



Process Water Oxygen Transfer Rate Test Results

Abstract

A critical aspect of Activated Sludge wastewater treatment plant design is estimation of field or process water oxygen transfer from clean water transfer data. The effects of water temperature, total dissolved solids and operating dissolved oxygen concentration are well defined and predictable. The affect of wastewater contaminants on the volumetric transfer rate constant, K_{La} , are less well defined. The ratio of the process water K_{La} to the clean water K_{La} is also known as the Alpha Factor (α).

α varies depending on the aeration process, tank geometry and water characteristics. α values ranging from 0.3 for fine bubble diffusion up the .85 for low speed surface aerators have been reported in literature. Measurement procedures for determination of α have been debated at length. Unlike clean water oxygen transfer measurement, no standard has been developed for process water oxygen transfer, however a standard guideline has been published by a joint committee of WEF and ASCE⁶.

The clean water oxygen transfer capabilities of the Mazzei AirJection Venturi Aeration process have been tested and the results have been certified by a professional engineer. The purpose of this paper is to determine the α factor for the AirJection[®] process under field conditions.

The wastewater used was primary clarifier effluent, which due its high contaminant levels should represent worst-case conditions for Alpha determination.

General:

Several process water oxygen transfer rate (OTR) tests have been completed in a 15 foot tall 3000 gal (max) poly tank using municipal wastewater at the Kern County Sanitation Authority WWTP in Bakersfield CA. Test conditions were under steady state dissolved oxygen conditions in 13.5 feet of water. The oxygen transfer rate was determined via the mass balance method, i.e. the mass of oxygen injected into the tank per unit time relative to the mass of oxygen in the off gas from the tank ^{3,6,8,9,10}.

The dirty water OTR values were compared to the standard oxygen transfer rates (SOTR) as determined by GSEE, Inc.⁴ and several SOTR test runs in the 3000 gal poly tank under similar operating conditions.

A great deal of support and guidance in this project was provided by the professional engineers at GSEE, Inc. They reviewed and confirmed the test procedure, witnessed the testing and reviewed the test results. Their valuable support is greatly appreciated.

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Test Procedure:

The Mazzei AirJection system employed in these tests was comprised of a centrifugal pump which circulated water through a 2" model 2081 Mazzei Injector. The model 2081 injector was situated at the top of the tank where it aspirated air into the water flow supplied by the pump. The volume of air aspirated was dependant on the injector inlet pressures employed. During the dirty & clean water tests, the injector was operated at inlet pressures of 10, 12 & 13.5 PSIG, which resulted in water circulation rates of 45, 49 & 52 GPM. The volumetric power investment at the three operating pressures of 10, 12 & 13.5 PSI are 0.69 WHP/1000ft³, 0.88 WHP/1000ft³ & 1.07 WHP/1000ft³ respectively. The Air/water mixture produced by the model 2081 Injector was then discharged near the bottom of the tank through two Mazzei N25 which directed the mixture across the bottom of the tank at an exit velocity of about 18 ft/s.

The top of the tank was sealed as tightly as possible so as to direct all of the off-gas out through a 2' PVC vent pipe through which the % O₂ saturation & volumetric off-gas flow rate could be measured.

Steady state DO conditions were produced by continually pumping water into the tank from the primary clarifier at the WWTP & continually discharging an exactly equal volume out of the tank through a 2" drain pipe 8' from the bottom of the tank. The aeration system was operated continuously until a relatively constant dissolved oxygen concentration was achieved. The steady state DO ranged from about 0-3.47 mg/l depending on the aeration system operating pressure as well as the condition of the wastewater from the primary clarifier at the time of the test. The Oxygen Uptake Rate (OUR) of the primary clarifier wastewater varied from day to day and during the day. The wastewater's OUR, as demonstrated by lower steady state DO, often increased as the day progressed. On some days the OUR was high all day.

For each test run, six sets of data points were collected. During the alpha factor calculation, the average and standard deviation of these data sets were calculated.

Dissolved Oxygen Measurement:

During the dirty water tests, the tank DO was measured using Royce Model 900 and YSI 50B Dissolved Oxygen Analyzers calibrated in air following the manufacturers directions. The Royce DO probe was suspended 5' below the water surface. The YSI DO probe was suspended 5' from the tank bottom. Both probes were suspended with the membrane up to prevent the collection of bubbles on the membrane.

Off-gas % O₂ Saturation Measurement:

The % Oxygen saturation in the off-gas was measured using a Teledyne Analytical Instruments Model 320P/D Portable Oxygen Analyzer equipped with a built in air pump for sampling. The meter was calibrated with dry air to 20.9% Oxygen. After each off-gas sample the meter was rechecked vs. air and adjusted as needed.

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CO₂ was scrubbed from both the calibration air and off gas sample by scrubbing through a solution of 5% NaOH. Moisture was removed by drawing both the calibration air and off gas samples through a desiccant column filed with a mixture of Calcium Sulfate and Silica Gel. Both the caustic scrubber solution and the desiccant were changed daily.

The precision level of the 320P/D Oxygen meter is to one decimal point; therefore, the calculation of feed gas O₂ mass was rounded to 20.9% rather than the actual for dry air of 20.946%.

