

Note from the coordinates at the right hand side of the trend display that the maximum flow rate is 50 GPM.

Click on the white label above the trend reading "System Pr Drop." The coordinates at the RH side of the trend are now 0 – 30 psi. The present system pressure drop (read the LOAD trend) is 20 psi. Now click on the label "Process Flow (PV-1)" above the controller.

For this exercise, we will use percent, rather than engineering value. Select **View | Display Range | Percent of Span**. Notice that the scale is now 0 – 100%.

For convenience in reading numerical values of flow rate, in percent of span, click on **View | Data Monitor**. Leave the Data Monitor on display for the rest of this exercise.

3. FLOW RATE VS CONTROLLER OUTPUT

3.1 Equal Percentage Valve

Select **Process | Change Parameters** and check or set the following process parameter:

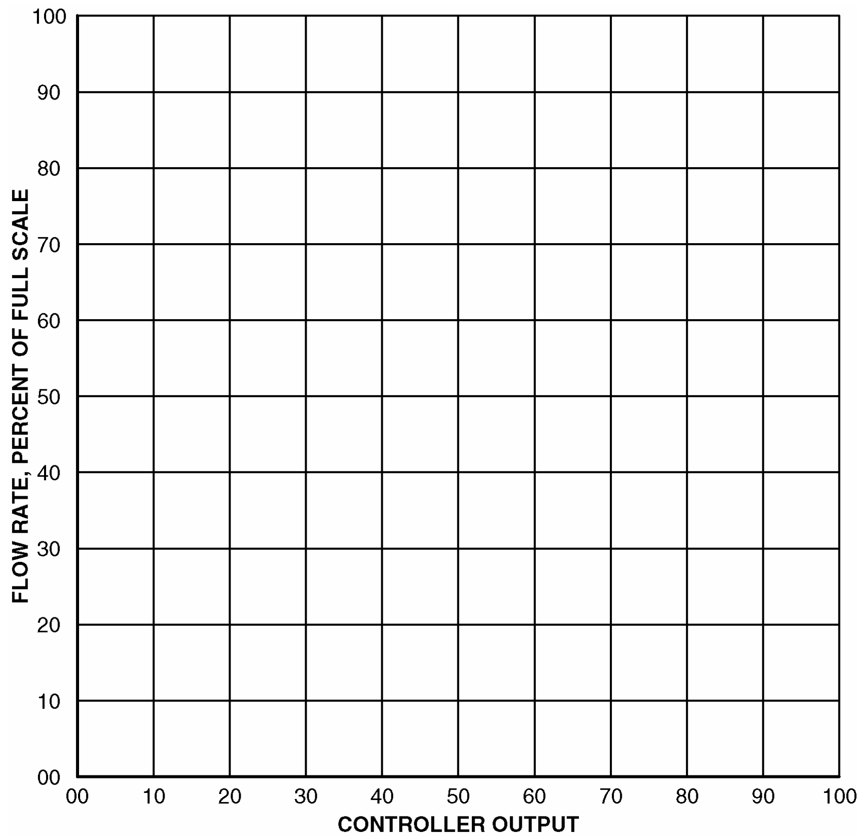
Pressure Drop Ratio	1.0
Valve Pos: 0=No; 1=Y	1.0
Valve: 0=EqPct; 1=Linear	0.0
Valve Cv:	11.18
Meas Noise: 0 = Off; 1=On	0.0

For three different cases (three different pressure drop ratios) determine the flow rate at a series of controller output values (with the controller in Manual). Make the settings and record the flow data in the Table 1.

(Note that the theoretical flow rate for an equal percentage valve does not go to zero at zero valve position. This is one reason why is it not good practice to use a the control valve as a shut-off valve.)

Table 1 **EQUAL PERCENTAGE VALVE**			
	Case 1-EP	Case 2-EP	Case 3-EP
	Small valve, large line (usually not realistic)	Typical valve and line size relation	Significantly oversized valve, small line
Pressure Drop Ratio	1.0	0.3	0.1
Valve: Cv-max	11.18	20.41	35.35
Controller Output	Flow Rate (Controller in Manual)		
0.1%			
10%			
20%			
40%			
60%			
80%			
90%			
99.9%			

Plot the data from Table 1 for each of these cases on the graph, Figure 1, below:



NOTE: These curves are based on a “theoretically ideal” equal percentage valve. A real valve with equal percentage characteristics will approximate these curves.

