STEALTH INTERNATIONAL INC.

DESIGN REPORT #1001

IBC ENERGY DISSIPATING VALVE

FLOW TESTING OF 12" VALVE

This report will discuss the results obtained from flow testing of a 12" IBC valve at Alden Research labs, conducted on July 18-19, 2006. Testing was performed to determine the flow coefficients and pressure recovery factors for standard and enhanced plate designs. Comparison of test results is made to computational fluid dynamics (CFD) modeling results performed on the same valve design. Validation to the accuracy of computer modeling results is achieved. A discussion of hydraulic performance, cavitation indices, and end of line conditions is also presented.

1. Description of Testing

1.1. Testing Layout

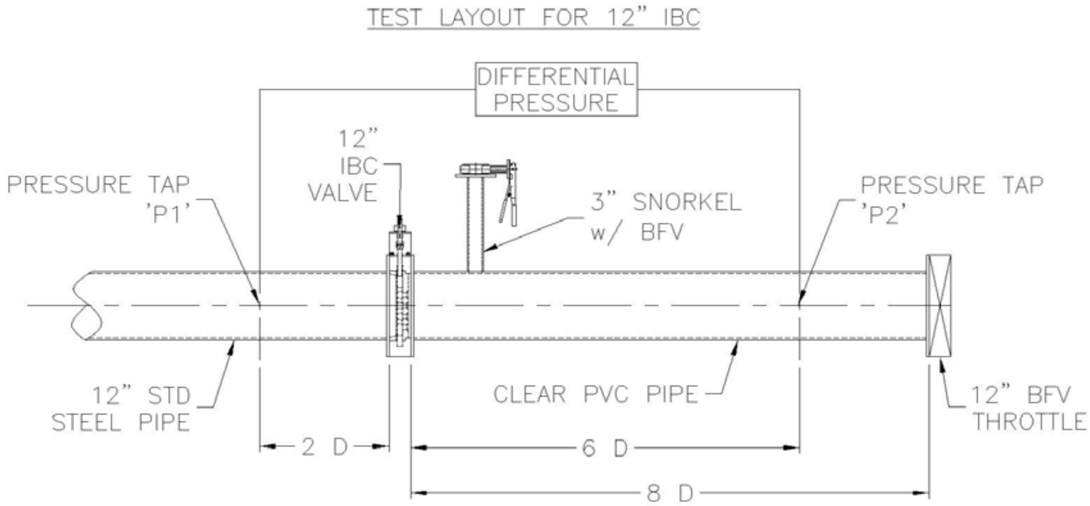

Figure 1 – Test Section Layout

The figure above depicts the test layout used at Alden labs. A 12 inch prototype IBC valve was installed with a clear pipe spool downstream, the clear PVC enabled videos to be taken of the flows emerging from the IBC valve. For end of line and free discharge testing, a 3 inch diameter standoff (snorkel) was used for air intake. During in-line testing the air intake was isolated using a butterfly valve. Two sets of plates were used for the 12 inch IBC valve. One set was the standard design of tapered orifice holes. The other set was of the enhanced flow design, incorporating slots to increase available flow area by 15 percent. Further discussion of the plate styles will follow in the results section.

Testing for flow coefficients and pressure recovery factors was performed in accordance with ANSI/ISA S75.02-1996 "Control Valve Capacity Test Procedures". Differential pressure was measured using a transmitter connected at the pressure tap locations shown in the figure above. Flow rates were measured using the gravimetric method (weigh tank). Further description of the testing instruments, accuracy, and piping layout can be found in the Alden lab report.

1.2. In-Line Testing Procedure

Flow coefficients were determined by measuring flows with three different pressure drops applied across the IBC valve (5, 10 & 15 psi). These measurements were repeated at each 10% increment of valve opening, from 100%-10% of total valve stroke, for both sets of plates. Pressure recovery factor was determined by holding the upstream pressure fixed at 40 psig and throttling the downstream butterfly valve to decrease the pressure drop until maximum flow was achieved. Flow rate measurements were taken at several pressure drops to determine when maximum flow was reached. Videos were taken of the clear pipe spool during maximum flow conditions, to visualize the amount of cavitation present.

1.3. End-of-Line Testing Procedure

The piping layout was modified such that the downstream pipe would discharge freely into the weigh tank. Flow rates were measured for the air intake closed and open. These measurements were taken with the IBC valve 90% and 50% open, for both sets of plates. Videos were taken of the clear pipe spool to visualize the change in flow profile, as well as the flow pattern emerging from the IBC valve.

