BROWN INDUSTRIES, INC.

GGBL Building

Ann Arbor, MI 48109-2136

DATE: December 31, 2001

TO: Dr. Scott Fogler, Plant Manager.

FROM: Pablo LaValle, Plant Engineer.

SUBJECT: Process Control Simulator Valve Characteristics.

As you verbally requested in August 2001, I have generated data on the flow characteristics of the pneumatically-actuated steam flow-control valve installed in the process control simulator located in room 3000 G.G. Brown.

This valve is a direct-acting (air to open) 1/2-inch Pick brand, model 32-24588 with pneumatic actuator. The actuator is controlled by an electronic signal from the controller. The nominal control range for this actuator is 3 to 15 psig, corresponding to 1 to 9 volts signal respectively, with 1 volt corresponds to a fully closed valve and 9 volts corresponding to a fully open valve.

The valve was characterized using steam at various pressures and valve positions. The steam pressure was monitored with the installed pressure sensor connected to the computer data acquisition and the valve position was adjusted by selecting the desired voltage with the open-loop control program. The flow of cold water to the heat exchanger was set to the maximum possible to allow for the condensation of the steam flow to be measured. The steam flow was measured after it condensed as the overflow of liquid leaving the recirculating loop. An attempt was made to characterize the valve using a model presented in Coughanowr[1] and Perry's[2].

$$m = \frac{q}{q_{\max}} = f\left(\frac{L}{L_{\max}}\right) \qquad 1$$

Where:
m = Fractional flow
L = Valve stem travel
$L_{\max}$ = Maximum valve travel (fully open valve)
q = Steam flow rate (at a valve position L)
$q_{\max}$ = Maximum steam flow rate (in a fully open valve)

The value of $L/L_{\max}$ is directly proportional to the output voltage from the controller with $L/L_{\max} = 0$ for V = 1 volt; and $L/L_{\max} = 1$ for V = 9 Volts.

The maximum flow rate $q_{\max}$ is a function of the steam supply pressure and it was measured at various steam pressures with the control valve fully opened. Figure 1 is a

[1] Process systems analysis and control, Donald R. Coughanowr, second edition, equation 20.4.
[2] Chemical engineers handbook, R.H. Perry, D.W. Green, seventh edition, Figure 8-82.

graph representing the maximum flow of steam as a function of steam supply pressure (psig). The model for this flow is shown in equation 2.

$$q_{\max} \approx \sqrt{16.7(P - 9.6)} \qquad 2$$

Where:

P = Steam pressure in psig

$q_{\max}$ = Steam flow in a fully open valve in grams per second

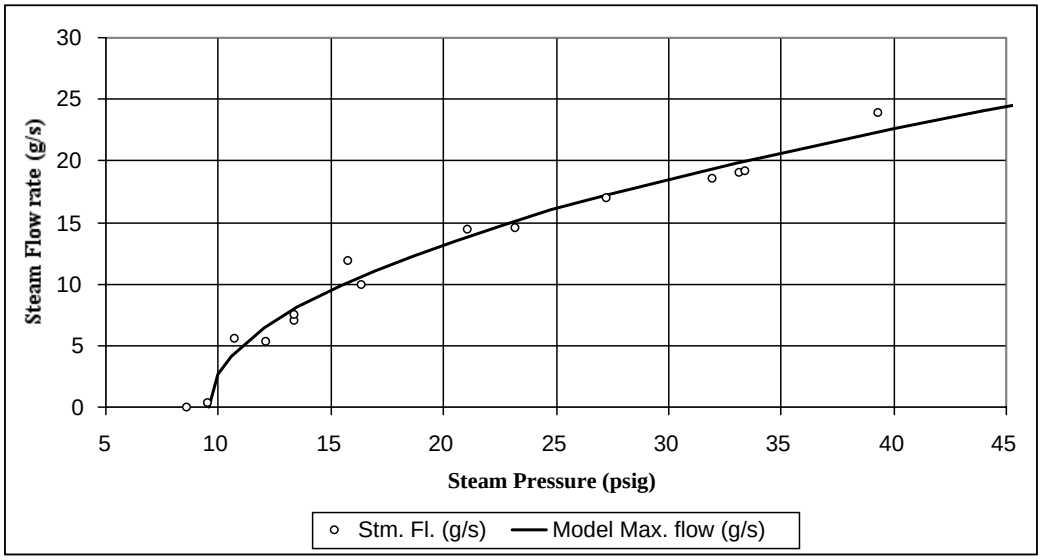

Figure 1: Maximum steam flow rate as function of steam supply pressure

Equation 2 was used in all the test measures to calculate the value of $q_{\max}$ and thus the value of fractional flow q/ $q_{\max}$. Figure 2 is a plot of fractional flow vs. valve position. Table 1 shows the test data as well as the calculated steam flow rates.

