CONTROL VALVE SIZING FOR OPTIMUM KILN OPERATION

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The purpose of this paper will be to provide some useful guidelines for control valve sizing on your kiln applications.

REQUIRED INFORMATION

Systematic collection of required service conditions is not only helpful but essential in determining the proper sizes of valves needed to meet the range of pressures and flow conditions. The service conditions need to be compiled for minimum, normal and maximum flow conditions. Also, special considerations should be given to start-up and shut-down conditions. If the source pressure will vary, the full range of expected operating conditions should be considered in your valve sizing. First the lowest source pressure with the maximum flow requirement is calculated, then the normal source pressure with the normal flow condition, and lastly the highest source pressure with the minimum flow condition. Taking into account all these different variables will give us the turndown ratio (largest c_v required divided by the lowest c_v required) required by our application. A typical globe valve for a dry kiln would have a turndown of approximately 40:1.

Probably the most controversial subject relating to control valve sizing is pressure drop. The dilemma stacks up this way; on one side we have the process designer who realizes that pressure drop across a valve consumes energy. On the other side we have the instrument engineer who knows that it's this pressure drop that provides the driving force moving the steam through the pipeline. The key is striking a balance between using too small a pressure drop, which would require an unnecessarily large valve, and a large pressure drop which would waste energy, and cost money. Part of our pressure drop considerations should also include any line losses from our source to the valve at each flow rate.

The most widely accepted and most commonly used tool for collection of all this service condition information is a specification sheet (see Attachment 1). This provides us with a permanent record of our original conditions should the need arise to modify any part of the valve sizing requirements. The data sheet should provide space for special considerations to our valve sizing, such as notes regarding cavitation or noise levels and any special piping layouts.

This suggested data gathering technique will lead to better overall valve sizing. However, our sizing will only be as good as the information provided.

INHERENT VS. INSTALLED VALVE CHARACTERISTICS

The flow relationship through a control valve is obtained by contouring the valve internal trim parts so that the flow through the valve follows a predetermined relationship with the valve's travel. This is referred to as inherent valve characteristics. However, the flow through a valve is influenced by more than just the flow area of the valve. If the pressure drop across the valve varies it can cause fluctuations in the flow, even though the valve area is constant. So our flow is a

PROJECT ______	DATA SHEET ______ of ______
UNIT ______	SPEC ______
P.O. ______	TAG ______
ITEM ______	DWG ______
CONTRACT ______	SERVICE ______
•MFR. SERIAL	

No.	Section	Item	Units	Max Flow	Norm Flow	Min Flow	Shut-Off	
1		Fluid				Crit Press PC		
2	SERVICE CONDITIONS	Flow Rate					—	
3		Inlet Pressure						
4		Outlet Pressure						
5		Inlet Temperature						
6		Spec Wt/Spec Grav/Mol Wt					—	
7		Viscosity/Spec Heats Ratio					—	
8		Vapor Pressure P_V					—	
9		*Required C_V					—	
10		*Travel	%				0	
11		Allowable/*Predicted SPL	dBA	/	/	/	—	
12								

No.	Section	Item	No.	Section	Item
13	LINE	Pipe Line Size — In ______	53	ACTUATOR	*Type ______
14		& Schedule — Out ______	54		*Mfr & Model ______
15		Pipe Line Insulation	55		*Size ______ Eff Area ______
16	VALVE BODY/BONNET	*Type ______	56		On/Off ______ Modulating ______
17		*Size ______ ANSI Class ______	57		Spring Action Open/Close ______
18		Max Press/Temp ______	58		*Max Allowable Pressure ______
19		*Mfr & Model ______	59		*Min Required Pressure ______
20		*Body/Bonnet Matl ______	60		Available Air Supply Pressure:
21		*Liner Material/ID ______	61		Max ______ Min ______
22		End Connection — In ______	62		*Bench Range ______ / ______
23		Connection — Out ______	63		Actuator Orientation ______
24		Flg Face Finish ______	64		Handwheel Type ______
25		End Ext/Matl ______	65		Air Failure Valve ______ Set at ______
26		*Flow Direction ______	66		
27		*Type of Bonnet ______	67		Input Signal
28		Lub & Iso Valve ______ Lube ______	68	POSITIONER	*Type ______
29		*Packing Material ______	69		*Mfr & Model ______
30		*Packing Type ______	70		*On Incr Signal Output Incr/Decr ______
31			71		Gauges ______ By-pass ______
32	TRIM	*Type ______	72		*Cam Characteristic ______
33		*Size ______ Rated Travel ______	73		
34		*Characteristic ______	74	SWITCHES	Type ______ Quantity ______
35		*Balanced/Unbalanced ______	75		*Mfr & Model ______
36		*Rated C_V ______ F_L ______ X_T ______	76		Contacts/Rating ______
37		*Plug/Ball/Disk Material ______	77		Actuation Points ______
38		*Seat Material ______	78		
39		*Cage/Guide Material ______	79	AIR SET	*Mfr & Model ______
40		*Stem Material ______	80		*Set Pressure ______
41		______	81		Filter ______ Gauge ______
42			82		
43	SPECIALS/ACCESSORIES	NEC Class ______ Group ______ Div ______	83	TESTS	*Hydro Pressure ______
44		______	84		ANSI/FCI Leakage Class ______
45		______	85		______
46		______	86		
47		______			
48		______			
49		______			
50		______			
51		______			
52					