2. Test Results

A presentation is made of the final results from the Alden lab report. All formulas and methods for data evaluation are from ANSI/ISA S75-02-1996. More description of the coefficients and theory can be found in ANSI/ISA S75.01 "Flow Equations for Sizing Control Valves".

2.1. Flow Coefficient - C_v

Valve flow coefficients were calculated from measurements of flow and head loss. Preliminary data from Alden included the calculated flow coefficients for each test run. An average coefficient was taken from the three runs for each opening increment and each style of plate. Table 1 below lists these flow coefficients and Figure 2 show the two plate styles. The enhanced plate has 15% greater flow area, compared to the standard plate. The resulting increase in flow coefficient is given in Table 2. Area ratio as shown in figure 2 is the ratio of flow area (total holes) to nominal area (valve size).

Opening %	Standard Cv	Enhanced Cv	Increase %
100	894	1034	15.7
90	844	961	13.9
80	708	795	12.3
70	510	602	18.0
60	322	420	30.4
50	194	275	41.8
40	111	166	49.5
30	52.1	88.5	69.9
20	14.4	33.2	130.6
10	0.34	4.23	1144.1

Table 1 – Flow Coefficients for Standard and Enhanced Plate Designs.

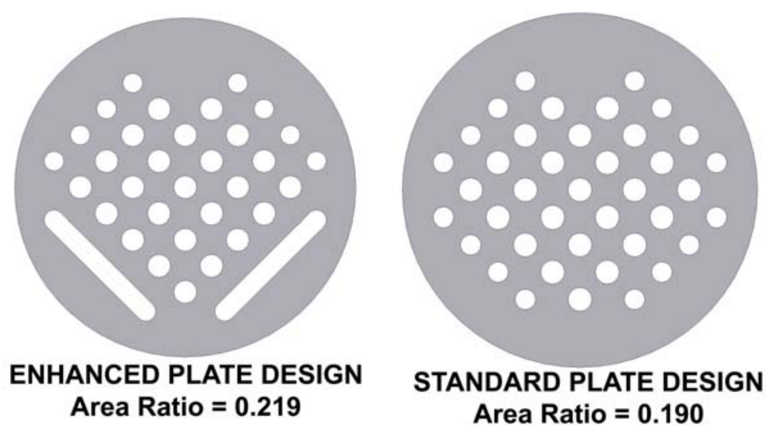

Figure 2 – Standard and Enhanced Plates

2.2. Valve Characteristic

Figure 3 below is a graphical representation of the data from Table 2. From ANSI/ISA S75.02 the tolerance on calculated flow coefficients is +/- 5% as indicated by the error bars in figure 3. From the shape of the curves, it can be seen that the IBC valve characteristic is not purely linear or equal percentage. Instead the IBC valve characteristic can be described as equi-linear, showing equal percentage at the ends of travel and a nearly linear characteristic in between. For the range of valve opening from 50-90% the flow curve is roughly linear. This range is the ideal control range for operating the IBC valve. Figure 4 shows the plot of characteristic curve for the valve with standard plates. A line of best fit is shown in the control range along with the corresponding equation.

