MIXING TESTS OF
6" STATIC MIXER
WESTFALL MANUFACTURING COMPANY
PURCHASE ORDER NUMBER 11095
FEBRUARY 1995 - ARL NO. 25-95/C805

ALDEN RESEARCH LABORATORY, INC.
30 SHREWSBURY STREET
HOLDEN, MASSACHUSETTS 01520

INTRODUCTION

A 6" static mixing device was tested at the Alden Research Laboratory, Inc. for Westfall Manufacturing Company under their Purchase Order Number 11095 using ARL's standard test procedures, QA-AGF-7-86 Revision 3. The purpose of the testing was to define the mixing effectiveness of the device and to determine the overall head loss. The static mixer consisted of a shaped orifice plate and three injection ports spaced 45 degrees radially, as shown in Figure 1.

STATIC MIXER INSTALLATION

The static mixer was installed in Test Line 2 in Building 2. Water was provided through a 40" penstock from the main laboratory pond, resulting in a gross gravity head of approximately 18 feet, which was sufficient to obtain the flow required. The detailed piping arrangement, immediately upstream and downstream of the static mixer, is shown in Figure 2 including pressure tap and sample locations. Careful attention was given to aligning the model static mixer with the test line piping and to assure no gaskets between flanged sections protruded into the flow. Vents were provided at critical locations of the test line to purge the system of air.

MIXING MEASUREMENT

Sample Locations

Mixing effectiveness was measured by determining the relative concentration of a fluorescent tracer at vertical planes 5 and 10 pipe diameters downstream of the mixer (the ten diameter location is shown on Figure 2). The tracer used for concentration measurements was a fluorescent dye, Rhodamine WT. Spatial distribution of tracer concentration was measured at twelve locations on two diameters. The sample locations were located in the center of three annuli having equal areas, shown in Figure 3. A continuous flow was withdrawn from each location through individual tubes having control valves and free jet discharge. Twelve 250 ml

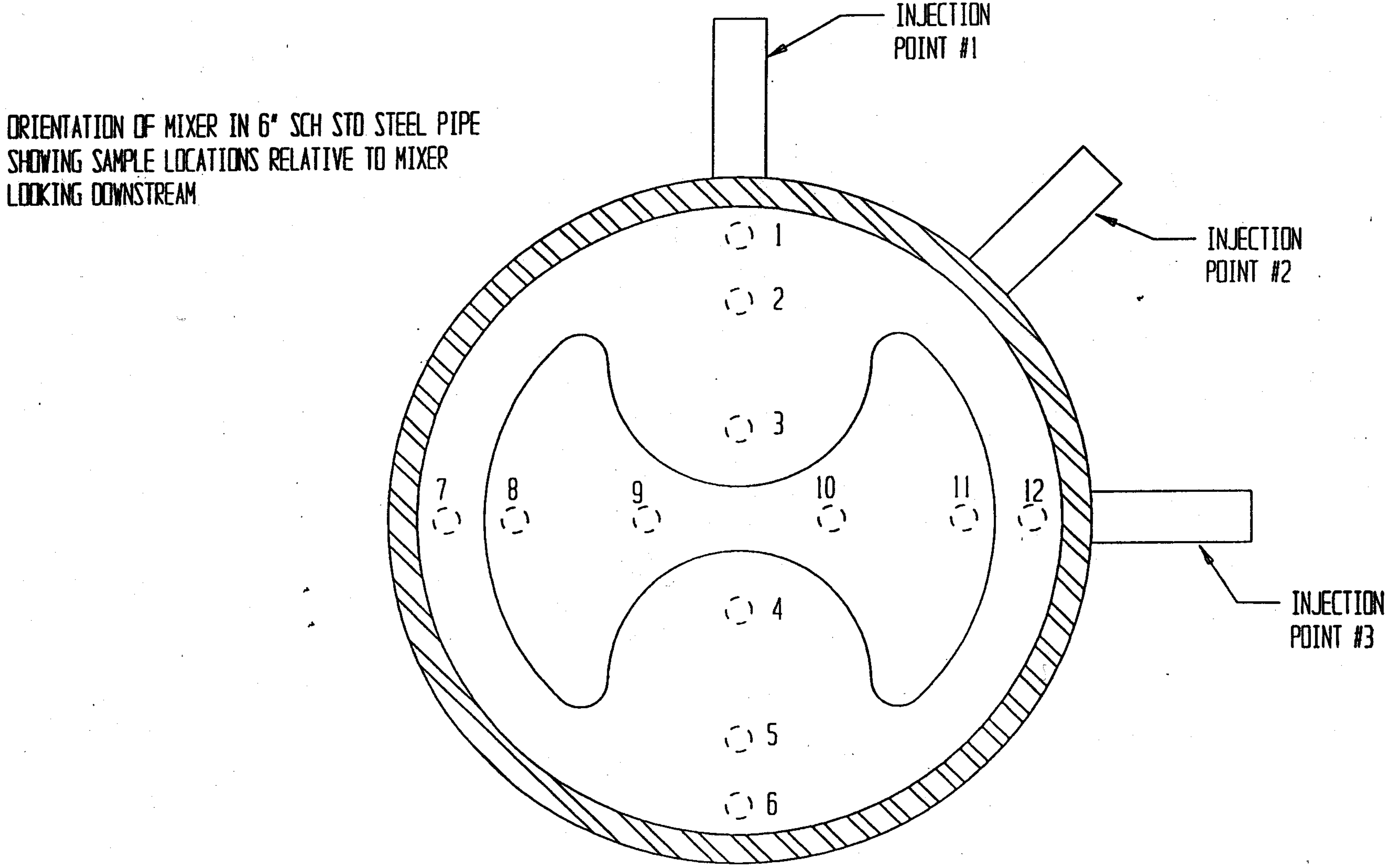
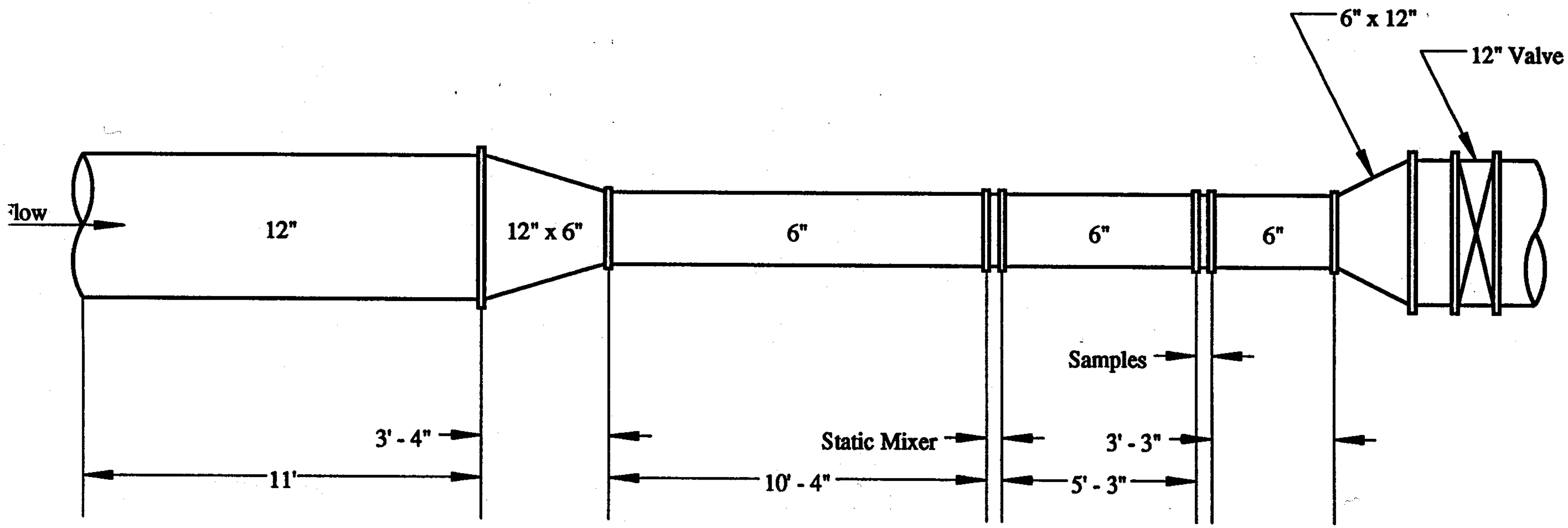


Figure 1 Static Mixer Design Showing Injection Ports and Sample Orientation

Figure 2 Elevation of Static Mixer Installatiom



Westfall Manufacturing Company
Purchase Order Number 11095
February 1995

bottles were installed on a rack, which was slid under the discharge jet of the sample lines to obtain simultaneous samples from all locations. The sample flows were approximately equal, and a one minute average sample was taken at each position.

Concentration Measurement

A Turner Designs Model 10 fluorometer evaluated dye concentration. The fluorometer was capable of detecting concentrations of about 0.01 ppb, such that a mixed concentration of less than 10 ppb provided sufficient measurement accuracy while maintaining a concentration sufficiently low to be undetectable by eye. Concentration of the samples was determined by fluorescence intensity measurements.