The data with a pressure drop ratio of 1.0 represents the manufactured characteristics of the valve. The other two data columns, with a pressure drop ratio of 0.3 and 0.1 represent installed characteristics of the valve, since the pressure drop ratio (if it is less than 1.0) is a function of the actual line characteristics into which the valve is installed.

3.2 Linear Valve:

Select **Process | Change Parameters** and check or set the following process parameter:

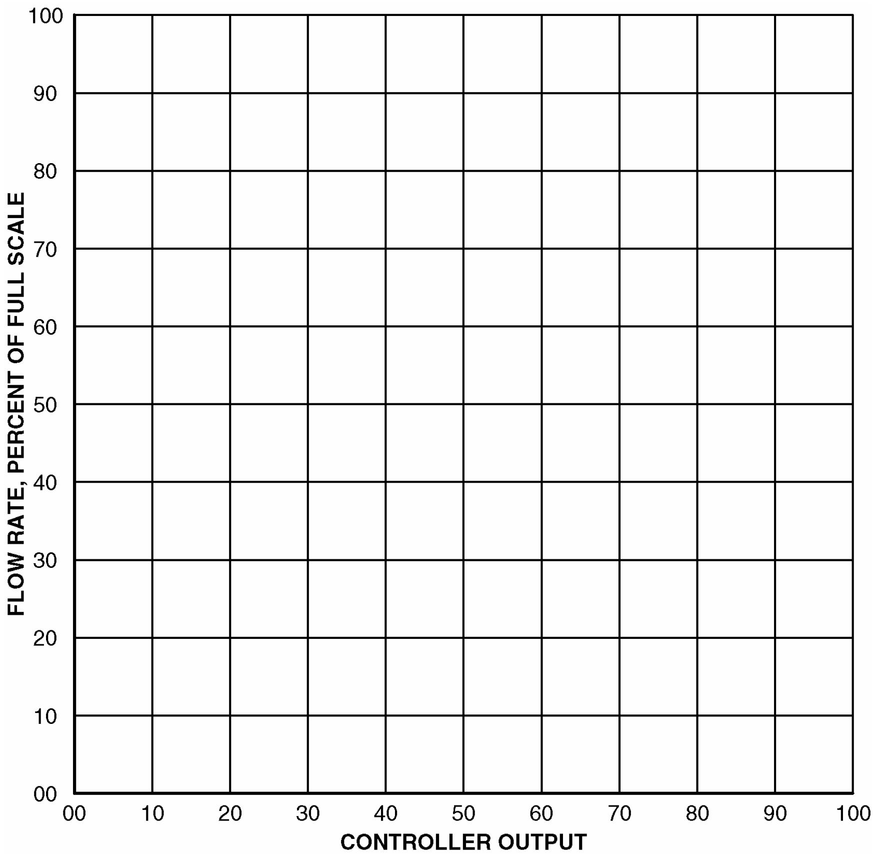
Pressure Drop Ratio	1.0
Valve Pos: 0=No; 1=Yes	1.0
Valve: 0=EqPct; 1=Linear	1.0
Valve Cv:	11.18
Meas Noise: 0=Off; 1=On	0.0

For three different cases (three different pressure drop ratios) determine the flow rate at a series of controller output values (with the controller in Manual). Make the settings and record the flow data in Table 2 below.

Table 2
LINEAR VALVE

	Case 1-L	Case 2-L	Case 3-L
	Small valve, large line (usually not realistic)	Typical valve and line size relation	Significantly oversized valve, small line
Pressure Drop Ratio	1.0	0.3	0.1
Valve: Cv-max	11.18	20.41	35.35
Controller Output	Flow Rate (Controller in Manual)		
0.1%			
10%			
20%			
40%			
60%			
80%			
90%			
99.9%			

Plot the data for each of the cases in Table 2 on the following graph.



NOTE: These curves are based on a "theoretically ideal" linear valve. A real valve with linear characteristics will approximate these curves.