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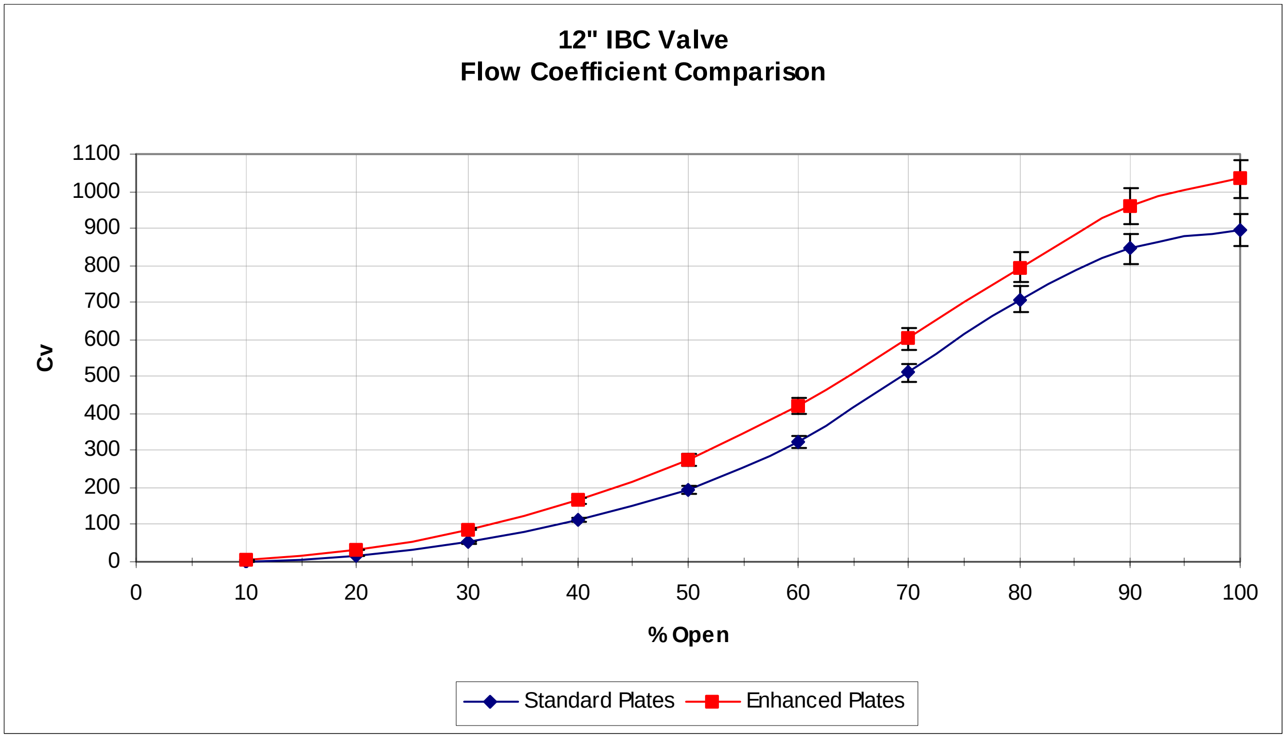
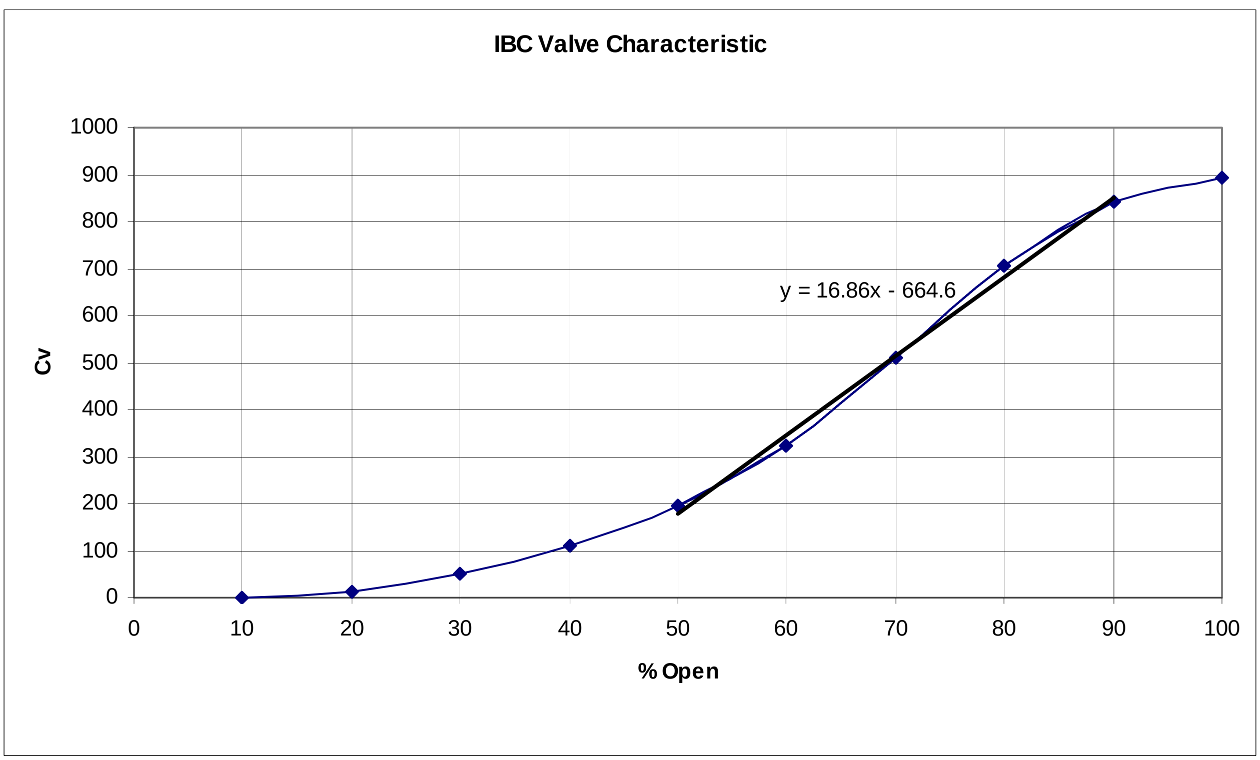