Rhodamine WT has low adsorption characteristics and is supplied at nominal 20 percent concentration by weight. A stock injection solution was prepared by dilution of the supplied solution with distilled water. Only comparative concentration measurements were required, and the true stock solution concentration need not be known to attain good measurement accuracy. The mixed concentration at the sampling location, ranging from 5 to 10 ppb, assured sufficient measurement accuracy in the linear response region of the fluorometer response. Fluorescence is a function of water temperature, and sample temperature variations from the water temperature during calibration are accounted for by:

$$C = C_r \ e^{k(T_r - T_c)} \qquad (1)$$

where C = concentration (ppb)
C_r = apparent concentration at temperature T_r (ppb)
T_c = calibration temperature (F)
T_r = temperature of sample (F)
k = temperature correction coefficient (1/ F)

The temperature coefficient, k, used was 0.01444/ F, which is a standard value for Rhodamine WT and has been verified at ARL.

Instrumentation Description

The Turner Designs Model 10 fluorometer, used to measure dye concentration, has multiple ranges to increase the range of measurable concentrations. Two range settings are available, X1 and X100 having a 100 to 1 effect on output. Within each range, the sensitivity may be changed from X1 to X31.6 in four equal steps, having a maximum 30-fold effect on output. The instrument span and zero offset are also adjustable to match the output to the measured concentration. The fluorometer was set up to read in the upper one third of the output of the X1 sensitivity scale on the X1 range to ensure good resolution for a wide concentration range.

Fluorometer voltage output and two RTD thermometers, measuring water and instrument temperatures, were recorded by a portable computer with a 12 bit analog to digital converter. A platinum resistance temperature sensor, mounted in a 1/8" diameter rod, measured the water sample temperature, which was used to correct measured fluorometer voltage output to calibration water temperature with Equation (1). Fluorometer output, water temperature, and filter temperature were read at eight hertz and, after 80 readings (about 10 seconds), the averages and standard deviations were calculated, stored, and printed. During data acquisition, individual temperature and fluorometer readings were displayed on the PC monitor for evaluation. Average fluorometer output, corrected to the calibration temperature, was also displayed versus time. Variation of the corrected output from the previous test point was displayed as a percent to show trends on a magnified scale. After the fluorometer output reached a steady value and sufficient data were recorded for each sample, several 10 second readings at a given location were averaged for concentration calculation.

Dye Injection Method

Primary stock dye solution flow was about 1 ml/sec, so the dye solution was injected into a transport flow by a constant displacement pump, whose variable stroke controlled the dye release to achieve a mixed concentration of between 5 and 10 ppb. The injection pump and a 100 ml pipette with reduced area measuring stations were supplied from a 20 liter Mariotte vessel (a vessel which maintains a constant inlet pressure on the injection pump regardless of liquid level in the vessel). Dye injection flow was constant for each test and was measured by the volumetric method. When the supply line from the Mariotte vessel was shut off via a valve, dye was supplied to the pump solely from the pipette, which is a Class A vessel having a volume uncertainty of 0.1 percent. A digital timer with 0.001 sec resolution was started and stopped as the meniscus of the dye passed the measuring locations on the pipette. A rotameter was used to measure the transport flow, which was set at 0.5 percent of the total flow.

HEAD LOSS MEASUREMENT

To measure the static mixer head loss, pairs of pressure taps were installed at each of two sections; one pipe diameter upstream and ten pipe diameters downstream of the mixer. The taps at each section were manifolded together to obtain a physical average. A differential pressure transducer with a span of 250 inches of water was used to measure the head loss using a PC based data acquisition system. The transducer and data acquisition system were calibrated with a pneumatic dead weight tester having an accuracy of 0.02 percent. Pressure data were averaged over a minimum of 150 seconds to obtain a precise average, while the flow was measured by the gravimetric method.

FLOW MEASUREMENT METHODS

Flow was measured by the gravimetric method using a tank mounted on Fairbanks scales having a capacity of 50,000 pounds (resolution 5 lb). Water flowing through the primary element was diverted into the tank with an electrically operated knife edge passing through a rectangular jet produced by a diverter head box. A Hewlett-Packard "5301A" 10 MHz Frequency Counter (resolution 0.001 sec), activated by an optical switch on the knife edge, determined the time of diversion. A thermistor thermometer measured the water temperature to allow calculation of the water specific weight. The volumetric flow rate was calculated by Equation (2).

$$q_a = \frac{W}{T\gamma} \qquad (2)$$

where

q_a	=	volumetric flow, ft^3/sec
W	=	net accumulated weight, lbs
T	=	diversion time, sec
γ	=	water specific weight at run temperature, corrected for buoyancy, lbs/ft^3

The weigh tank is periodically calibrated with 10,000 lbs of weights, the calibration of which is traceable to NIST. A computer is used to calculate flow rate from the raw data to assure consistency. Weigh tank calibrations and the specific weight of water as a function of temperature are stored on disk file. Data were recorded manually and on disk file for later review and reporting. As an option, flow may be expressed in many different units as required by the application of standard conversions.

A head loss coefficient was defined as the head loss in feet of water divided by the velocity head. Above a pipe Reynolds number of about 100,000 the head loss coefficient is constant and may be used to calculated head losses versus flow.

$$K_l = (q_a / a_p)^2 / (2\,g) \quad (3)$$

where a_p = area pipe, ft^2
g = local gravitational constant, 32.1625 ft^2 / sec

TEST PROCEDURE

After checking the installation, water was introduced into the system to equalize line and model temperature to water temperature. Vent valves in the test line were opened to remove air from the system. Prior to a test run, the control valve was set to establish the desired total flow. The injection flow was set at the desired value (about 0.5 percent of the total flow) and the dye injection initiated. Initially, flow was diverted away from the weigh tank. After steady state conditions in the test line had been reached, in about five minutes, the weigh tank discharge valve was closed and the weigh tank scale indicator and the electric timer were both zeroed. The flow was then diverted into the weigh tank, which automatically started the timer. During the collection time, the 250 ml sample bottles were filled. At the end of the run, flow was diverted away from the weigh tank and the timer was stopped to terminate the test run. The weight of water in the tank, elapsed time, and water temperature were recorded. The concentrations of the 12 samples were determined immediately after each test, which analysis required about one hour.

TEST RESULTS

Spacial distribution of concentration was measured for each of the injection ports. Two tests were conducted at each flow for tests at the 10 diameter spacing to obtain an estimate of measurement precision. Table 1 lists the measured parameters for each test, including the identification letter, transport flow in gpm, total flow in gpm, dye injection flow in ml/sec, and coefficient of variation.

Table 1

Test Condition Summary

Test	Injection Port	Injection Flow gpm	Total Flow gpm	Coefficient of Variation
A	1	3.2	643	0.0099
B	1	3.2	643	0.0095
C	2	3.2	643	0.0274
D	2	3.2	643	0.0215
E	3	3.2	643	0.0468
F	3	3.2	643	0.0433
G	1	3.2	643	0.042
H	2	3.2	643	0.182
I	3	3.2	643	0.249

Concentration measurements for each injection port and the two sample locations are listed in Tables 2 through 7. Since the response of the fluorometer is linear with concentration, sample voltage minus background voltage is directly proportional to concentration. Measured voltages are listed for each location, and the relative concentration at the downstream locations is calculated as the voltage minus the average background voltage. The deviation of each relative concentration from the mean of the twelve readings is listed as percent of the mean of the twelve concentrations. Percent deviation is plotted versus the measurement position number (see Figure 3) for each test in Figures 4 through 9. For the 10D sample locations two tests were conducted for each injection location to evaluate data scatter. Typical data scatter was less than 1 percent, and the maximum was about 2 percent. The coefficient of variation (CoV), defined as the standard deviation of the concentrations at the twelve locations divided by the mean concentration, was calculated for each test and listed in Table 1.

Six tests were conducted with the sample position ten diameters downstream of the static mixer, two each for the three injection ports. For Port # 1, the maximum deviation from the average was about 2 percent with a vertical gradient (points 1 through 6 in the direction of the injection port) from + 2 percent at the injection side to -2 percent at the opposite side. The concentration variation across the other diameter (perpendicular to the injection direction in the center) was less than 1 percent. The coefficient of variation averaged 0.0097. Port #2 was at 45 degrees to the horizontal and resulted in larger deviations. The samples on the vertical diameter had slightly less concentration variation, but on the horizontal diameter the variations were from +5 percent at the injection side to -6 percent, with an average coefficient of variation of about 0.0245. The horizontal injection port (#3) had the largest deviations, with the horizontal diameter (in the direction of the injection) having variations of ±8 percent and a coefficient of variation of 0.045.

The sample ports were moved to five diameters downstream of the mixer and tests conducted with each injection port. Performance degraded in all cases. Port #1 (vertical) had the best performance with a maximum deviation of about +7.7 percent at top sample location. The coefficient of variation increased to 0.042 from the 0.0099 at 10D. The other two ports had very large horizontal gradients, a maximum of 40 percent deviations and coefficient of variations of 18.2 percent and 24.9 percent for ports #2 and #3. Figure 7 plots the deviations for all three injection locations.