Rev	Date	Revision	Orig	App

*Information supplied by manufacturer unless already specified.

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ISA FORM S20.50, Rev. 1

Attachment 1. Control Valve Data Sheet

function of both the travel of the valve and the pressure drop.

When control valves are tested at the factory, the pressure drop is held constant so the resulting flow becomes a function of valve travel. The flow curve obtained by holding the pressure drop constant is called the inherent flow characteristic. Figure 1 shows three of the most common inherent flow characteristics.

In most cases the valves are installed in systems where the pressure drop is allowed to change. The resulting flow verses travel relationship is called the installed flow characteristic.

For an example of how the installed flow characteristic can affect the valve's inherent flow characteristics, let's look at a curve for a valve with a linear inherent characteristic. We will assume that our valve is installed in a system where the pressure drop across the valve will increase with flow increases. At low flow and corresponding low valve travel, the pressure drop will also be low. This flow condition is shown by point (a) on the lower flow curve in Figure 2.

As the flow increases the travel increases, and the pressure drop across the valve also increases. Since each of the curves in Figure 2 represents a constant pressure drop, it follows that these new flow conditions must be plotted on one of the higher pressure drop curves as shown by point (b), (c) and (d).

If we connect all these data points together as shown in Figure 2, the resulting installed flow characteristic for this linear valve more nearly matched the equal percentage characteristic.

If the pressure drop were to change with flow in a different way, the resulting flow characteristic will also be different. Figure 3 shows that the same valve will exhibit a type of quick opening characteristic when it is installed in a system where the pressure drop across the valve decreases as flow increases.

The important issue here is that there can be many different installed flow characteristics for any given valve. In order to really understand the type of flow characteristic that any given valve will exhibit in a system it is essential that you understand the flow vs. drop characteristics of the entire system.

PULLING IT ALL TOGETHER

Now that we all fully understand what information is required and why, just what do we do with all this accumulated information? As far as valve sizing is concerned our options are:

1. Work the formulas out long hand, yuk!
2. Valve sizing slide rules.
3. Old magnetic tape type calculators.
4. Personal computer.

EXAMPLE VALVE SIZING CALCULATION

Figure 4 shows a portion of a typical data sheet for a kiln application. Using the Neles-Jamesbury control valve sizing program as an example of a modern sizing program, we enter the given process data into the computer. Figure 5 is a screen print of what appears on the screen after entering the data and performing the calculation. Many sizing programs, including the Neles-Jamesbury program, automatically enter the ratio of specific heats for steam, the saturation temperature, given the pressure, and the density based on the pressure and temperature. If you are using a program that does not calculate these values or if you are performing hand calculations, you must obtain them from a steam table. The Neles-Jamesbury

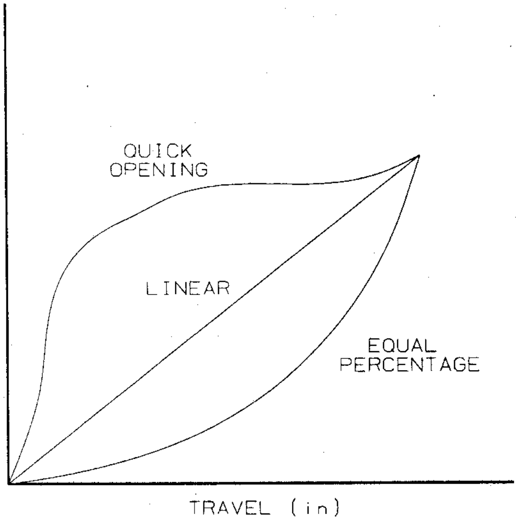


Figure 1. Common inherent flow characteristics for valves.