Figure 3 (above) – IBC Valve Characteristic Curves, both plate designs

Figure 4 (below) – IBC Valve Characteristic Curve with Linear Fit, Standard Plate



2.3. Liquid Pressure Recovery Factor - F_L

Liquid pressure recovery factor was determined by finding the maximum flow through the fully open valve with upstream pressure held constant. Test line configuration restricted the upstream pressure to be held at 40 psig. Downstream pressure was varied until changing the pressure drop produced no increase in flow. Flow measurements were taken in this range of pressure drops to verify that maximum flow has been established. By plotting the flow rate against the square root of pressure drop a plateau is seen in the flow curve. Figures 5 and 6 below show the flow curve plots for standard and enhanced plate designs, respectively.

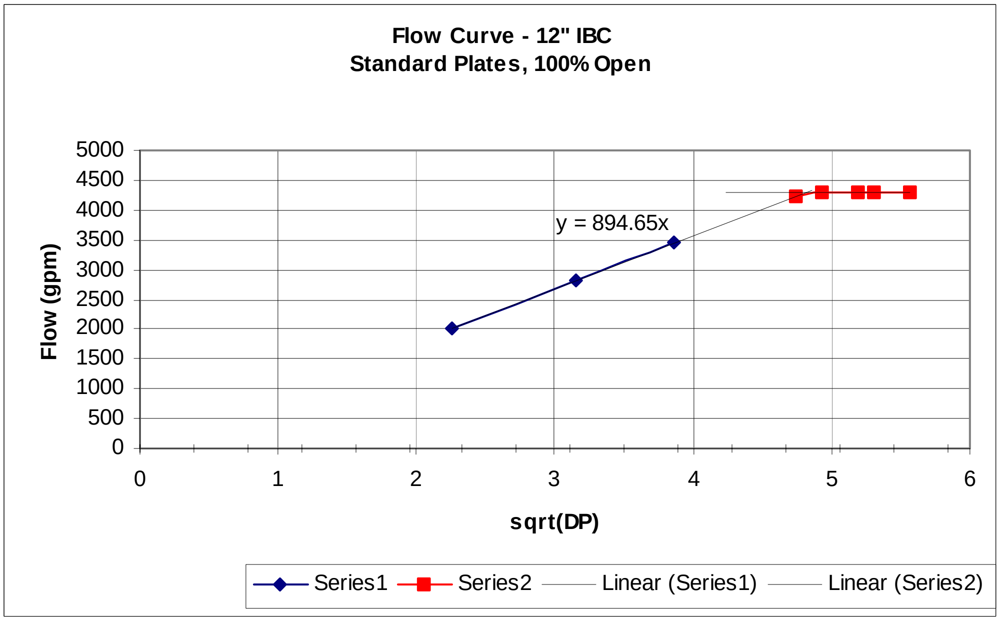
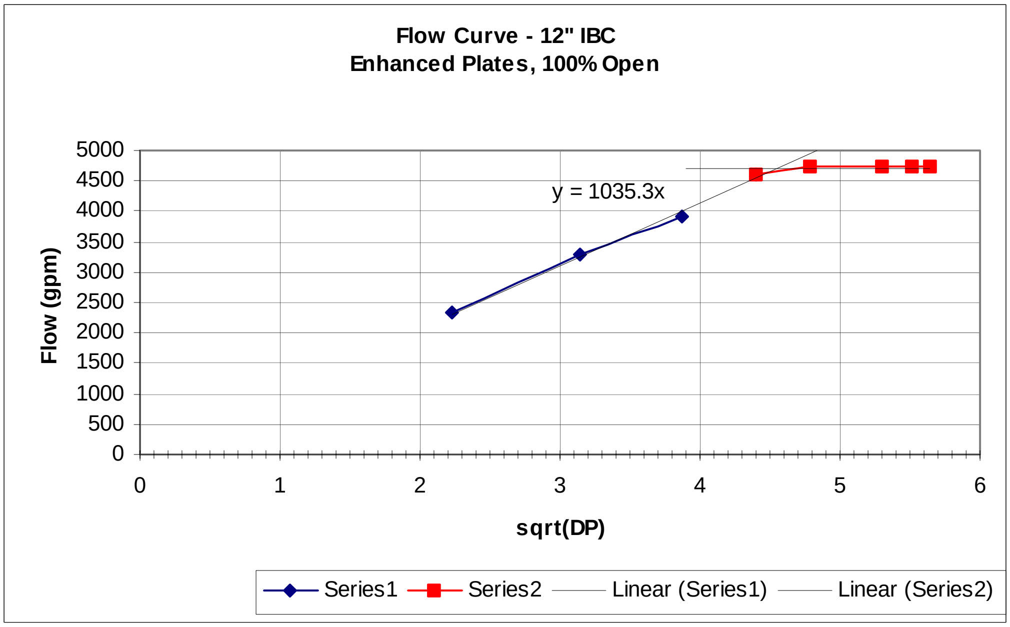