Head loss was measured over a range of flow from 440 gpm to 636 gpm to obtain sufficiently large differential heads to provide good measurement accuracy. The pipe head loss without the static mixer was measured over a range of flows to allow calculation of the net head loss due to the mixer. The pipe loss test data is shown in a table with the power law curve fit used to calculate head loss for the mixer head loss tests. The static mixer head loss was characterized by a loss coefficient, which was defined as the measured differential head divided by the velocity head. For form type head losses such as the mixer, the coefficient should be constant above a minimum Reynolds number of about 100,000. A Table lists the static mixer head loss test data with the calculated pipe loss, net loss and loss coefficient. The loss coefficient is plotted versus flow. Test run 4 showed a deviation from the other data and is not considered reliable. The average loss coefficient without run 4 was 13.63.

by a loss coefficient, which was defined as the measured differential head divided by the velocity head. For form type head losses such as the mixer, the coefficient should be constant above a minimum Reynolds number of about 100,000. A Table lists the static mixer head loss test data with the calculated pipe loss, net loss and loss coefficient. The loss coefficient is plotted versus flow. Test run 4 showed a deviation from the other data and is not considered reliable. The average loss coefficient without run 4 was 13.63.

Figure 7 5D Samples All Injection Ports
643 GPM

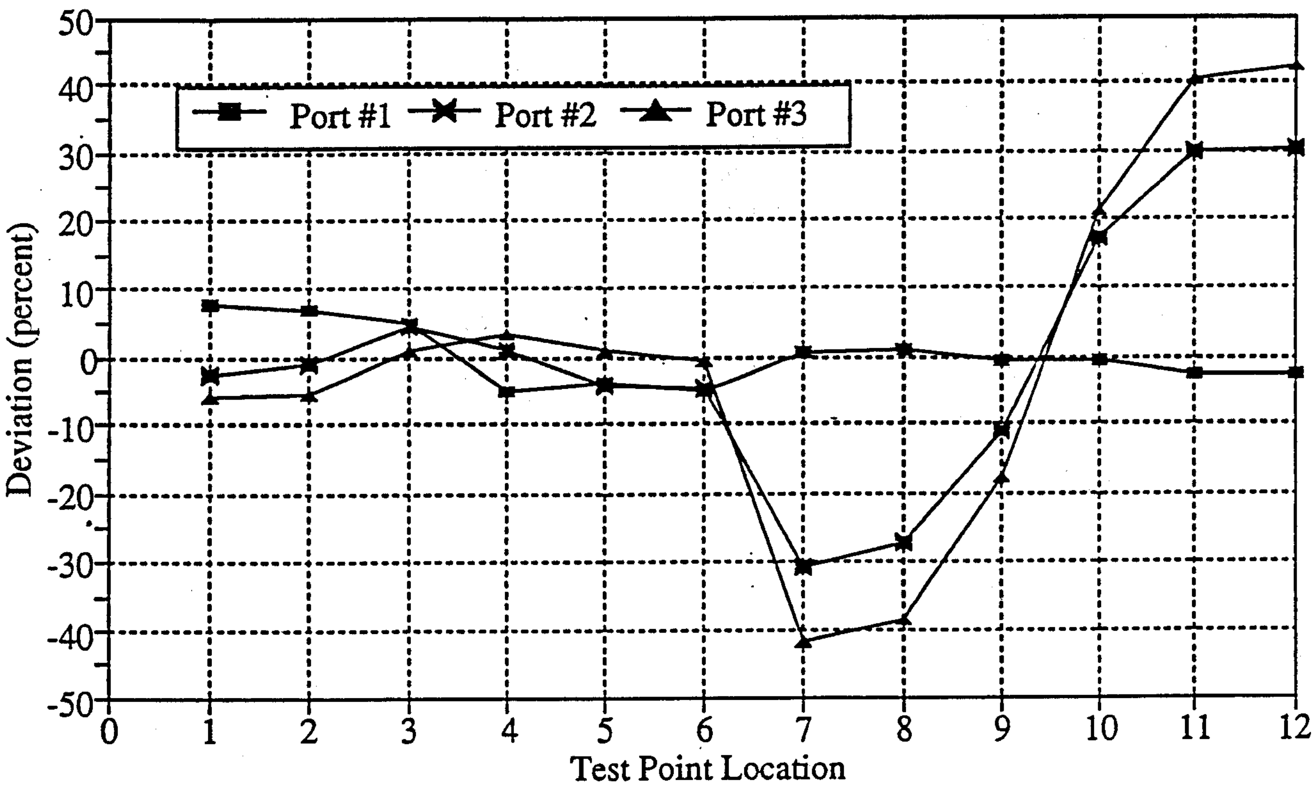


Table 5
Westfall Mixing Tests
Injection Port #1
Sample at 5D
643 GPM

Location	Test G Output voltage	Background Concentration	Relative Concentration	Deviation percent
1	1.0240	0.0348	0.9892	7.69
2	1.0154	0.0348	0.9806	6.75
3	0.9989	0.0348	0.9641	4.95
4	0.9066	0.0348	0.8718	-5.09
5	0.9176	0.0348	0.8828	-3.90
6	0.9077	0.0348	0.8729	-4.97
7	0.9566	0.0348	0.9218	0.35
8	0.9615	0.0348	0.9267	0.88
9	0.9481	0.0348	0.9133	-0.58
10	0.9483	0.0348	0.9135	-0.55
11	0.9284	0.0348	0.8936	-2.72
12	0.9276	0.0348	0.8928	-2.81
	Average	0.0348	0.9186	
	Standard Deviation		0.0386	4.202
CoV	0.0420			

Figure 4 Injection Port #1 10D Samples
643 GPM Average COV 0.0097

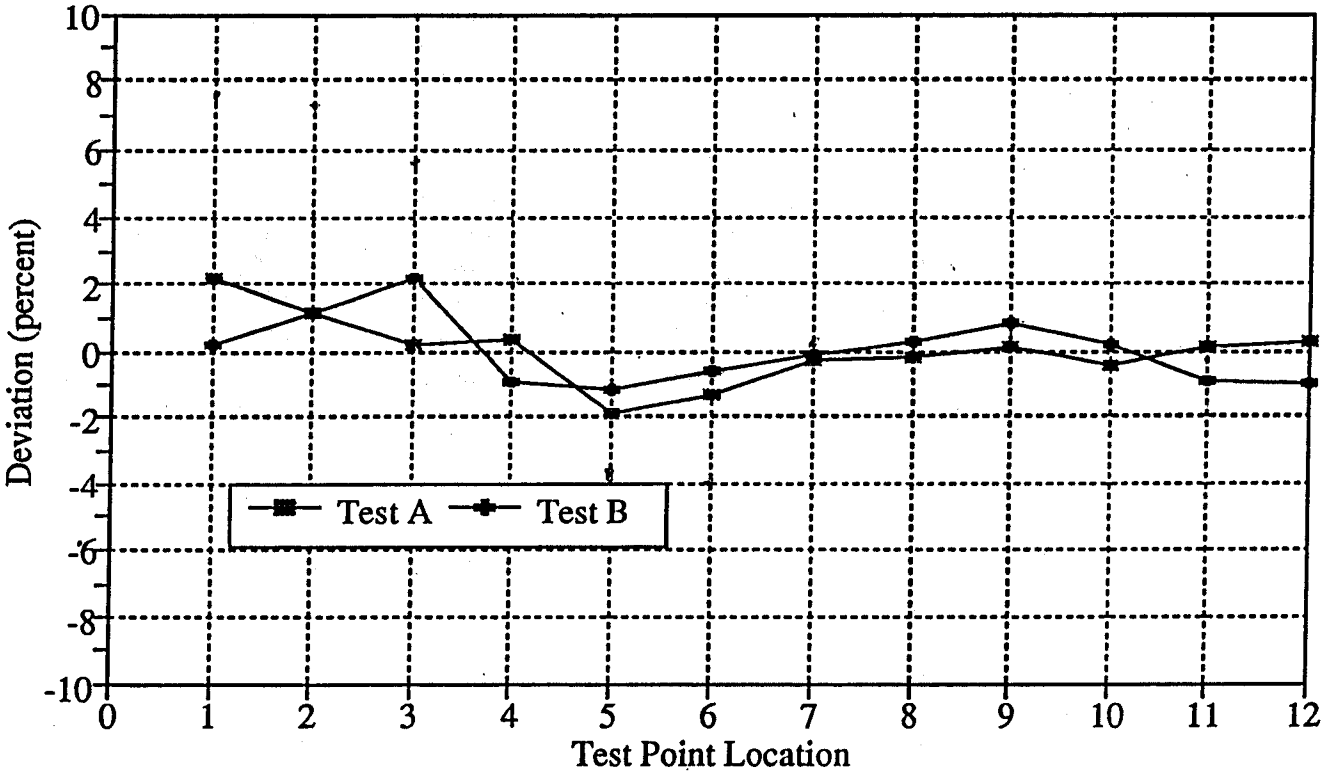


Table 2
Westfall Mixing Tests
Injection Port #1
Sample at 10D
643 GPM

Location	Test A Output voltage	Background Concentration	Relative Concentration	Deviation percent
1	1.0450	0.0363	1.0087	2.15
2	1.0345	0.0363	0.9982	1.09
3	1.0256	0.0363	0.9893	0.19
4	1.0270	0.0363	0.9907	0.33
5	1.0050	0.0363	0.9687	-1.90
6	1.0108	0.0363	0.9745	-1.31
7	1.0202	0.0363	0.9839	-0.36
8	1.0218	0.0363	0.9855	-0.19
9	1.0249	0.0363	0.9886	0.12
10	1.0197	0.0363	0.9834	-0.41
11	1.0242	0.0363	0.9879	0.05
12	1.0260	0.0363	0.9897	0.23
	Average	0.0363	0.9874	
	Standard Deviation		0.0097	0.987
CoV	0.0099			