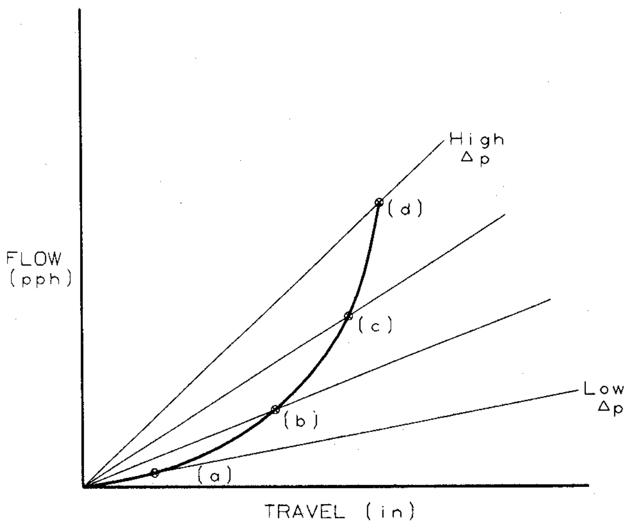


Figure 2. Installed flow characteristic of a linear valve (bold line) for the case where pressure drop increases with flow. Also shown is the inherent flow characteristic at several constant pressure drops.

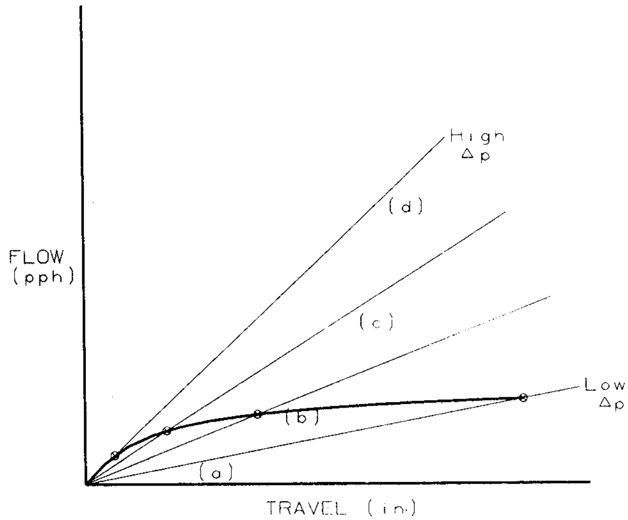
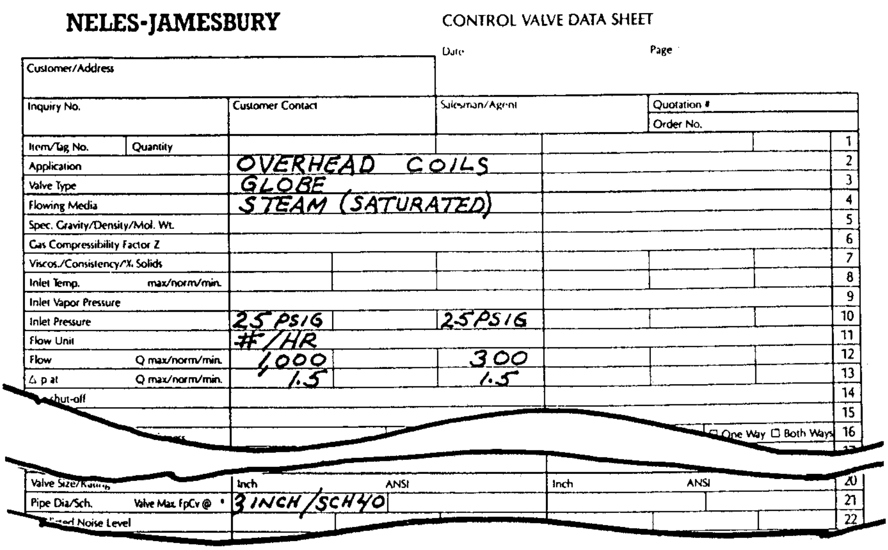


Figure 3. Installed flow characteristic of a linear valve (bold line) for the case where pressure drop decreases with flow. Also shown is the inherent flow characteristic at several constant pressure drops.