3.3 Interpretation of Data:

For any of these cases, the **process gain,** $\left(\dfrac{\Delta\,\text{flow}}{\Delta\,\text{valve position}}\right)$**,** is represented by the slope the curve. If the slope is relatively constant, then the control loop response should be relatively constant at all operating points. If the slope varies greatly, then unless the controller is retuned the control loop response will also vary.

(This is perhaps oversimplified, because it only considers the steady state gain; in actuality, the dynamics of the loop may also vary with operating point.)

Suppose that our operation covers the upper 75% of the flow range (25 – 100%). From the data taken, if the valve has a typical pressure drop ratio of 0.3, which appears to be the better selection of valve characteristics in order to maintain approximately the same response (without changing the tuning parameters) over most of the range of the valve?

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If the application happens to be such that a relatively constant pressure drop is maintained across the valve, which appears to the better selection of valve characteristics?

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3.4 Confirmation of Interpretation:

We will test 4 of the previous cases to see how control loop responds at a low and a high operating point, with no change in controller tuning. The following table gives settings that should be made for each of these test cases. Sub-section number refers to the subsection activities listed following the table.

Subsection No	1	2	3	4
Test Case	2-EP	1-EP	1-L	1-L
Test Description	EqPct valve. Variable ΔP	EpPct valve. Constant ΔP	Linear valve. Variable ΔP	Linear valve. Constant ΔP
Process Params				
Press Drop Ratio	0.3	1.0	0.3	1.0
Valve Cv-max	20.41	11.18	20.41	11.18
Valve:0=EqPct;1=Lin	0.0	0.0	1.0	1.0
Controller Tuning				
Gain	0.8	1.5	1.0	1.0
Reset, Min/Rpt	0.15	0.15	0.15	0.15

For all sub-sections, set or check the following process parameters.

Valve Pos? 0=No: 1=Yes 1.0
Meas Noise: 0=Off; 1=On 0.0

1. Set the process model and controller tuning parameters as listed above for column 1.

Put the controller in Auto and set the set point at 50%. Then make set point changes of 10% up or down, within the range of 40% to 90%. Does the closed loop response appear to be approximately the same at all points within this range?

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Set the set point at 40%, then make 10% set point changes to 30%, 20% and 10%. Does the loop appear to get more sluggish at lower flow rates?

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Could this be predicted from the graph, Figure 1, for case 2-EP? ___________

Yes. The curve you plotted for Case 2-EP shows a relatively constant slope (process gain) in the upper half of the range, but a lower slope in the lower half.

2. Set the process model and controller tuning parameters as listed above for column 2..

With a the controller in Auto and the same controller tuning as used above, start with a set point of 20%. Make 10% set point changes to 30%, 40%, 50%,60%, 70%, 80%.

The control loop should first appear overly sluggish (for a flow loop), then less sluggish, finally more and more oscillatory as the set point is increased. Do you observe this?

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Does this indicate that for best tuning the controller gain should be increased or decreased at the higher set points ____________________

(For this situation, the controller gain should be decreased to compensate for the higher process gain at higher set points.)

3. We will now repeat parts 1 and 2 of "Confirmation of Interpretation", but this time with a linear valve. Set the process model controller tuning parameters as listed for column 3.

   Put the controller in Auto and set the set point to 20%. When the loop has settled out, change the set point to 30% and observe the response.

   Now change the set point to 70%. When the loop has settled out, change the set point to 80% and observe the response.

   For a 10% set point change, where was the loop the most sluggish, at low operating point or high operating point? ____________________

   Is this predictable from the graph for Case 2-L? __________

   (Yes. The process gain is higher at the lower set point.)

4. Set the process model and controller tuning parameters listed for column 4.

   Put the controller in Auto and set the set point to 20%. When the loop has settled out, change the set point to 30% and observe the response.

   Now change the set point to 70%. When the loop has settled out, change the set point to 80% and observe the response.

   For a 10% set point change, where was the loop the most sluggish, at low operating point or high operating point, or about the same?

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   Is this predictable from the graph for Case 1-L? __________

   (Yes. For this condition, the process gain does not change.)