Figure 5 (above) – Flow Curve for Standard Plates

Figure 6 (below) – Flow Curve for Enhanced Plates



The linear portion of the flow curve has a slope equal to the flow coefficient of the valve. The plateau corresponds to the maximum flow rate of the valve. The intersection of these two lines occurs at the allowable pressure drop. Tables 2 and 3 below show data used for plotting the flow curves. Calculated liquid pressure recovery factor for the standard plate design is 0.65. For the enhanced plate design, the calculated pressure recovery factor is 0.62. The enhanced plate design offers better pressure recovery because of the reduced resistance to flow from the slots.

	Q (gpm)	DP (psi)	sqrt(DP) (psi^-0.5)	Cv	σ (P2-Pv)/DP
Series 1	2024	5.084	2.254773	898	9.689
	2821	9.924	3.150238	895	4.476
	3441	14.846	3.853051	893	2.661
Series 2	4242	22.494	4.742784	894	1.416
	4295	24.368	4.936395	870	1.230
	4306	26.984	5.194613	829	1.014
	4306	28.107	5.301604	812	0.933
	4306	30.97	5.56507	774	0.755

Table 2 – Flow Curve Data, Standard Plate Design

	Q (gpm)	DP (psi)	sqrt(DP) (psi^-0.5)	Cv	σ (P2-Pv)/DP
Series 1	2340	4.989	2.233607	1048	9.893
	3287	9.869	3.141496	1046	4.507
	3914	15.01	3.874274	1010	2.621
Series 2	4604	19.377	4.401931	1046	1.805
	4726	22.849	4.780063	989	1.378
	4730	28.06	5.297169	893	0.937
	4730	30.401	5.51371	858	0.788
	4735	31.762	5.635779	840	0.711

Table 3 – Flow Curve Data, Enhanced Plate Design

2.4. End-of-Line Flow Coefficient

The IBC valve with enhanced plates was run with the pipe end discharging freely into the weigh tank. The purpose of this testing was to demonstrate the effect on flow coefficient for the IBC valve in end-of-line conditions. Air intake was controlled to the downstream spool piece using a butterfly valve. Flows were measured for 90% and 50% openings with the air intake valve open and closed. Results are presented in table 4 below. For end-of-line conditions with air valve open the flow coefficient was 15% lower. With the air valve closed the flow coefficient was 3% higher, although the flow was unsteady and pulsating. Further discussion of these results will follow in the next section.

Open %	Air Intake	End-of-Line Cv	In-Line Cv	Diff %
90	Open	828	961	-16.1
90	Closed	986	961	2.6
50	Open	238	275	-15.5
50	Closed	284	275	3.2

Table 4 – Flow Coefficient Comparison for End-of-Line Conditions

3. Discussion

3.1. Hydraulic Performance

As water flows through the IBC valve it is divided into an array of jets via tapered orifices. Fluid acceleration through the orifices causes pressure drop. Minimum pressure occurs in the vena contracta at the throat of each individual jet. Downstream of the IBC valve, jet interaction and turbulent mixing occurs as the individual jets combine within the recovery zone. Pressure recovery occurs as the combined jet is slowed and dissipated from resistance of the downstream fluid and mixing interaction. Length of the recovery zone is approximately 2 pipe diameters, as observed during the tests. Flow coefficient is used to determine the amount of permanent pressure drop for a given flow rate. Pressure recovery is represented by the liquid pressure recovery factor. Both terms are important for sizing the IBC control valve.