NELES-JAMESBURY CONTROL VALVE DATA SHEET

Date Page

Customer/Address				
Inquiry No.	Customer Contact	Salesman/Agent	Quotation # / Order No.	
Item/Tag No. / Quantity				1
Application	OVERHEAD COILS			2
Valve Type	GLOBE			3
Flowing Media	STEAM (SATURATED)			4
Spec. Gravity/Density/Mol. Wt.				5
Gas Compressibility Factor Z				6
Viscos./Consistency/% Solids				7
Inlet Temp. max/norm/min.				8
Inlet Vapor Pressure				9
Inlet Pressure	25 PSIG	25 PSIG		10
Flow Unit	#/HR			11
Flow Q max/norm/min.	1,000	300		12
Δ p at Q max/norm/min.	1.5	1.5		13
…shut-off				14
				15
			☐ One Way ☐ Both Ways	16
Valve Size/Rating	Inch ANSI		Inch ANSI	20
Pipe Dia/Sch. Valve Max FpCv @	3 INCH/SCH40			21
…Noise Level				22

Figure 4. Control valve data sheet for kiln heat valve.

program, along with the programs issued by some other manufacturers, contains tables of valve c_v versus percent opening for various valve styles. We have entered trim code V1SL which is the code for a model V1S stem-guided globe valve with linear trim. Since the valve will be installed in a three-inch line, the most likely possibilities for the selected valve size are three-inch, two-inch or one-and-one-half-inch. We begin by entering a trial valve size of three-inch. When all of the required information has been entered, the computer displays the calculated results which appear below the line in Figure 5.

The "rated capacity F_pC_v" is the capacity of the selected valve size and style at 100 percent open when the reduction in capacity caused by any pipe reducers that may be attached to the valve is taken into account.

The "calculated capacity F_pC_v" is the flowing capacity required of the valve (and any attached pipe reducers) at each of the specified flow conditions.

The "percent of full travel" calculations makes it unnecessary for us to consult tables of valve c_v versus valve opening to determine what percentage of opening the valve will be operating at, at each of the specified flow conditions. In the case of the three-inch Model V1S globe valve, the opening range of approximately 15.2% at minimum flow and 35.8% at maximum flow indicate that although the three inch valve would work, it is probably oversized and we should see if a smaller (and less expensive) valve would also work. As a rule of thumb, many engineers try to select a valve that operates over a range of 20% to 80 or 85% open from minimum to maximum flow.

The "sound pressure level" is a measure of the noise generated by the valve. Most users try to keep noise below 85 or 90 dBA. In this case, the noise is quit low.

The "fluid velocity (outlet)" is the velocity, expressed as a Mach number in the outlet of the valve body. Outlet velocities exceeding 0.5 Mach should be avoided as they generate high noise levels which are in addition to the noise calculated in the "sound pressure level" calculation.

The "x_{tp}*k*p_1 / 1.4" calculation is the pressure drop at which flow would become fully choked in the valve due to reaching sonic velocity at the vena contracta.

Because the three inch valve is only using the lower end of its range, we will continue by trying a two-inch valve. Figure 6 is a screen print of the computer after performing the calculation (the only change is to the valve size). The opening range (percent of full travel) of 24.4% to 68.7% from minimum to maximum flow uses a greater portion of the valves range and would be a better choice than a three-inch valve, both because it would cost less and also because it would be able to give smoother, more accurate control.

Checking a one and one half inch valve (Figure 7) shows that it does not have sufficient capacity to handle the maximum flow condition.

If you were using a computer program that does not include built in tables of c_v versus percent opening, or if you were using a slide rule or doing the calculations by hand, the procedure would be to first determine the required range of c_v from minimum to maximum flow (see the top portion of Figure 8) and then look at the tables of c_v versus opening published by the valve manufacturer. The table at the bottom of Figure 8 is a typical c_v table. The required c_v range of 12.77 at minimum flow and 42.58 at maximum flow would result in a three-inch valve operating between about 15% and 35% open and a two-inch valve operating between about 25% and 68% open. A one-and-one-half-inch valve has a maximum capacity of 36 and therefore could not meet the maximum flow requirement of 42.58. These results agree with the percent open calculations of Figures 5, 6, and

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NELSIZE  STEAM SIZING                         press <F1> for helplines

Pipe     inlet diameter   in.  3.000      thickness        in.
         outlet           in.  3.000      or schedule no.       40

Fluid    description           SATURATED STEAM
         ratio of sp. heat     1.300


Flow rate                 lb/h 1000.0     300.00
Upstream  temperature     degF 267.26     267.26
          pressure        psiA 40.000     40.000
          density        lb/ft30.095      0.095
Pressure  differential    psi  1.500      1.500
Valve  V1SL    size in.3       SERIES V1S LINEAR GLOBE VALVE
------------------------------------------------------------------
rated capacity FpCv            123.00
calculated capacity  FpCv      42.58      12.77
percent of full travel         35.829     15.180
sound pressure level     dBA   57.7       50.3
fluid velocity (outlet)Mach    0.038      0.011
Xtp*k*P1 / 1.4            psi  28.416     28.600


 Size ( /reduction). Type L to get a list
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Figure 5. Screen output from valve-sizing program executed for a 3-inch valve.