Location	Test B Output voltage	Background Concentration	Relative Concentration	Deviation percent
1	0.9939	0.0341	0.9598	0.19
2	1.0032	0.0341	0.9691	1.16
3	1.0124	0.0341	0.9783	2.12
4	0.9831	0.0341	0.9490	-0.94
5	0.9813	0.0341	0.9472	-1.13
6	0.9864	0.0341	0.9523	-0.60
7	0.9912	0.0341	0.9571	-0.09
8	0.9949	0.0341	0.9608	0.29
9	0.9995	0.0341	0.9654	0.77
10	0.9935	0.0341	0.9594	0.15
11	0.9835	0.0341	0.9494	-0.90
12	0.9824	0.0341	0.9483	-1.01
	Average	0.0341	0.9580	
	Standard Deviation		0.0091	0.954
CoV	0.0095			
	Average Coefficient of Variation			0.0097

Westfall Mixing Tests WFL9

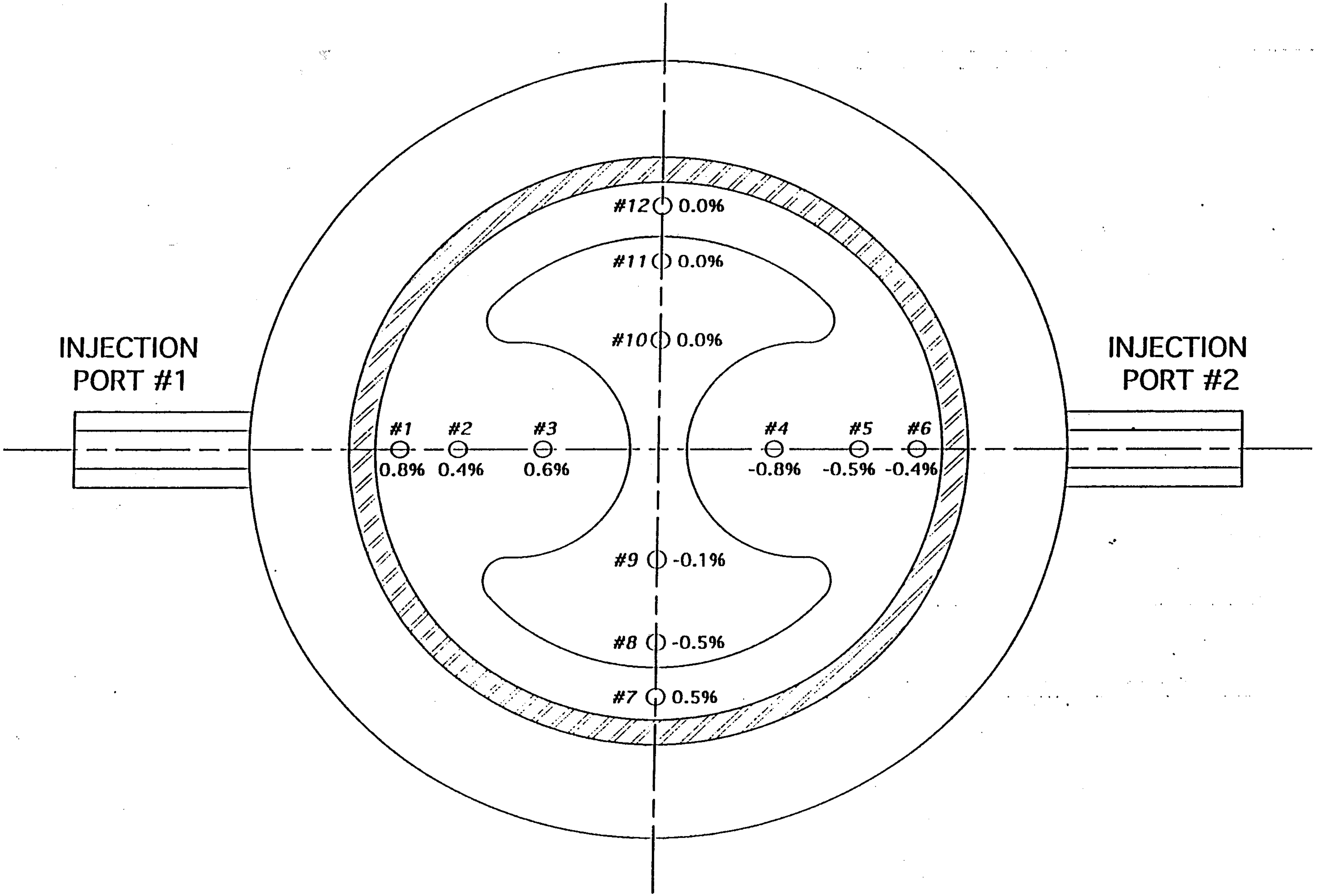
Injection Port #1&4, Sample 10D DS, 428 GPM, Sideflow 0.2 GPM

0.0625" ID Injection Port Tubes with 0.25" Protrusion Behind Mixer Tab

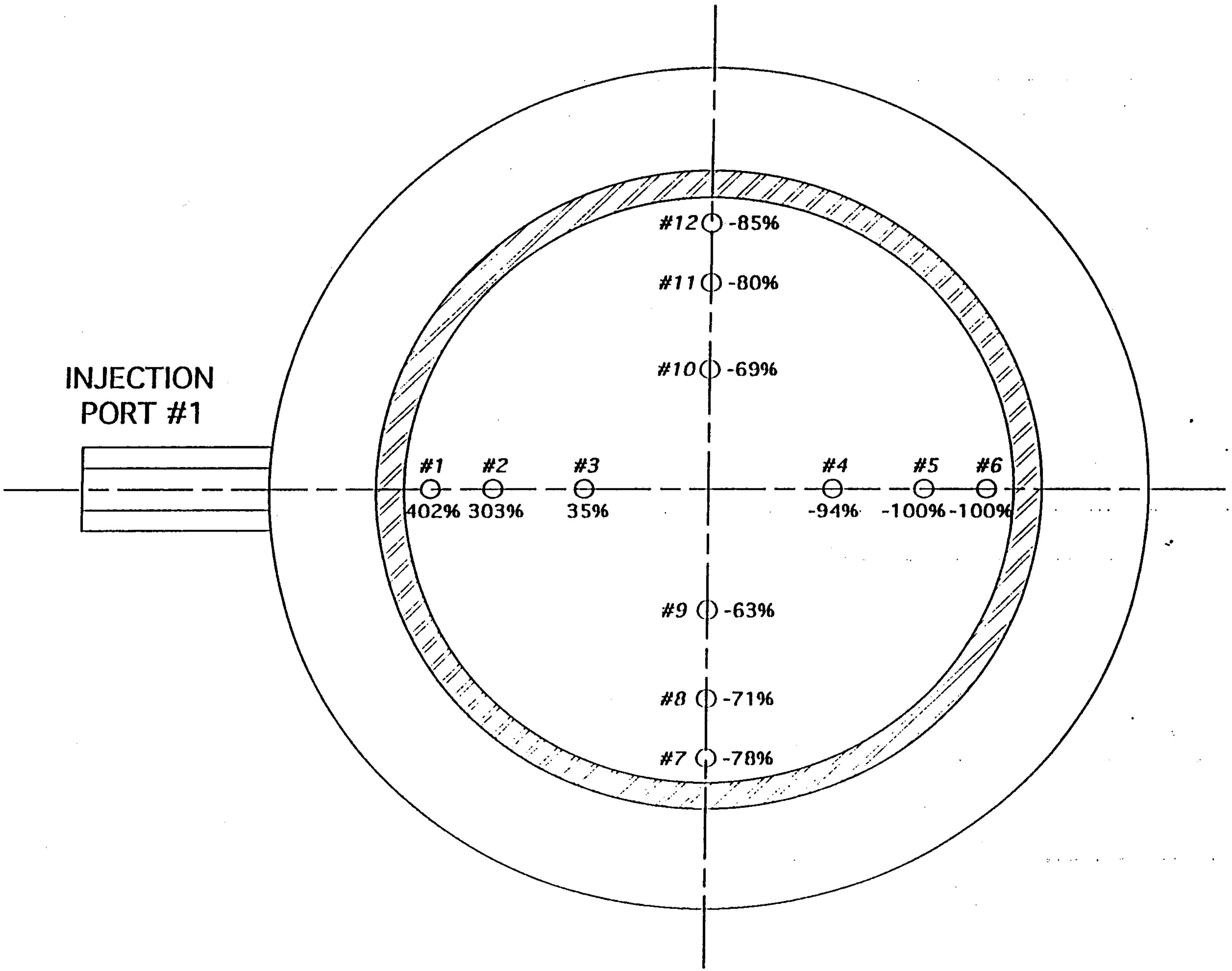
Location	Test V Output voltage	Background Concentration	Relative Concentration	Deviation percent
1	0.8206	0.0211	0.7995	-0.15
2	0.8206	0.0211	0.7995	-0.15
3	0.8249	0.0211	0.8038	0.39
4	0.8118	0.0211	0.7907	-1.24
5	0.8200	0.0211	0.7989	-0.22
6	0.8222	0.0211	0.8011	0.05
7	0.8290	0.0211	0.8079	0.90
8	0.8196	0.0211	0.7985	-0.27
9	0.8218	0.0211	0.8007	0.00
10	0.8261	0.0211	0.8050	0.54
11	0.8205	0.0211	0.7994	-0.16
12	0.8241	0.0211	0.8030	0.29
	average	0.0211	0.8007	
	std		0.0041	
COV	0.0051			