Air Flow Measurement:

The airflow rates were measured using a volumetric device constructed from two 55-gallon steel drums (refer to the attached pictures & drawings). The drums were connected near their bottoms by a 2" conduit. A sight glass was installed on the connecting conduit in order to measure the water level in the drums. A steel ruler on the sight glass was used to measure water level. The 2' opening of one drum was left open to the atmosphere. The 2" opening of the other drum was connected via valve/pipes to the injector suction piping and off-gas piping.

The drums were filled half way with water. By manipulation of the valves on the suction/off-gas piping, the water levels in the drums could be changed relative to each other. For example, when one drum was connected to the suction port of the injector the water level in that drum was drawn up and the level in the drum vented to atmosphere would be pulled down. Conversely, when connected to the off gas piping the level in that drum pushed down while the level in the drum vented to the atmosphere was pushed up. By measuring the rate of water displacement in inches per second, a measurement of the feed gas and off-gas flow rates was achieved.

Calibration of this device was achieved by empirical comparison of the feed gas flow rates to measurements made with a Dwyer Model 471 Digital Thermo Anemometer. It was found the anemometer indicated flow rates about 1.61 times as high as the simple measurement of the water displacement would indicate. The volume of the head space (including the 2' piping) above the water in the drum connected to the tank was calculated to range from 5.208 ft³ to 3.351 ft³ across a water displacement range of 8". The ratio of the 5.208/3.351 = 1.554, which correlates well with the factor determined by the anemometer of 1.6111. For feed gas flow rate calculation the 1.554 ratio was used to correct the water displacement rate to the actual airflow rate.

Because the off-gas measuring piping is connected to the top of the tank, which adds additional volume, an additional correction factor for the off-gas flow had to be determined. In order to determine this factor, the tank was filled with fresh water to the operating depth of 13.5' and aerated for several hours in order to completely saturate it with air. Under these conditions, the feed gas rate and off-gas rate had to be equal. The water displacement rates of feed-gas vs. off-gas were then compared over a range of

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feed gas rates. The ratio of the off-gas displacement times to the feed-gas displacement times were plotted on a chart. A correction factor formula for the off-gas water displacement times was calculated by the computer to be:

$$\text{Off-gas Correction Factor} = 0.0011 \times \text{water displacement time} + 1.595$$

This formula was used to correct the off-gas water displacement times for calculation of the off-gas flow rates. The reason this line slopes up is that the leak-rate of the tank has a greater affect at long displacement times relative to short displacement times.

Please refer to the attached calculation sheets and charts for a more in depth analysis of this subject.

Feed-gas Flow Rate Calculation:

During all test runs the gas-flow rates were measured by timing the displacement rate of water in the drums over a displacement range of 8". The area of the drums is 2.7858 ft². The correction factor of 1.554 (as detailed above) was used to correct the measured CFM to actual CFM.

$$1.554 \times 8"/12"/ft \times 2.7858 \text{ ft}^2 \times 60\text{s}/\text{min} / \text{displacement time (s)} = \text{Feed-gas CFM}$$

Off-gas Flow Rate Calculation:

The formula for off-gas is the same as for the feed-gas except the displacement time is divided by the off-gas correction factor as detailed above.

During the testing 150 separate data points were collected. The CFM Off-Gas values vs. the CFM Feed values are plotted in the attached chart. The R2 correlation of the power regression line fit on the cart was 0.8659, which is good considering the difficulty in precisely measuring airflow under field conditions.

Correction to Standard Temperature:

Both the feed-gas and off-gas flow rates were corrected to standard temperature (78 °F or 20 °C) as follows^{12,13}.

$$\text{CFM} \times (293.2/(273+\text{Gas temp } ^\circ\text{C})) = \text{SCFM}$$

Relative Humidity and Temperature Measurement:

The relative humidity (RH) and temperature of the feed gas was measured with a Dwyer model TH-10 Humidity/temperature pen which was calibrated against the supplied RH standards following the manufacturers directions. The RH of the off-gas was assumed to be 100%. Off-gas temperature was measured with the Orion Model 840 oxygen meter.

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The affect of humidity on gas volume was calculated by two methods, which yielded identical results. The first method follows:

The dew Point % H2O concentration relative to air temperature was calculated from a psychrometric chart¹³ and tabulated in the attached table. The dry Feed Air volume was calculated from the measured wet air volume as follows:

$$\text{Wet CFM} \times (((100 - \text{Dew Point \% H2O})/100) \times (\text{RH}/100)) = \text{Dry Feed Air CFM}$$

The O2 concentration of the off-gas was calculated using the dew point % H2O only (because the gas was assumed to be 100 % saturated), and the % O2 saturation (as measured by the average of the Orion & YSI DO meters as detailed above. The off-gas O2 % concentration was calculated as follows:

$$\text{Wet CFM} \times (((100 - \text{Dew Point \% H2O})/100) = \text{Dry Off-Gas CFM}$$

Alternatively, the partial pressure of water vs. air temperature at 100% humidity as depicted in the attached chart was used to correct for humidity with the following formula³:

$$\text{Dry CFM} = \text{Wet CFM} \times (\text{BP} - (\text{Rha} \times \text{Pva})) / (\text{BPs} - (\text{RHs} - \text{PVs}))$$