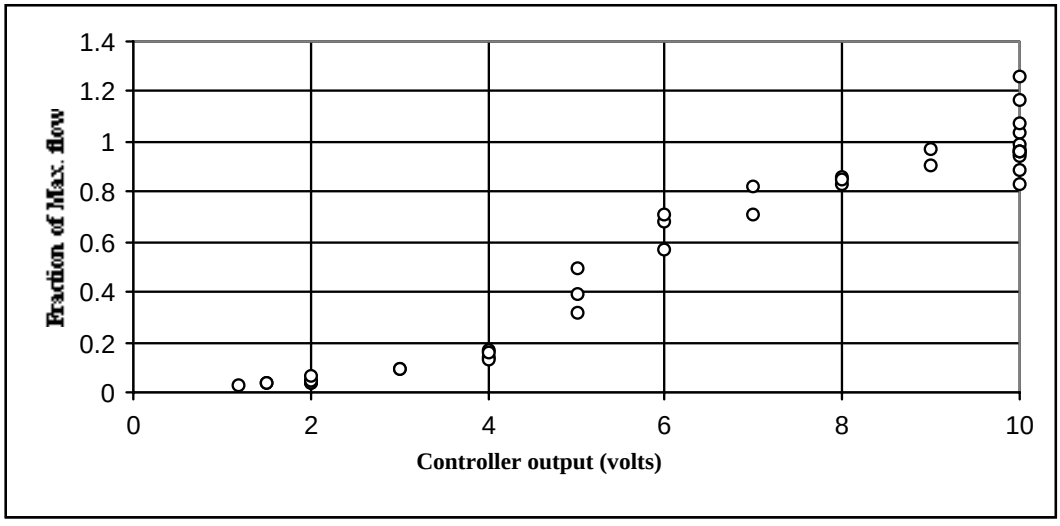

Figure 2: Fraction of Maximum flow vs. controller output

Table 1: Test data for Steam valve characteristics.

Controller output (volts)	Steam pressure (psig)	Weight of condensate (g)	Time of collection (s)	Steam mass flow rate (g/s)
10	10.72	322.8	58.26	5.54
10	15.74	407.1	34.25	11.89
10	21.08	428.4	29.68	14.43
10	27.21	422.9	24.87	17.00
10	33.1	822.4	43.21	19.03
10	39.32	844	35.25	23.94
10	33.38	854.3	44.56	19.17
10	23.15	813.5	55.59	14.63
10	16.33	607.6	60.69	10.01
10	13.33	451.9	63.84	7.08
10	12.07	331.8	61.84	5.37
10	8.6	0	30	0.00
10	9.48	61.5	147.32	0.42
10	13.33	472.4	62.25	7.59
9	13.51	468.3	63.43	7.38
8	13.2	717.7	106.9	6.71
7	13.42	453.5	68.44	6.63
6	13.55	403	69.59	5.79
5	13.92	312.4	73.84	4.23
4	13.11	276	210.58	1.31
3	14.5	103.6	123.38	0.84
2	13.62	40.5	72.22	0.56
4	13.1	115.5	93.31	1.24
6	13.59	348.3	61.97	5.62
8	13.15	336.1	50.79	6.62
8	33.8	620.6	37.03	16.76
10	31.9	577.4	31.13	18.55
9	33.08	628	32.55	19.29
7	36.94	595.2	39.38	15.11
6	33.7	569	49.41	11.52
5	33.87	519.6	66.39	7.83
4	33.95	175.6	67.19	2.61
3	33.43	116.2	64.84	1.79
2	32.57	146.1	152.47	0.96
2	48.9	90.6	71.38	1.27
5	47.3	343.1	42.97	7.98
4	52.9	249.9	65.37	3.82
2	52.78	71.9	65.94	1.09
1.5	54.26	84	85.25	0.99
2	53.8	67.7	63.6	1.06
1.5	53.2	78.6	82.6	0.95
1.2	53.5	84.5	98.31	0.86

This data can be made available electronically if requested.

No attempt was made to create a mathematical model for the fractional flow shown in figure 2 because I am not sure what form of model the users of this information will need. Please let me know if any more work is required in this project.

Measures of steam flow below 1.2 volts are unreliable due to valve hysteresis. Flows can be measured with voltages as low as 0.8 V when the valve is closing and no flow will occur with voltages below 1.2 V when the valve is opening.