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NELSIZE  STEAM SIZING                         press <F1> for helplines

Pipe     inlet diameter   in.  3.000      thickness        in.
         outlet           in.  3.000      or schedule no.       40

Fluid    description           SATURATED STEAM
         ratio of sp. heat     1.300


Flow rate                 lb/h 1000.0     300.00
Upstream  temperature     degF 267.26     267.26
          pressure        psiA 40.000     40.000
          density        lb/ft30.095      0.095
Pressure  differential    psi  1.500      1.500
Valve  V1SL    size in.2       SERIES V1S LINEAR GLOBE VALVE
------------------------------------------------------------------
rated capacity FpCv            60.12
calculated capacity  FpCv      42.69      12.78
percent of full travel         68.759     24.419
sound pressure level     dBA   57.9       50.4
fluid velocity (outlet)Mach    0.085      0.026
Xtp*k*P1 / 1.4            psi  25.994     28.600


 Size ( /reduction). Type L to get a list
```

Figure 6. Screen output from valve-sizing program executed for a 2-inch valve.

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NELSIZE  STEAM SIZING                          press <F1> for helplines

Pipe      inlet diameter   in.   3.000        thickness       in.
          outlet           in.   3.000        or schedule no.      40

Fluid     description            SATURATED STEAM
          ratio of sp. heat      1.300


Flow rate                  lb/h 1000.0        300.00
Upstream   temperature    degF  267.26        267.26
           pressure       psiA  40.000        40.000
           density       lb/ft30.095          0.095
Pressure   differential    psi   1.500        1.500
Valve   V1SL   size in.1.5       SERIES V1S LINEAR GLOBE VALVE
-----------------------------------------------------------------------
rated capacity FpCv              32.30
calculated capacity  FpCv                     12.78
percent of full travel           too small 39.928
sound pressure level     dBA                  50.4
fluid velocity (outlet)Mach                   0.045
Xtp*k*P1 / 1.4             psi                28.362


 Size ( /reduction). Type L to get a list
```

Figure 7. Screen output from valve-sizing program executed for a 1.5-inch valve.

Tag #		CONDITION 1	CONDITION 2
Flow (mass)	#/hr	1000.00	300.00
Inlet Press Abs	psia	40.00	40.00
Delta P	psi	1.50	1.50
Terminal DP Ratio	Xt	0.70	0.70
Inlet Temp	Deg F	saturated	saturated
Line Size	inch	3.00	3.00
Pipe Schedule		40	40
Valve Size	inch	0.00	0.00
Saturation Temp	Deg F	267.21	267.21
Specific Vol.	ft^3/lb	10.49	10.49
Delta P Choked	psia	26.57	26.57
Required Cv		42.58	12.77
SPL	dBA	SPL < 75	SPL < 75
Valve Type		Linear Globe	Linear Globe

OPTIONS: <T>, <N>, <D>, <P>, <Q> <F1> - HELP

NELES-JAMESBURY SERIES V1S GLOBE VALVE
LINEAR FLOW CHARACTERISTIC

SIZE	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
1"	0.6	2.3	4.2	6.3	8.2	10	13	15	18	19
1-1/2"	1.2	5.2	9.6	13	17	21	25	29	32	36 TOO SMALL
2"	2.5	9.5	17	24	30	37	45	53	59	64
3"	5	20	35	48	61	75	91	105	115	123

Figure 8. Example using computer program that does not calculate c_v as a function of valve position. This information is obtained from the table in the lower portion of the Figure.

INSTALLED FLOW CHARACTERISTIC

The Neles-Jamesbury program has the unique capability of plotting the installed flow characteristic of a valve. For most processes, the installed characteristic of the control valve plus the rest of the system should be linear. When the pressure drop across the valve remains constant with changing flow, the installed characteristic will equal the inherent characteristic. A valve with a linear characteristic was chosen for the sizing example because the specified pressure drop remained constant, and an overall linear installed characteristic was desired. The upper portion of Figure 9 shows the installed characteristic of the two inch linear valve of Figure 6, which is linear as expected. The lower portion of Figure 9 shows the installed gain, which is simply the slope of the installed flow characteristic at any particular point. An ideal, perfectly linear installed flow characteristic would have a constant gain at all flow rates. It is extremely difficult to manufacture a perfectly linear valve, and the variation in gain with flow is the result in slight variations in the slope of the valve's flow characteristic. As a rule of thumb we try to select a valve whose installed characteristic is reasonably linear throughout the specified flow range as evidenced by an installed gain that remains within the range of 0.5 and 2. Figure 9 indicates that the selected linear two-inch valve meets this criteria.