Location	Test W Output voltage	Background Concentration	Relative Concentration	Deviation percent
1	0.8373	0.0214	0.8159	1.73
2	0.8307	0.0214	0.8093	0.91
3	0.8295	0.0214	0.8081	0.76
4	0.8205	0.0214	0.7991	-0.36
5	0.817	0.0214	0.7956	-0.80
6	0.8164	0.0214	0.7950	-0.87
7	0.8248	0.0214	0.8034	0.17
8	0.8173	0.0214	0.7959	-0.76
9	0.8217	0.0214	0.8003	-0.21
10	0.8192	0.0214	0.7978	-0.53
11	0.8248	0.0214	0.8034	0.17
12	0.8218	0.0214	0.8004	-0.20
	average	0.0214	0.8020	
	std		0.0061	
COV	0.0076			

Average Coefficient of Variation 0.0063



WESTFALL MIXING TESTS (test V,W)
Average Percent Concentration Deviation at Locations *#1* thru *#12*
10 Diameters Downstream from Mixer



WESTFALL MIXING TESTS (test U / no mixer)
Percent Concentration Deviation at Locations *#1* thru *#12*
10 Diameters Downstream from Injection Point

Table 1
Westfall Mixer
Test Summary

Test	Flow gpm	Sideflow gpm	Port Number	Remarks	Coefficient of Variation
A	643	3.2	1&4		0.0093
B	643	3.2	1&4		0.0061
C	643	3.2	1&4		0.0093
A(r)	643	3.2	1&4		0.0059
				average	0.0077
D	646	3.2	1		0.0107
E	646	3.2	1		0.0105
				average	0.0106
F	434	3.2	1&4		0.0090
G	434	3.2	1&4		0.0081
				average	0.0086
H	421	1.6	1&4		0.0045
I	421	1.6	1&4		0.0066
				average	0.0056
J	421	0.8	1&4		0.0046
K	421	0.8	1&4		0.0046
				average	0.0046
L	439	0.4	1&4		0.0154
M	439	0.4	1&4		0.0113
				average	0.0134
N	439	0.4	1&4	1/8" Injector @ 0.25"	0.0093
O	439	0.4	1&4	1/8" Injector @ 0.25"	0.0058
				average	0.0076
P	439	0.2	1&4	1/8" Injector @ 0.25"	0.0079
Q	439	0.2	1&4	1/8" Injector @ 0.25"	0.0086
				average	0.0083
R	439	0.1	1&4	1/8" Injector @ 1.75"	0.0121
S	439	0.1	1&4	1/8" Injector @ 1.75"	0.0076
				average	0.0099
T	439	0.1	1&4		0.0130
U	419	0.2	1	No Mixer	1.6248
V	428	0.2	1&4	1/16" Injector @ 0.25"	0.0051
W	428	0.2	1&4	1/16" Injector @ 0.25"	0.0076
				average	0.0064

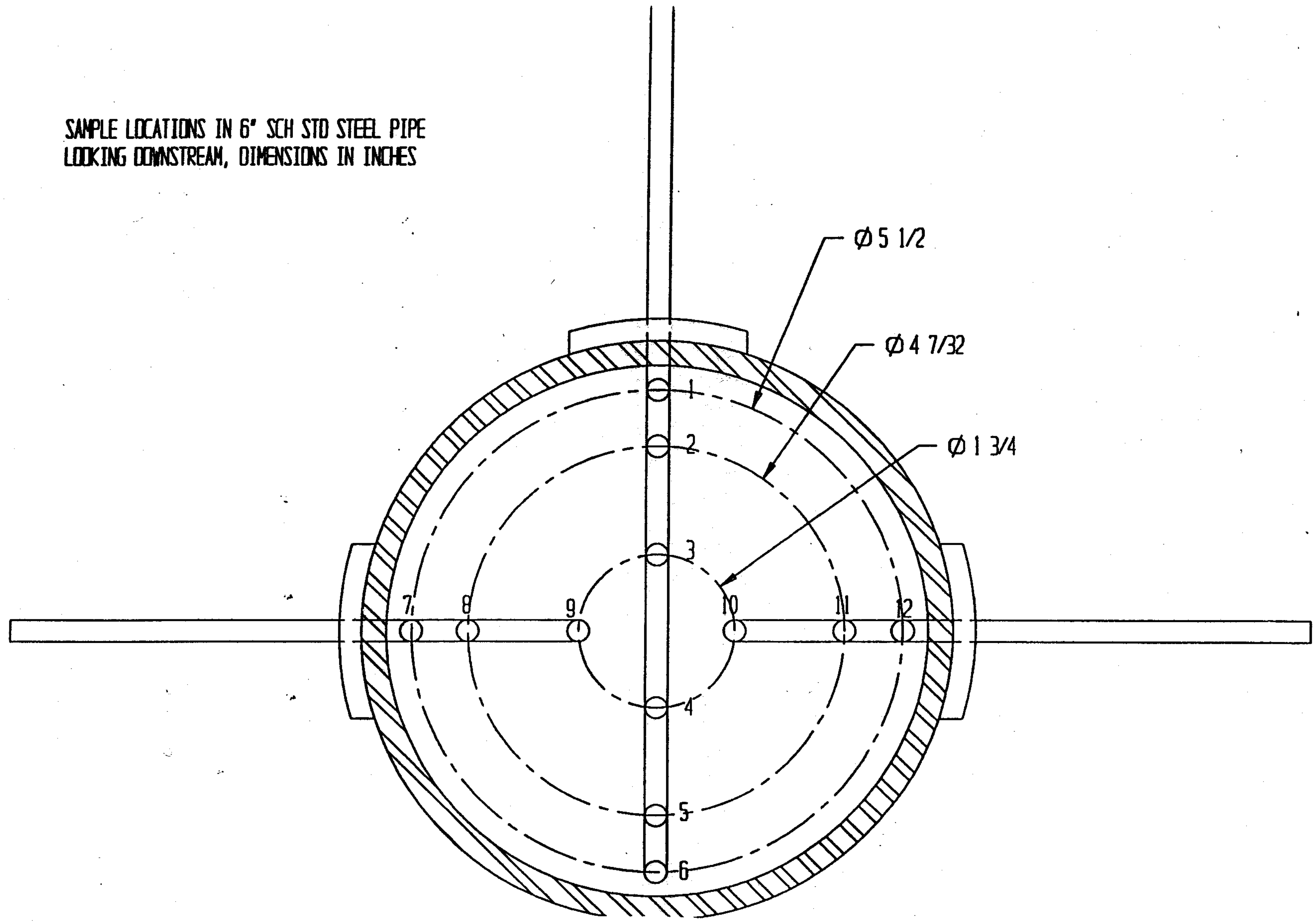


Figure 3 Detail of Sample Port Design

.7 & .9 CoV

ADDENDUM TO THE MIXING TESTS OF A 6" STATIC MIXER WESTFALL MANUFACTURING COMPANY PURCHASE ORDER NUMBER 03-5801

ALDEN RESEARCH LABORATORY, INC.
30 SHREWSBURY STREET
HOLDEN, MASSACHUSETTS 01520

Westfall Static Mixer
Alden Laboratory Test Data

1 Reference: Test I.D. # 1 thru 8
.8 Beta from 1 thru 5 diameters upstream from the tab and upstream from the opening

---

2 Reference: Test I.D. # 9 thru 11
.9 Beta CoV@ 7.3 ft/sec thru 15 ft/sec.

---

3 Reference: Test I.D. # 12 thru 16
.7 Beta CoV @ 1 ft/sec. thru 7.3 ft/sec.

ADDENDUM TO THE MIXING TESTS OF A
6" STATIC MIXER
WESTFALL MANUFACTURING COMPANY

A static mixing device was tested at Alden, for Westfall Manufacturing Company in 1995, using Alden's standard test procedures, QA-AGF-7-86 Revision 3. The purpose of testing was to define mixing effectiveness and overall head loss. The static mixer consisted of a shaped orifice plate with two 0.25" diameter injection ports spaced 90 degrees apart, as shown in Figure A1. The results of this testing may be found in Alden Report Number 25-95/C805.