BPs = Standard Barometric Pressure

BP = Site Barometric Pressure

RH = Relative Humidity , % (s =Standard 36%, a = Actual operating conditions)

PV = Vapor Pressure of Water (s=standard 0.3391, a = at air temperature)

Oxygen Mass Calculation & OTR:

Oxygen has specific weight of 0.08305 #/SCF @ 20 °C (Annex A). Therefore, the mass of O2 in the feed-gas and off-gas are calculated as follows^{12,13}:

$$\text{Dry Feed-Gas SCFM} \times (20.9/100) \times 0.08305 \# \text{ O2/SCF} = \#/\text{min O2 Feed}$$

And

$$\text{Dry Off-Gas SCFM} \times (\text{O2 \%}/100) \times 0.08305 \# \text{ O2/SCF} = \#/\text{min O2 Off-Gas}$$

Oxygen Transfer Rate Calculation (OTR):

The OTR is the difference in the mass of O2 in the feed-gas relative to the off-gas. The OTR in units of # O2/hour is calculated as follows^{6,9}:

$$(\text{Feed-gas \# O2/min} - \text{Off-gas \# O2/min}) \times 60 \text{ min/hour} = \text{OTR \# O2/hour}$$

Alpha Calculation:

A procedure for determination of **SOTR** from **AOTR** (actual oxygen transfer rate under operating conditions) is detailed in Off-Gas Process Water Oxygen Transfer Measurement, GSEE Inc. The calculation procedure follows:

$$SOR = \frac{AOTR}{\alpha \left[\frac{\beta \times C_{sw} - C_L}{C_{ss}} \right] \Theta^{(T-20)}}$$

where:

SOR	=	Standard Oxygen Requirement
$AOTR$	=	Actual Oxygen Transfer Rate
α	=	Oxygen Transfer Coefficient
	=	$\frac{OTE \text{ waste water}}{OTE \text{ clean water}}$
β	=	Oxygen Solubility Coefficient
	=	$\frac{C_{smT} \text{ for waste water TDS level}}{C_{smT} \text{ for clean water (0 mg/l TDS)}}$
Θ	=	Temperature correction factor (normally 1.024)
C_L	=	Aeration basin dissolved oxygen level, mg/l

$$C_{sw} = C_{SM}T \left[\frac{BP + 0.4335 \times DWD \times f}{14.7} \right]$$

$$C_{ss} = 9.092 \left[\frac{BP + 0.4335 \times DWD \times f}{14.7} \right]$$

where:

$C_{SM}T$	=	Oxygen saturation value at 1 ATM and test liquid temperature, from "STANDARD METHODS", mg/l
DWD	=	Air release or Diffuser water depth, Ft.
f	=	Effective Depth Factor (Avg. 0.45 For the AirJection Process from the GSEE SOTR Test Results)

From this equation α is calculated as follows:

$$Alpha = \frac{AOTR}{SOTR \left[\frac{\beta \times C_{sw} - C_L}{C_{ss}} \right] \Theta^{(T-20)}}$$

The Alpha factor was calculated by this procedure relative to the GSEE SOTR test data. The results are detailed in the attached Test Results Summary table.

SOTR Values:

SOTR values for the AirJection process have also been determined @ GSEE Inc. in Lavergne TN⁴. Alpha values are calculated based on this data are expressed in the



attached calculation sheets. Attached are charts which depict a distillation of the GSEE SOTR test results into SOTR vs. water depth at gas/liquid ratios of 0.05-0.80 in increments of 0.05Vg/Vl at operating pressures of 10, 12 and 15 PSI¹⁴. The power regression formulas on these charts are the ones used to calculate the SOTR values used in the Alpha calculation. For the 13.5 PSI data sets, the SOTR was interpolated from the 12 PSI and 15 PSI data. Following is a tabulation of the results:

Conclusion:

These results indicate that the alpha factor for the AirJection process is likely to be about 0.93 with wastewater similar to the typical municipal sewage used for the testing. **Since all of the process water testing was performed using raw primary effluent water, these results should be viewed as worst-case results.** Normally process water oxygen transfer tests are performed in complete mix activated sludge basins where the quality of the process water is equivalent to the aeration basin effluent. Aeration basin effluent will typically be cleaner and less contaminant loaded than primary clarifier effluent, and hence will typically yield higher process water transfer rates and Alpha's.

The test procedures and test results were witnessed and reviewed by the professional engineers from GSEE Inc. The results have been deemed reasonable and appropriate relative to the test conditions employed following the procedures outlined in the Standard Guidelines for In-Process Oxygen Transfer as published by a joint committee of the WEF and ASCE aeration systems subcommittees⁶. As such, these test results can be used as guidelines for aeration system designs which utilize the Mazzei Injector Corporation AirJection[®] Process.