Comparing the results between standard and enhanced plates, it can be seen that increasing the available flow area with slots will increase the flow coefficient. At 100% open the percentage increase in flow coefficient is roughly the same as the percentage of increased area. A computer model of the 12" valve with standard plates was simulated using CFD. Flow coefficient calculated from the model results was found to be 923, deviating from the test results by 3.2%. Validation of computer results was achieved showing accuracy of the computer model.

To optimize energy dissipating requirements of the IBC valve we would need to raise the pressure recovery factor. By reducing the hole diameter and increasing the number of holes we can achieve higher permanent pressure loss. As a tradeoff, controllability is reduced for smaller hole diameters since valve travel is smaller. Further CFD models shall study various hole patterns to increase pressure recovery factor and flow coefficient. Results from flow testing can be scaled for other valve sizes if geometric similarity of the plates is maintained. CFD studies will be conducted for alternate plate geometries to estimate flow coefficients within reasonable accuracy.

3.2. Cavitation

Calculated values for cavitation index (σ) are shown in Tables 2 and 3. Please note that the cavitation indices shown are based on downstream pressure (P2). For the standard plate design at the allowable pressure drop (maximum flow) the corresponding cavitation index is 1.30, which is in the incipient cavitation region. At the highest pressure drops during the maximum flow runs, cavitation indices were close to 0.7, within the constant cavitation region. Levels of cavitation during these runs were observed to be quite tame even though maximum flow capacity of the valve was reached. This demonstrates suitability of the IBC valve operating in high pressure drop flows, beyond allowable pressure drop from valve sizing. Further studies should be conducted into measuring the intensity of cavitation at higher pressure drops.

3.3. End-of-Line Flows

With the end of the pipe freely discharging and the air intake closed, the downstream piping section filled with water. A choking effect was observed as air flowed from the free end of the pipeline upstream towards the recovery zone. Flow during these conditions was unsteady as pockets of air made their way towards the IBC valve in opposite direction to the water. Once the air intake valve was opened, the downstream piping section emptied and the IBC valve operated as free discharge. Since air was being admitted into the low pressure recovery zone it was able to flow in the same direction as the water, towards the pipe outlet. Common application of the IBC valve will often have the discharge directed into a stilling well or waterway. Such installation will often have the IBC valve located close to the discharge outlet, creating end-of-line flow conditions. Testing observations have demonstrated the importance of having air intake available within the recovery zone downstream of the IBC valve. By allowing air to enter the recovery zone, the IBC valve operates in free discharge. Testing results from table 4 show that flow coefficient decreases by about 16% when the valve is operating as free discharge. This can be attributed to the presence of ambient pressure in the downstream piping and reduced flow as the pipe is no longer full. The jet emerging from the IBC valve in free discharge is stable demonstrating the capability of the IBC valve to be mounted directly on the end of a pipe with no hood, provided there is sufficient room for the discharge jet. Figure 7 shows two screenshots from the IBC valve operating at 50% open in end-of-line with air intake closed. Note the air pocket at the top of the spool piece. Pockets of air were drawn from the end of the pipe causing the flow profile to fluctuate in an unsteady manner. Figure 8 shows two screenshots of the IBC valve operating at 90% open with the air intake open. Note the jet profile and the extra water flowing from the slots at the bottom of the enhanced plates. Time constraints did not allow for testing the standard plates in free discharge. Jet profile for the standard plates would be similar, with less water filling the bottom section of the pipe. For reference, the black dot on the pipe seen in the images, is located 2 pipe diameters downstream of the IBC valve.