As a continuation of the original testing, three mixers were tested for mixing efficiency under Westfall Manufacturing Company Purchase Order Number 03-5801. The purpose of the testing was to define the variation of mixing effectiveness with open areas and injection location. Three mixer plates with beta ratios of: 0.7, 0.8, and 0.9 (ratio of open to total area) were tested in standard 6" pipe. Testing of the 0.8 beta ratio static mixer, a continuation of tests conducted at Alden in 1995, documented mixing with sidewall injection at 1 and 5 pipe diameters upstream of the mixer to compare to the earlier work, for which injection was at the mixer plate and concentration measurements were at 10 diameters downstream of the mixer. For each upstream injection location, tests were conducted with the injection port aligned to the mixer plate's #1 and #3 injection ports. Tests of the 0.7 and 0.9 beta ratio mixers used injection at the mixer plate Port #1 over a range of flows through the mixer.

Figure A1 illustrates the alignment of the mixer plate lobes relative to the numbered sampling ports. Several repeat tests were performed in order to confirm expected experimental data scatter. Sampling was performed in a plane ten diameters downstream of the mixer with three sampling locations on each of four radii, with sampling port located as shown in Figure A2. The previously used sampling equipment for the 6" line was used. Procedures were essentially identical to the earlier mixing tests. The dye tracer injection flow was fixed at 0.5 gpm for all tests.

TEST RESULTS

Spatial distribution of tracer concentration was measured for each test condition in Table A1. Repeat tests were conducted to obtain an estimate of measurement precision. Table A1 lists the plate beta ratio, injection location, flow and average flow velocity, and the coefficient of variation (CoV).

Individual concentration measurements for each test condition are listed for each sample port in Tables A6 through A21. Since the response of the fluorometer is linear with concentration, the sample voltage minus background voltage, is directly proportional to concentration. Measured voltage is listed for each sample port, and the relative concentration at each port is calculated as the voltage minus the average background voltage. The deviation of each relative concentration from the mean concentration of the twelve port readings is listed as percent of the mean. The coefficient of variation (CoV) is defined as the standard deviation of the concentrations at the twelve locations divided by the mean concentration.

TABLE A1

Test Condition Summary

Test ID Number	Beta	Injection Location	Total Flow (gpm)	Area Average Velocity ft./sec	CoV
1	0.8	Aligned to Mixer port # 1, 1D upstream of mixer	656	7.3	0.0316
2	0.8	Aligned to Mixer port # 3, 1D upstream of mixer	656	7.3	0.0689
3	0.8	Aligned to Mixer port # 1 (repeat), 1D upstream	656	7.3	0.0299
4	0.8	Aligned to Mixer port #1, 5D upstream	656	7.3	0.0218
5	0.8	Aligned to Mixer port #3, 5D	656	7.3	0.0560

		upstream			
6	0.8	Mixer port # 1	277	3.0	0.0178
7	0.8	Mixer port # 1 (repeat)	277	3.0	0.0157
8	0.8	Mixer port # 1	404	4.5	0.0126
9	0.9	Mixer port # 1	657	7.3	0.0529
10	0.9	Mixer port # 1 (repeat)	657	7.3	0.0536
11	0.9	Mixer port # 1	1355	15.0	0.0506
12	0.7	Mixer port # 1	270	3.0	0.0118
13	0.7	Mixer port # 1	409	4.5	0.0098
14	0.7	Mixer port # 1	662	7.3	0.0090
15	0.7	Mixer port # 1	190	2.0	0.0079
16	0.7	Mixer port # 1	90	1.0	0.0079
Tracer transport flow = 0.5 gpm through the 0.25" diameter injection ports					

The 0.8 beta ratio plate was tested to define the mixing effectiveness with injection through a sidewall port at two upstream distances and two radial positions at a single area average velocity (flow). Additional tests were conducted with injection at Mixer Port #1 at pipe velocities of 3.0 ft/sec and 4.5 ft/sec, to compliment the original work performed at 7.3 ft/sec. Repeat tests were included for both the upstream and mixer port tests to confirm data scatter.

A 0.9 beta mixer was tested to define its mixing effectiveness with injection at Mixer Port #1 at two flows corresponding to pipe velocities of 7 ft/sec and 15 ft/sec. A repeat test at the 7ft/sec velocity was included to confirm any data scatter with these test conditions.

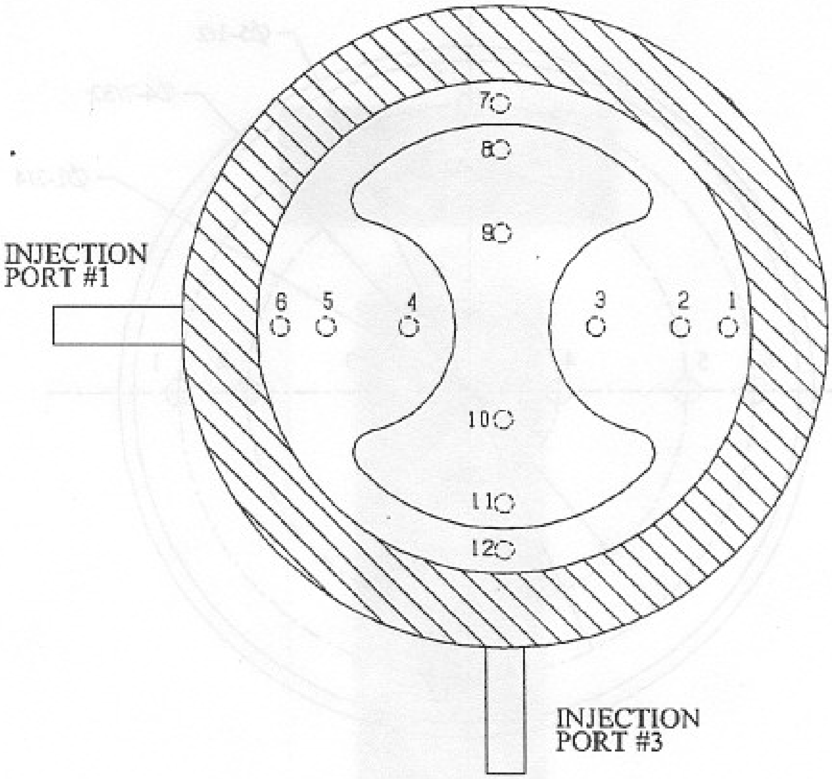
A 0.7 beta mixer was tested to define its mixing effectiveness at five flows corresponding to pipe velocities of 1, 2, 3, 4.5, and 7.3 ft/sec with injection at Mixer Port #1.

In general, the downstream concentration distributions correlated to the alignment of the injection port being used; that is, higher concentrations occurred at the ports that were in line with the radial location of the injection port. Sampling ports 5-6 were aligned with the #1 mixer port axis and when tracer was injected through this port, or upstream aligned to the this port, these ports registered concentrations above the average, whereas ports 1 and 2, on the opposite side of the pipe, had concentrations slightly below the average.

For the 0.8 beta mixer, injecting 1 diameter upstream from the mixer, aligned with the mixer port #1, produced sample deviations of about 5%, as listed in Table A6, and a CoV of about 1.6 times that of test with injection at port #1 on the mixer plate. Injection 1D upstream, aligned to port # 3, produced the highest variations in the samples, with a concentration 11 percent above the mean value at port 12 (see Table A7) and corresponding low concentration at port 7 on the opposite side of the pipe. Injection port # 3 and sample port 12 were aligned at the bottom of the pipe. For injection aligned with port #1 a similar, but less pronounced variation occurred between taps 6 and 1.

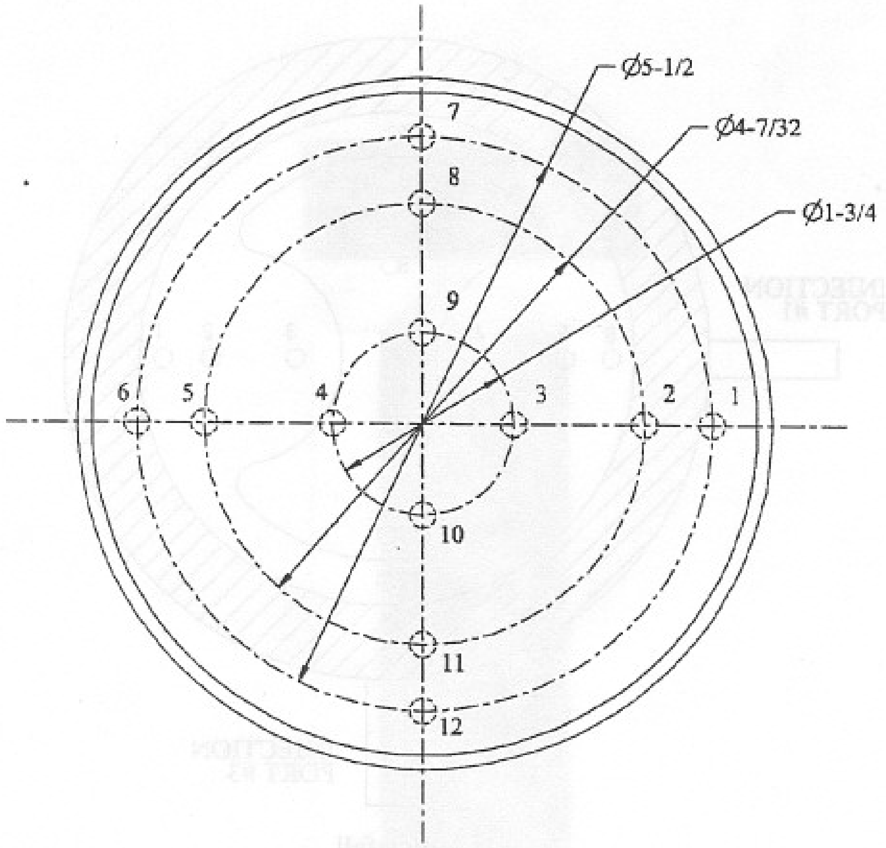
The 5D upstream injection showed less effective mixing than the plate injection, but was improved over the D upstream injection due to greater pre-mixing occurring before the tracer passed through the plate.