Annex A Calculation Details

Oxygen Density:

- 1.0 mole of Gas = 22.414 l @ 273.2 °K and 14.696 PSIA
- @ 20 °C 22.414 l/mole x (273.2+20)/273.2 = 24.055 l/mole
- 1.0 mole Oxygen = 32 g/mole therefore 32 g/mole / 24.055 l/mole = 1.3303 g/l
- 1.3303 g/l x 28.317 l/ft³/45359 g/# = 0.08305 # O₂/ ft³ @ 20 °C

CRC Handbook of Chemistry & Physics, 58th Edition 1977-1978

Humidity Correction via H₂O Partial Pressure Method:

Airflow rate is defined as follows:

SCFM = Standard Cubic Feet per Minute (14.7 PSIA, 68°F, 36% RH and a density of 0.075 Lb/Ft³)

ACFM or Actual Cubic Feet per Minute refers to air flowing at any condition other than standard. ACFM can be calculated as follows:

$$ACFM = \left[\frac{BP_s - (Rh_s \times P_{V_s})}{BP - (Rh_a \times P_{V_a})} \right] \times \frac{BP}{(BP + LP)} \times \frac{(460 + LT)}{528} \times SCFM \quad \text{Eq. 0-1}$$

Where:

- BP_s** = Standard Barometric Pressure, 14.7 PSIA
- Rh** = Relative Humidity, % (s = Standard 36%, a = actual operating conditions)
- P_{va}** = Vapor Pressure of Water, PSI (s = standard 0.3391, a = at actual Temperature)
- BP** = Site Barometric Pressure, PSIA
- LP** = Flowing Line Pressure, PSIG
- LT** = Flowing Line Temperature, °F
- 528** = Standard Temperature (460 + 68°F), °R