Figure 10 shows the resulting installed flow characteristic if we had misapplied an equal percentage trim valve. The installed flow curve is quite non-linear. The installed gain curve shows just how non-linear the installed flow characteristic is. Five of the nine points which are always plotted have gone completely off the scale. So that we can tell how far off the scale we have gone, the program always lists to the left of the installed gain curve what the maximum gain is. In this case it is 3.5 on a gain scale which cuts off at 2.5.

It is mentioned previously that if the pressure drop varies with flow, the installed characteristic will be different than the valve's inherent characteristic. If instead of a constant pressure drop of 1.5 psi across the valve, the pressure drop varies from 1.5 psi at maximum flow to 5 psi at minimum flow, the equal percentage valve of Figure 10 would take on the installed flow characteristic shown in Figure 11. Over the specified flow range of 300 pounds per hour to 1,000 pounds per hour (the area enclosed by the vertical dotted lines on the graph) the installed flow curve is quite linear. The gain or slope of the flow curve over the specified flow range is between 1 and 2 which satisfies our rule of thumb criteria for linearity (that is gain between 0.5 and 2). This indicates that the combination of the equal percentage valve and the pressure drop which decreases with increasing flow yields the desired linear installed flow characteristic.

If we were to misapply a linear valve in the system where pressure drop decreases with increasing flow the resulting installed flow characteristic would be that of Figure 12. Here the installed flow characteristic is non-linear in the direction of being quick opening. The first four points off the gain curve are so high as to be off the scale, with the maximum gain given at the left side of the graph as 2.9.

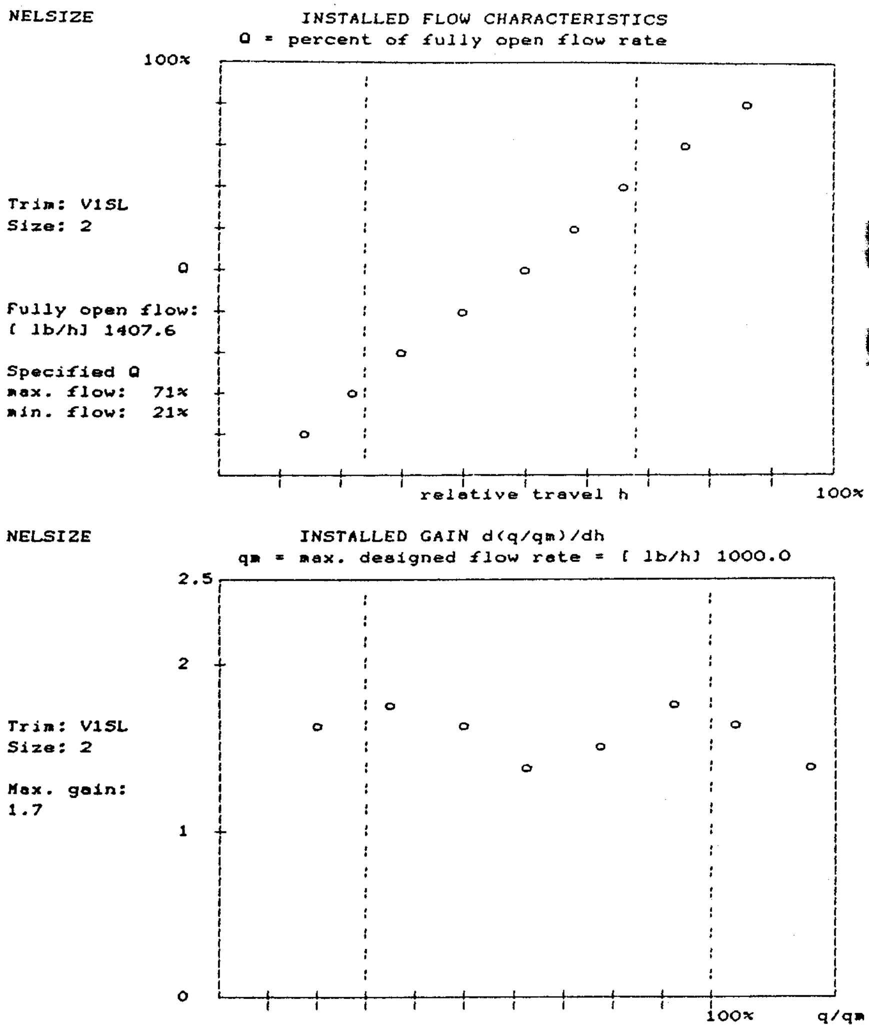
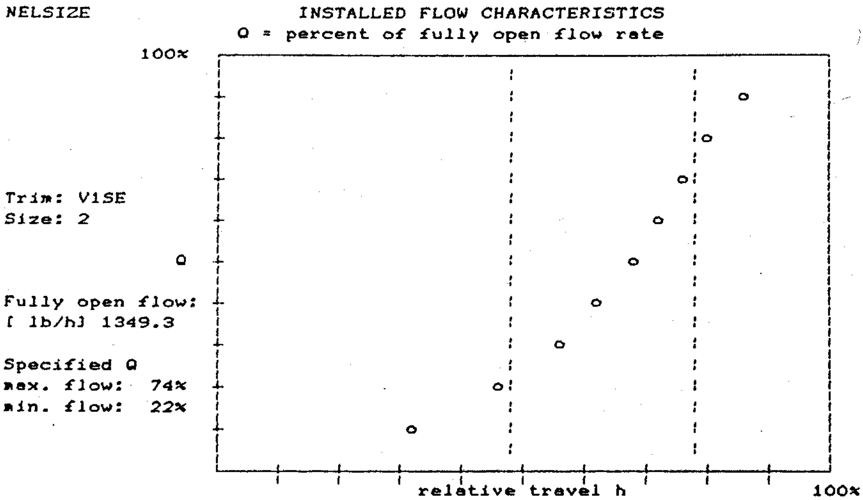