Test conditions 6 through 16 consisted of measuring the performance if each size mixer operating over a range of flows for the optimal injection location, Port #1. The average CoV for the 0.9 beta plate was 0.052. Mixing improved with the 0.8 beta plate and the data with this plate indicated a slight trend of better mixing efficiency with increasing velocity; decreasing from an average of 0.016 at 3 ft/sec pipe velocity, to 0.013 at 4.5 ft/sec, and from the1995 results, 0.0099 at 7.3 ft/s pipe velocity. The 0.7 beta plate had an average CoV of 0.0093 with a standard deviation of 0.0016 over a range of 1 to 7.3 ft/sec. Due to the excellent mixing and resolution of the measurements, no distinct trend could be discerned with velocity (flow). As the losses providing the mixing energy primarily are form, not friction, losses only slight variations in mixing would be expected over the flow range tested as form loss coefficients do not vary greatly with Reynolds numbers over about 300,000.



Westfall
Purchase Order Number: 03-5801
6" STD Mixer Meter
October, 2003

FIGURE A1 TYPICAL MIXER PLATE INSTALLATION



Westfall
Purchase Order Number: 03-5801
6" STD Mixer Meter
October, 2003

FIGURE A2 SAMPLING PORT LOCATIONS

TABLE A6
Test Condition 1

Injection:	Aligned to Mixer port #1		1D upstream of mixer	
Beta:	0.8			
Sample at:	10D downstream of mixer			
Flow:	656 GPM			

Location	Output Voltage	Background Concentration	Relative Concentration	Deviation
1	0.5953	0.0115	0.5838	-1.8%
2	0.5775	0.0115	0.5660	-4.8%
3	0.5909	0.0115	0.5794	-2.6%
4	0.6100	0.0115	0.5985	0.7%
5	0.6342	0.0115	0.6227	4.7%
6	0.6325	0.0115	0.6210	4.4%
7	0.5792	0.0115	0.5677	-4.5%
8	0.5967	0.0115	0.5852	-1.6%
9	0.6047	0.0115	0.5932	-0.2%
10	0.6147	0.0115	0.6032	1.4%
11	0.6209	0.0115	0.6094	2.5%
12	0.6164	0.0115	0.6049	1.7%
	Average:	0.0115	0.5946	
	Standard Deviation:		0.0188	
		CoV:	0.032	

TABLE A7
Test Condition 2

Injection:	Aligned to Mixer port # 3		1D upstream of mixer	
Beta:	0.8			
Sample at:	10D downstream of mixer			
Flow:	656 GPM			
Location	Output Voltage	Background Concentration	Relative Concentration	Deviation
1	0.6966	0.0115	0.6851	0.1%
2	0.6801	0.0115	0.6686	-2.4%
3	0.6863	0.0115	0.6748	-1.4%
4	0.7004	0.0115	0.6889	0.6%
5	0.7134	0.0115	0.7019	2.5%
6	0.7061	0.0115	0.6946	1.4%
7	0.6150	0.0115	0.6035	-11.9%
8	0.6231	0.0115	0.6116	-10.7%
9	0.6708	0.0115	0.6593	-3.7%
10	0.7306	0.0115	0.7191	5.0%
11	0.7576	0.0115	0.7461	9.0%
12	0.7746	0.0115	0.7631	11.4%
	Average:	0.0115	0.6847	
	Standard Deviation:		0.0471	
		CoV:	0.069	

TABLE A8
Test Condition 3

Injection: Aligned to Mixer port # 1 (repeat), 1D upstream
Beta: 0.8
Sample at: 10D downstream of mixer
Flow: 656 GPM

Location	Output Voltage	Background Concentration	Relative Concentration	Deviation
1	0.6701	0.0115	0.6586	-4.8%
2	0.6790	0.0115	0.6675	-3.5%
3	0.6903	0.0115	0.6788	-1.9%
4	0.7200	0.0115	0.7085	2.4%
5	0.7327	0.0115	0.7212	4.2%
6	0.7406	0.0115	0.7291	5.4%
7	0.6883	0.0115	0.6768	-2.2%
8	0.6962	0.0115	0.6847	-1.0%
9	0.7051	0.0115	0.6936	0.3%
10	0.7066	0.0115	0.6951	0.5%
11	0.7058	0.0115	0.6943	0.4%
12	0.7053	0.0115	0.6938	0.3%
	Average:	0.0115	0.6918	
	Standard Deviation:		0.0207	
		CoV:	0.030	

TABLE A9
Test Condition 4

Injection:	Aligned to Mixer port #1		5D upstream of mixer	
Beta:	0.8			
Sample at:	10D downstream of mixer			
Flow:	656 GPM			

Location	Output Voltage	Background Concentration	Relative Concentration	Deviation
1	0.6835	0.0115	0.6720	-3.3%
2	0.6850	0.0115	0.6735	-3.1%
3	0.6962	0.0115	0.6847	-1.5%
4	0.7129	0.0115	0.7014	0.9%
5	0.7267	0.0115	0.7152	2.9%
6	0.7364	0.0115	0.7249	4.3%
7	0.7099	0.0115	0.6984	0.5%
8	0.7113	0.0115	0.6998	0.7%
9	0.7066	0.0115	0.6951	0.0%
10	0.7068	0.0115	0.6953	0.0%
11	0.7016	0.0115	0.6901	-0.7%
12	0.7006	0.0115	0.6891	-0.8%
	Average:	0.0115	0.6950	
	Standard Deviation:		0.0152	
		CoV:	0.022	

TABLE A10
Test Condition 5

Injection:	Aligned to Mixer port #3		5D upstream of mixer	
Beta:	0.8			
Sample at:	10D downstream of mixer			
Flow:	656 GPM			

Location	Output Voltage	Background Concentration	Relative Concentration	Deviation
1	0.6886	0.0115	0.6771	-3.1%
2	0.6987	0.0115	0.6872	-1.7%
3	0.7083	0.0115	0.6968	-0.3%
4	0.7193	0.0115	0.7078	1.3%
5	0.7238	0.0115	0.7123	1.9%
6	0.7315	0.0115	0.7200	3.0%
7	0.6401	0.0115	0.6286	-10.0%
8	0.6565	0.0115	0.6450	-7.7%
9	0.6869	0.0115	0.6754	-3.3%
10	0.7353	0.0115	0.7238	3.6%
11	0.7604	0.0115	0.7489	7.2%
12	0.7737	0.0115	0.7622	9.1%
	Average:	0.0115	0.6988	
	Standard Deviation:		0.0391	
		CoV:	0.056	

TABLE A11
Test Condition 6

Injection: Mixer port # 1
Beta: 0.8
Sample at: 10D downstream of mixer
Flow: 277 GPM

Location	Output Voltage	Background Concentration	Relative Concentration	Deviation
1	0.6324	0.0116	0.6208	-0.1%
2	0.6294	0.0116	0.6178	-0.6%
3	0.6353	0.0116	0.6237	0.3%
4	0.6389	0.0116	0.6273	0.9%
5	0.6318	0.0116	0.6202	-0.2%
6	0.6313	0.0116	0.6197	-0.3%
7	0.6543	0.0116	0.6427	3.4%
8	0.6470	0.0116	0.6354	2.2%
9	0.6381	0.0116	0.6265	0.8%
10	0.6288	0.0116	0.6172	-0.7%
11	0.6130	0.0116	0.6014	-3.3%
12	0.6188	0.0116	0.6072	-2.3%
	Average:	0.0116	0.6217	
	Standard Deviation:		0.0111	
		CoV:	0.018	

TABLE A12
Test Condition 7

Injection:	Mixer port # 1 (repeat)
Beta:	0.8
Sample at:	10D downstream of mixer
Flow:	277 GPM

Location	Output Voltage	Background Concentration	Relative Concentration	Deviation
1	0.6458	0.0116	0.6342	1.6%
2	0.6381	0.0116	0.6265	0.3%
3	0.6341	0.0116	0.6225	-0.3%
4	0.6398	0.0116	0.6282	0.6%
5	0.6329	0.0116	0.6213	-0.5%
6	0.6342	0.0116	0.6226	-0.3%
7	0.6492	0.0116	0.6376	2.1%
8	0.6476	0.0116	0.6360	1.8%
9	0.6413	0.0116	0.6297	0.8%
10	0.6318	0.0116	0.6202	-0.7%
11	0.6215	0.0116	0.6099	-2.3%
12	0.6171	0.0116	0.6055	-3.0%
	Average:	0.0116	0.6245	
	Standard Deviation:		0.0098	
		CoV:	0.016	