GSEE Inc. Off-Gas Process Water Transfer Rate Measurement

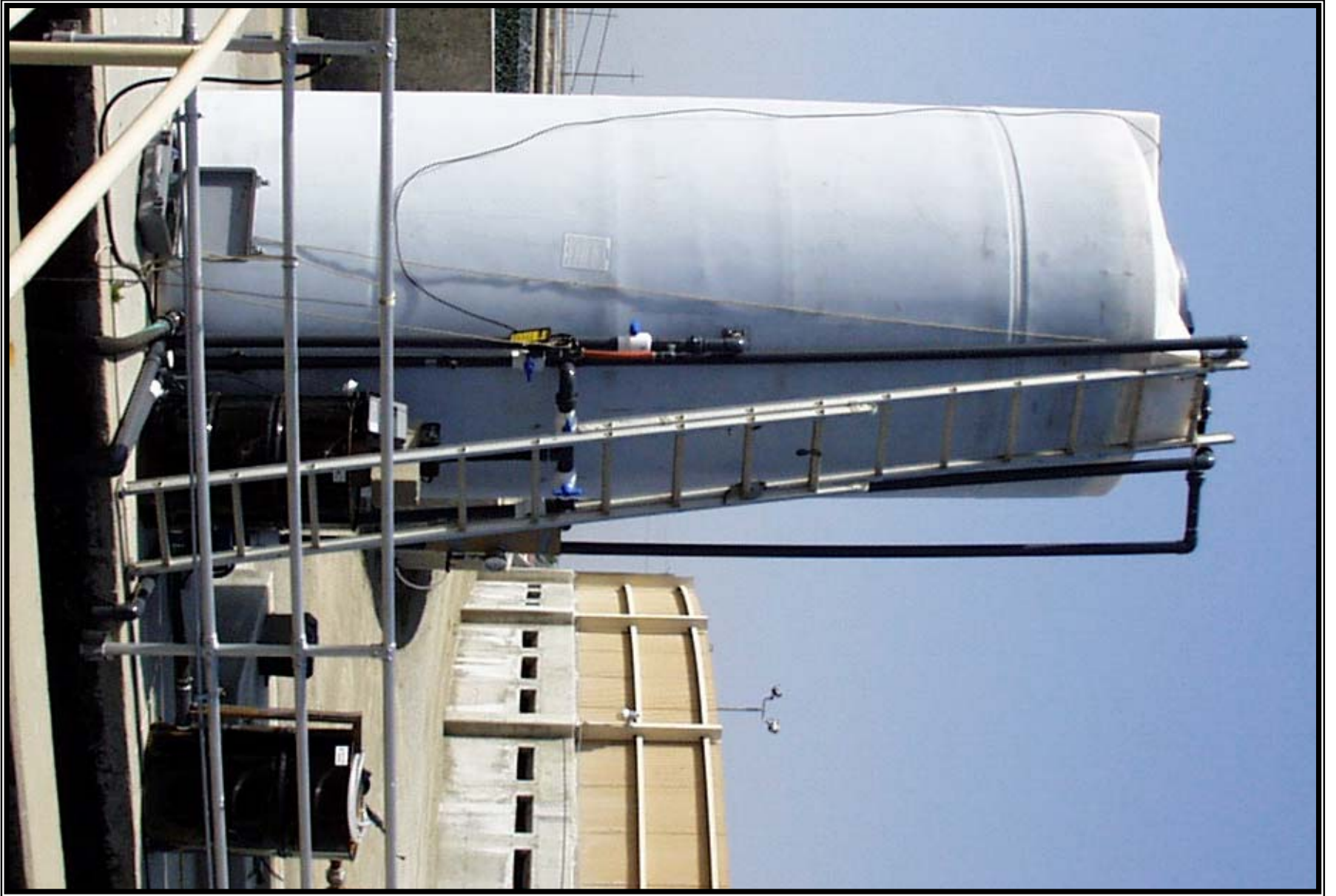


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Test Results Summary

Test Date	Operating Pressure	Alpha vs. GSEE SOTR GSEE Calculations
8/13/2003	10.0 PSI	0.88
8/18/2003	10.0 PSI	0.99
8/20/2003	10.0 PSI	0.88
9/12/2003	10.0 PSI	0.94
9/22/2003	10.0 PSI	0.95
	Average	0.93
	STDEV	0.05
8/13/2003	12.0 PSI	0.77
8/18/2003	12.0 PSI	0.99
8/20/2003	12.0 PSI	0.84
8/21/2003	12.0 PSI	0.90
8/29/2003	12.0 PSI	0.96
8/29/2003	12.0 PSI	0.89
9/11/2003	12.0 PSI	1.00
9/16/2003	12.0 PSI	0.94
	Average	0.91
	STDEV	0.08
8/12/2003	13.5 PSI	0.77
8/13/2003	13.5 PSI	1.07
8/19/2003	13.5 PSI	1.11
8/19/2003	13.5 PSI	0.77
8/20/2003	13.5 PSI	0.95
8/21/2003	13.5 PSI	0.86
8/28/2003	13.5 PSI	0.98
8/28/2003	13.5 PSI	0.85
9/5/2003	13.5 PSI	0.79
9/10/2003	13.5 PSI	0.91
9/15/2003	13.5 PSI	1.01
	Average	0.93
	STDEV	0.12