Figure 9. Upper: Installed flow characteristic of linear valve in Figure 7. Lower: Installed gain for same valve.



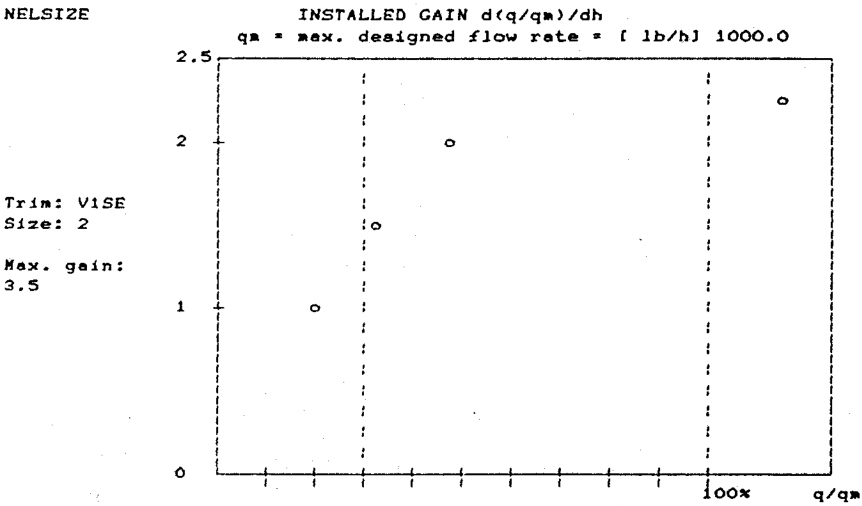


Figure 10. Improper use of a valve results in non-linear installed flow characteristics (upper) and gains outside the desired range of 0.5 to 2.0. Five of the nine points are off the plot.