TABLE A13
Test Condition 8

Injection: Mixer port # 1
Beta: 0.8
Sample at: 10D downstream of mixer
Flow: 404 GPM

Location	Output Voltage	Background Concentration	Relative Concentration	Deviation
1	0.6823	0.0116	0.6707	-2.0%
2	0.6829	0.0116	0.6713	-1.9%
3	0.6946	0.0116	0.6830	-0.2%
4	0.7042	0.0116	0.6926	1.3%
5	0.7010	0.0116	0.6894	0.8%
6	0.7039	0.0116	0.6923	1.2%
7	0.7061	0.0116	0.6945	1.5%
8	0.7005	0.0116	0.6889	0.7%
9	0.7022	0.0116	0.6906	1.0%
10	0.6948	0.0116	0.6832	-0.1%
11	0.6874	0.0116	0.6758	-1.2%
12	0.6878	0.0116	0.6762	-1.1%
	Average:	0.0116	0.6840	
	Standard Deviation:		0.0086	
		CoV:	0.013	

TABLE A14
Test Condition 9

Injection: Mixer port # 1
Beta: 0.9
Sample at: 10D downstream of mixer
Flow: 657 GPM

Location	Output Voltage	Background Concentration	Relative Concentration	Deviation
1	0.6620	0.0103	0.6517	-7.9%
2	0.6734	0.0103	0.6631	-6.3%
3	0.6995	0.0103	0.6892	-2.6%
4	0.7437	0.0103	0.7334	3.6%
5	0.7745	0.0103	0.7642	8.0%
6	0.7807	0.0103	0.7704	8.9%
7	0.7312	0.0103	0.7209	1.9%
8	0.7289	0.0103	0.7186	1.5%
9	0.7316	0.0103	0.7213	1.9%
10	0.7112	0.0103	0.7009	-1.0%
11	0.6933	0.0103	0.6830	-3.5%
12	0.6860	0.0103	0.6757	-4.5%
	Average:	0.0103	0.7077	
	Standard Deviation:		0.0374	
		CoV:	0.053	

TABLE A15
Test Condition 10

Injection: Mixer port # 1 (repeat)
Beta: 0.9
Sample at: 10D downstream of mixer
Flow: 657 GPM

Location	Output Voltage	Background Concentration	Relative Concentration	Deviation
1	0.6616	0.0106	0.6510	-8.2%
2	0.6756	0.0106	0.6650	-6.2%
3	0.6997	0.0106	0.6891	-2.8%
4	0.7488	0.0106	0.7382	4.1%
5	0.7774	0.0106	0.7668	8.2%
6	0.7860	0.0106	0.7754	9.4%
7	0.7278	0.0106	0.7172	1.2%
8	0.7279	0.0106	0.7173	1.2%
9	0.7304	0.0106	0.7198	1.5%
10	0.7102	0.0106	0.6996	-1.3%
11	0.6976	0.0106	0.6870	-3.1%
12	0.6920	0.0106	0.6814	-3.9%
	Average:	0.0106	0.7090	
	Standard Deviation:		0.0380	
		CoV:	0.054	

TABLE A16
Test Condition 11

Injection:	Mixer port # 1			
Beta:	0.9			
Sample at:	10D downstream of mixer			
Flow:	1355 GPM			
Location	Output Voltage	Background Concentration	Relative Concentration	Deviation
1	0.6239	0.0108	0.6131	-8.3%
2	0.6390	0.0108	0.6282	-6.1%
3	0.6641	0.0108	0.6533	-2.3%
4	0.7016	0.0108	0.6908	3.3%
5	0.7337	0.0108	0.7229	8.1%
6	0.7344	0.0108	0.7236	8.2%
7	0.6877	0.0108	0.6769	1.2%
8	0.6938	0.0108	0.6830	2.1%
9	0.6851	0.0108	0.6743	0.8%
10	0.6748	0.0108	0.6640	-0.7%
11	0.6615	0.0108	0.6507	-2.7%
12	0.6566	0.0108	0.6458	-3.5%
	Average:	0.0108	0.6689	
	Standard Deviation:		0.0338	
		CoV:	0.051	

TABLE A17
Test Condition 12

Injection: Mixer port # 1
Beta: 0.7
Sample at: 10D downstream of mixer
Flow: 270 GPM

Location	Output Voltage	Background Concentration	Relative Concentration	Deviation
1	0.7206	0.0104	0.7102	-1.4%
2	0.7144	0.0104	0.7040	-2.2%
3	0.7278	0.0104	0.7174	-0.4%
4	0.7356	0.0104	0.7252	0.7%
5	0.7422	0.0104	0.7318	1.6%
6	0.7463	0.0104	0.7359	2.2%
7	0.7316	0.0104	0.7212	0.2%
8	0.7264	0.0104	0.7160	-0.6%
9	0.7288	0.0104	0.7184	-0.2%
10	0.7305	0.0104	0.7201	0.0%
11	0.7306	0.0104	0.7202	0.0%
12	0.7308	0.0104	0.7204	0.0%
	Average:	0.0104	0.7201	
	Standard Deviation:		0.0085	
		CoV:	0.012	

TABLE A18
Test Condition 13

Injection: Mixer port # 1
Beta: 0.7
Sample at: 10D downstream of mixer
Flow: 409 GPM

Location	Output Voltage	Background Concentration	Relative Concentration	Deviation
1	0.7538	0.0105	0.7433	-1.9%
2	0.7560	0.0105	0.7455	-1.6%
3	0.7651	0.0105	0.7546	-0.4%
4	0.7696	0.0105	0.7591	0.2%
5	0.7774	0.0105	0.7669	1.2%
6	0.7768	0.0105	0.7663	1.2%
7	0.7718	0.0105	0.7613	0.5%
8	0.7634	0.0105	0.7529	-0.6%
9	0.7709	0.0105	0.7604	0.4%
10	0.7694	0.0105	0.7589	0.2%
11	0.7740	0.0105	0.7635	0.8%
12	0.7673	0.0105	0.7568	-0.1%
	Average:	0.0105	0.7575	
	Standard Deviation:		0.0074	
		CoV:	0.010	

TABLE A19

Test Condition 14

Injection:	Mixer port # 1
Beta:	0.7
Sample at:	10D downstream of mixer
Flow:	662 GPM

Location	Output Voltage	Background Concentration	Relative Concentration	Deviation
1	0.7595	0.0106	0.7489	-1.5%
2	0.7651	0.0106	0.7545	-0.8%
3	0.7642	0.0106	0.7536	-0.9%
4	0.7731	0.0106	0.7625	0.3%
5	0.7808	0.0106	0.7702	1.3%
6	0.7760	0.0106	0.7654	0.6%
7	0.7777	0.0106	0.7671	0.9%
8	0.7674	0.0106	0.7568	-0.5%
9	0.7772	0.0106	0.7666	0.8%
10	0.7721	0.0106	0.7615	0.1%
11	0.7762	0.0106	0.7656	0.7%
12	0.7639	0.0106	0.7533	-0.9%
	Average:	0.0106	0.7605	
	Standard Deviation:		0.0068	
		CoV:	0.009	

TABLE A20
Test Condition 15

Injection:	Mixer port # 1			
Beta:	0.7			
Sample at:	10D downstream of mixer			
Flow:	190 GPM			

Location	Output Voltage	Background Concentration	Relative Concentration	Deviation
1	0.7445	0.0104	0.7341	-0.7%
2	0.7423	0.0104	0.7319	-1.0%
3	0.7446	0.0104	0.7342	-0.7%
4	0.7496	0.0104	0.7392	0.0%
5	0.7570	0.0104	0.7466	1.0%
6	0.7605	0.0104	0.7501	1.4%
7	0.7506	0.0104	0.7402	0.1%
8	0.7561	0.0104	0.7457	0.9%
9	0.7534	0.0104	0.7430	0.5%
10	0.7475	0.0104	0.7371	-0.3%
11	0.7443	0.0104	0.7339	-0.7%
12	0.7471	0.0104	0.7367	-0.4%
	Average:	0.0104	0.7394	
	Standard Deviation:		0.0058	
		CoV:	0.008	

TABLE A21
Test Condition 16

Injection:	Mixer port # 1			
Beta:	0.7			
Sample at:	10D downstream of mixer			
Flow:	90 GPM			
Location	Output Voltage	Background Concentration	Relative Concentration	Deviation
1	0.6487	0.0099	0.6388	-0.6%
2	0.6484	0.0099	0.6385	-0.6%
3	0.6491	0.0099	0.6392	-0.5%
4	0.6562	0.0099	0.6463	0.6%
5	0.6592	0.0099	0.6493	1.0%
6	0.6589	0.0099	0.6490	1.0%
7	0.6540	0.0099	0.6441	0.2%
8	0.6513	0.0099	0.6414	-0.2%
9	0.6535	0.0099	0.6436	0.1%
10	0.6524	0.0099	0.6425	0.0%
11	0.6571	0.0099	0.6472	0.7%
12	0.6419	0.0099	0.6320	-1.7%
	Average:	0.0099	0.6427	
	Standard Deviation:		0.0051	
		CoV:	0.008	

CoV = SD/MEAN