Air Flow Measurement System



55 Gallon Drums



Sight Glass



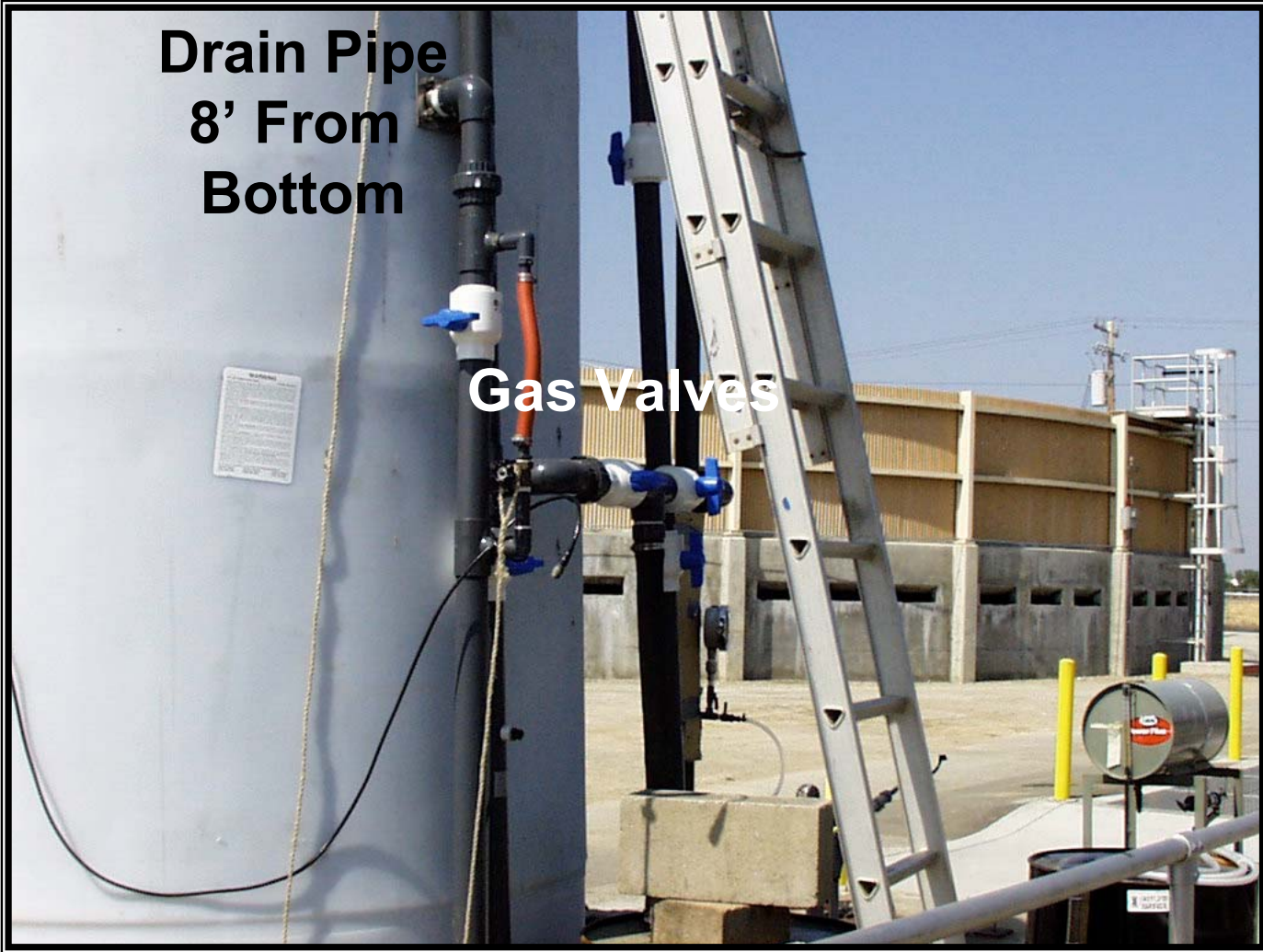
DO Meter



DO Probe Insertion Point

**Drain Pipe
8' From
Bottom**

Gas Valves



Primary Clarifier