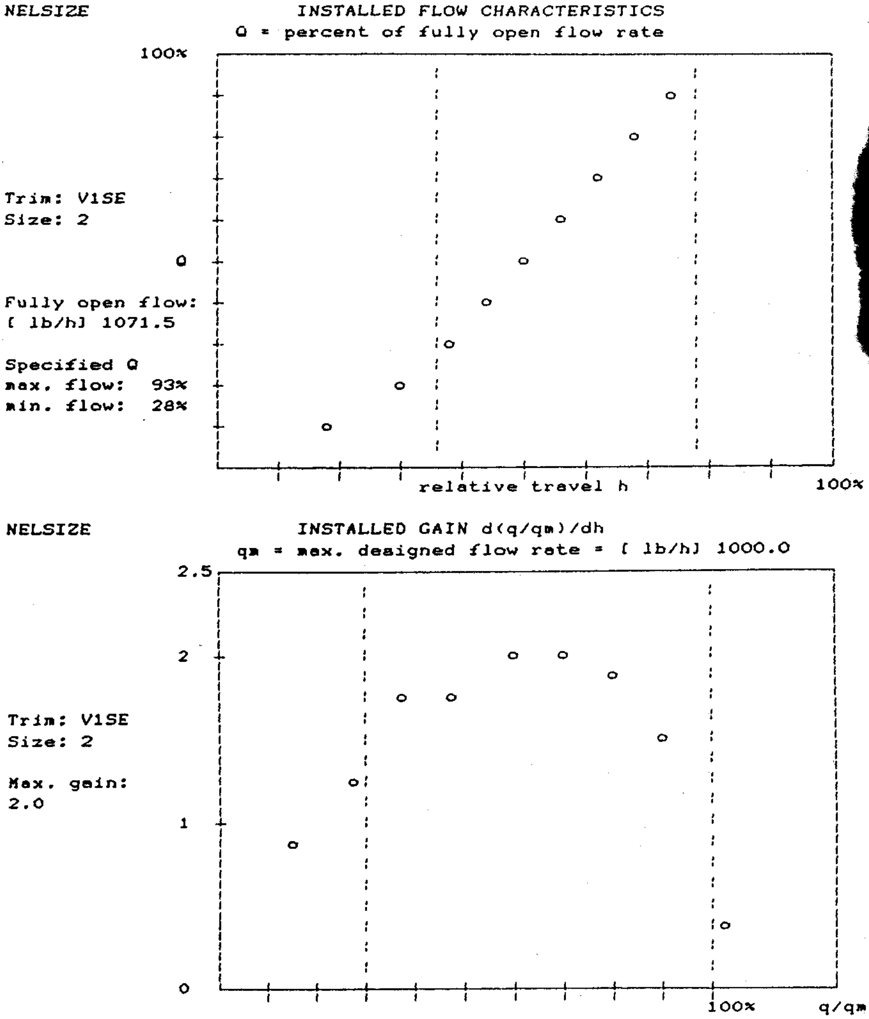
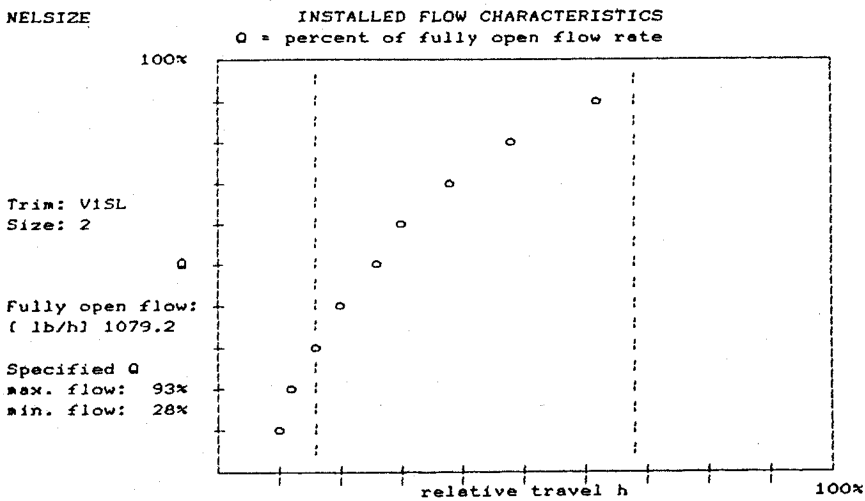


Figure 11. Installed flow characteristic of valve from example in Figure 10 except with 1.5 psi and 5 psi pressure drops at maximum and minimum flows, respectively.



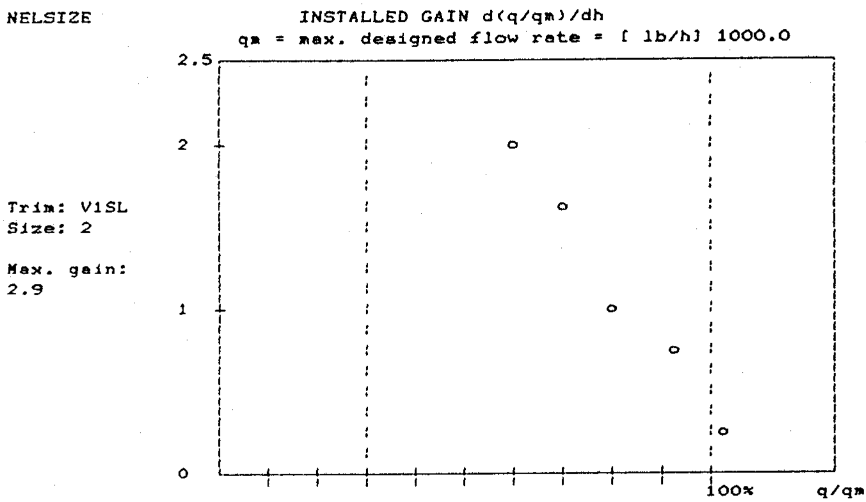


Figure 12. Installed flow characteristic for a linear valve misapplied to a system where pressure drop decreases with increasing flow.