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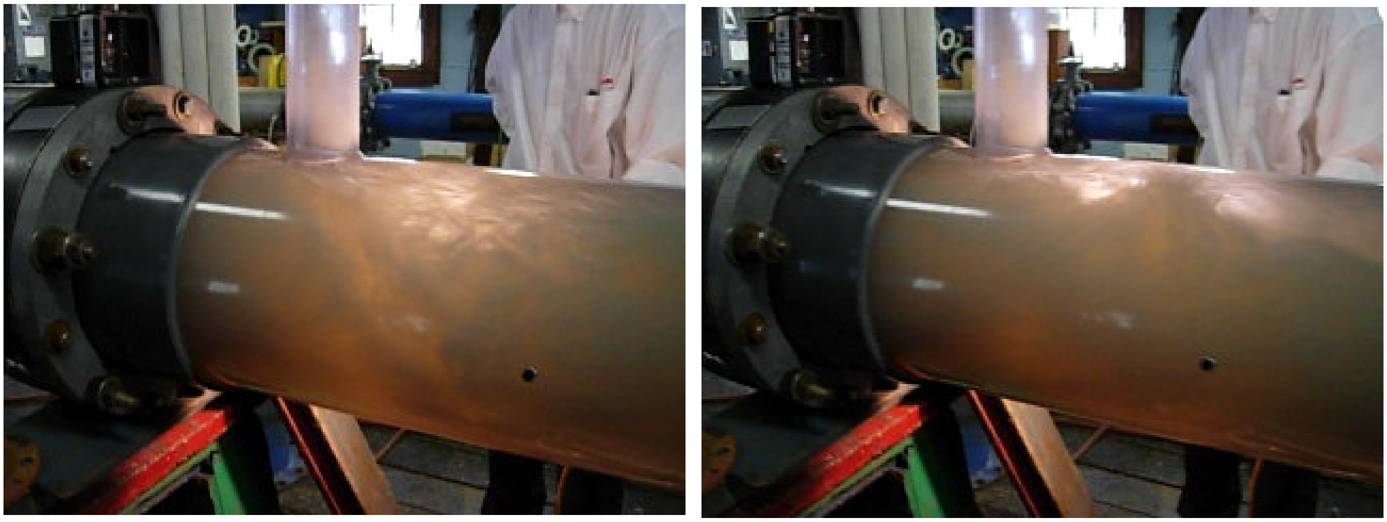

Figure 7 – End-of-Line Test, Enhanced plates, 50%open, air intake closed.

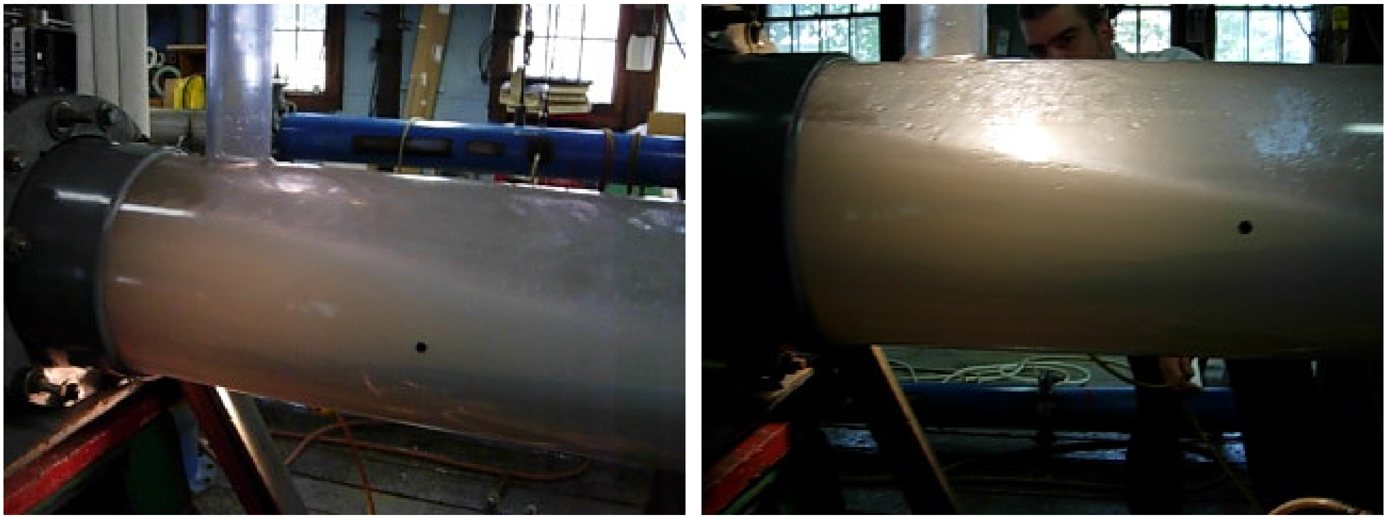

Figure 8 – End-of-Line Test, Enhanced plates, 90% open, air intake open.