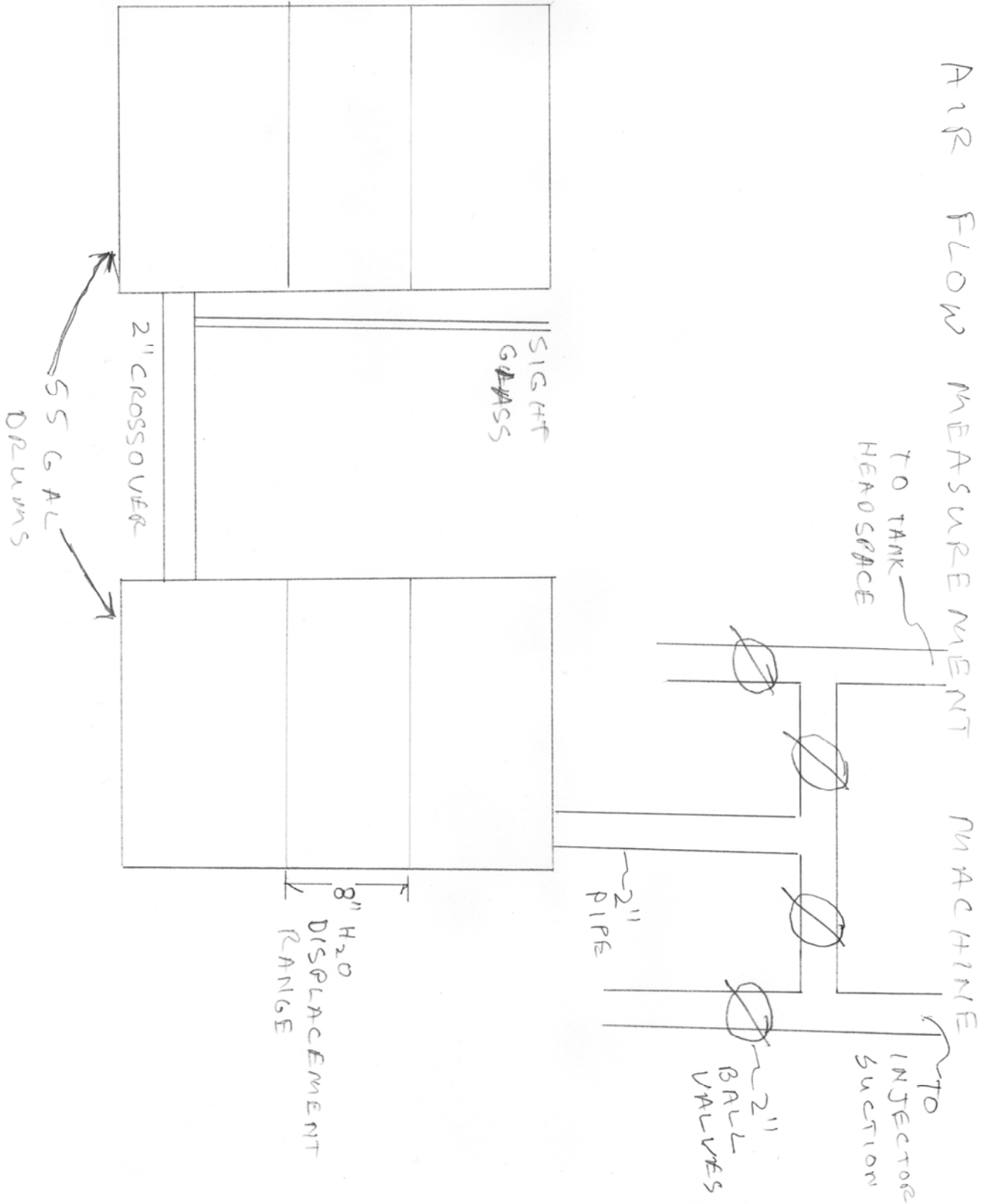




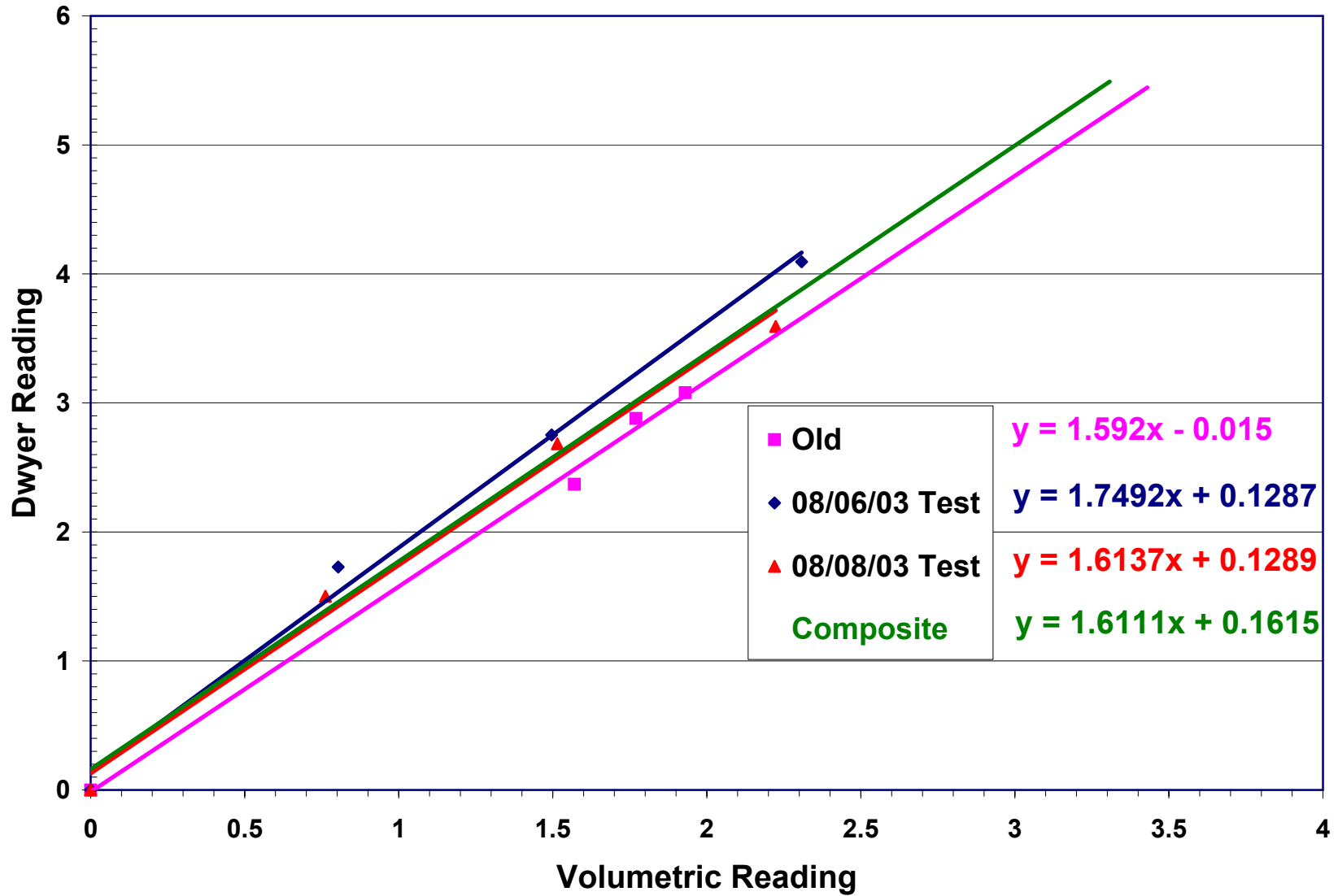


Setting the standard for efficiency

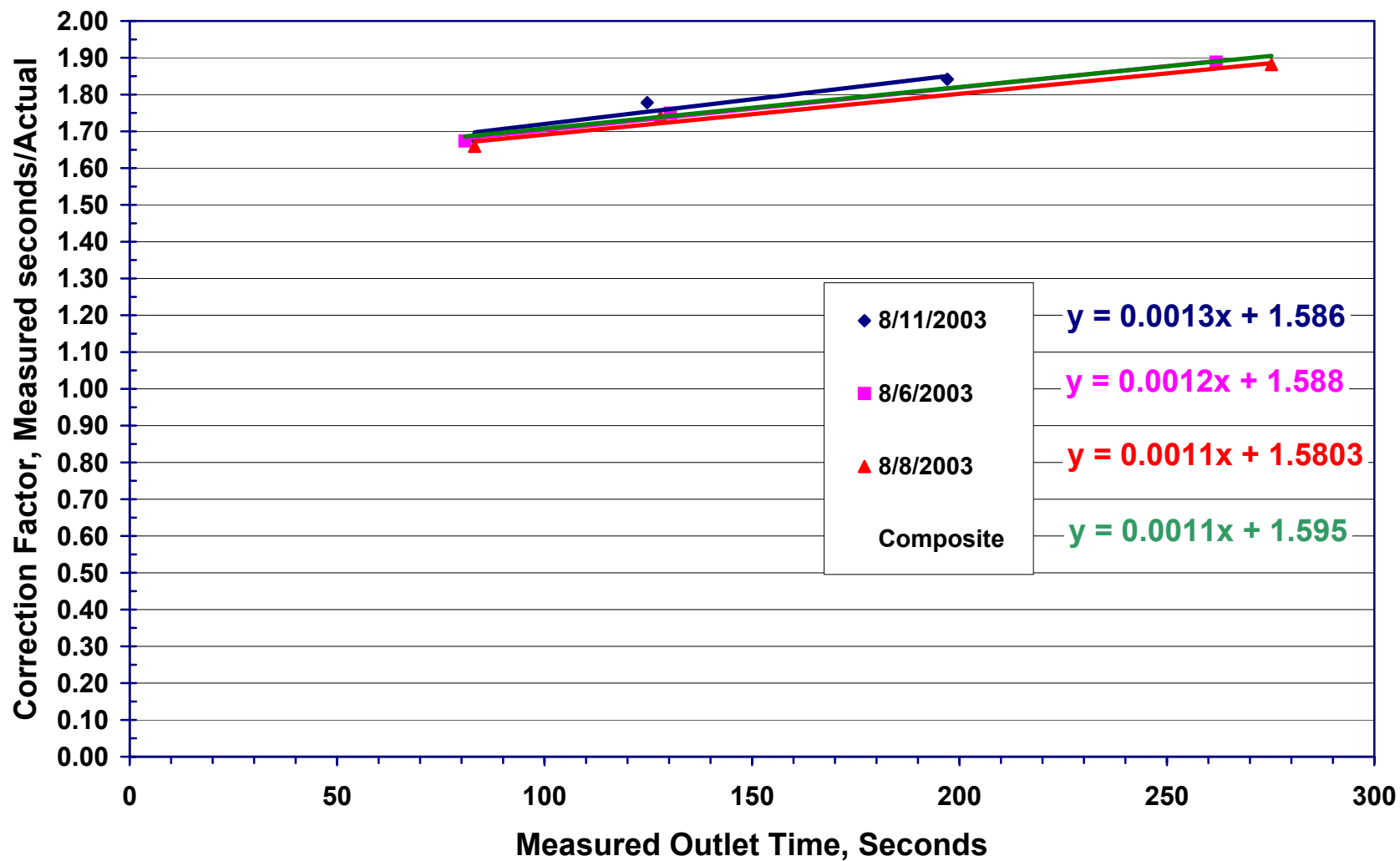
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Dwyer Meter vs. Volumetric



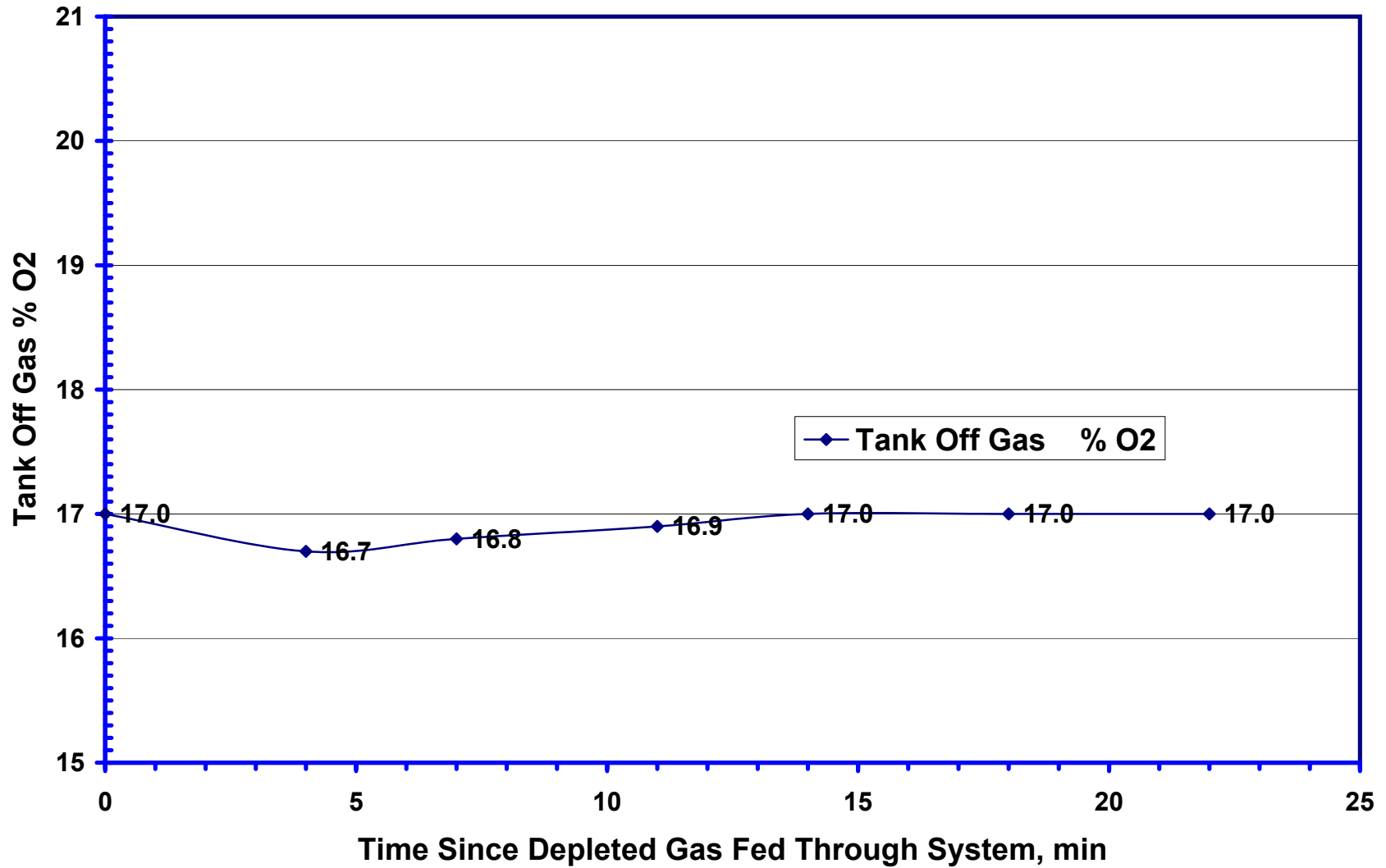
Outlet CFM Measurement Correction Factor



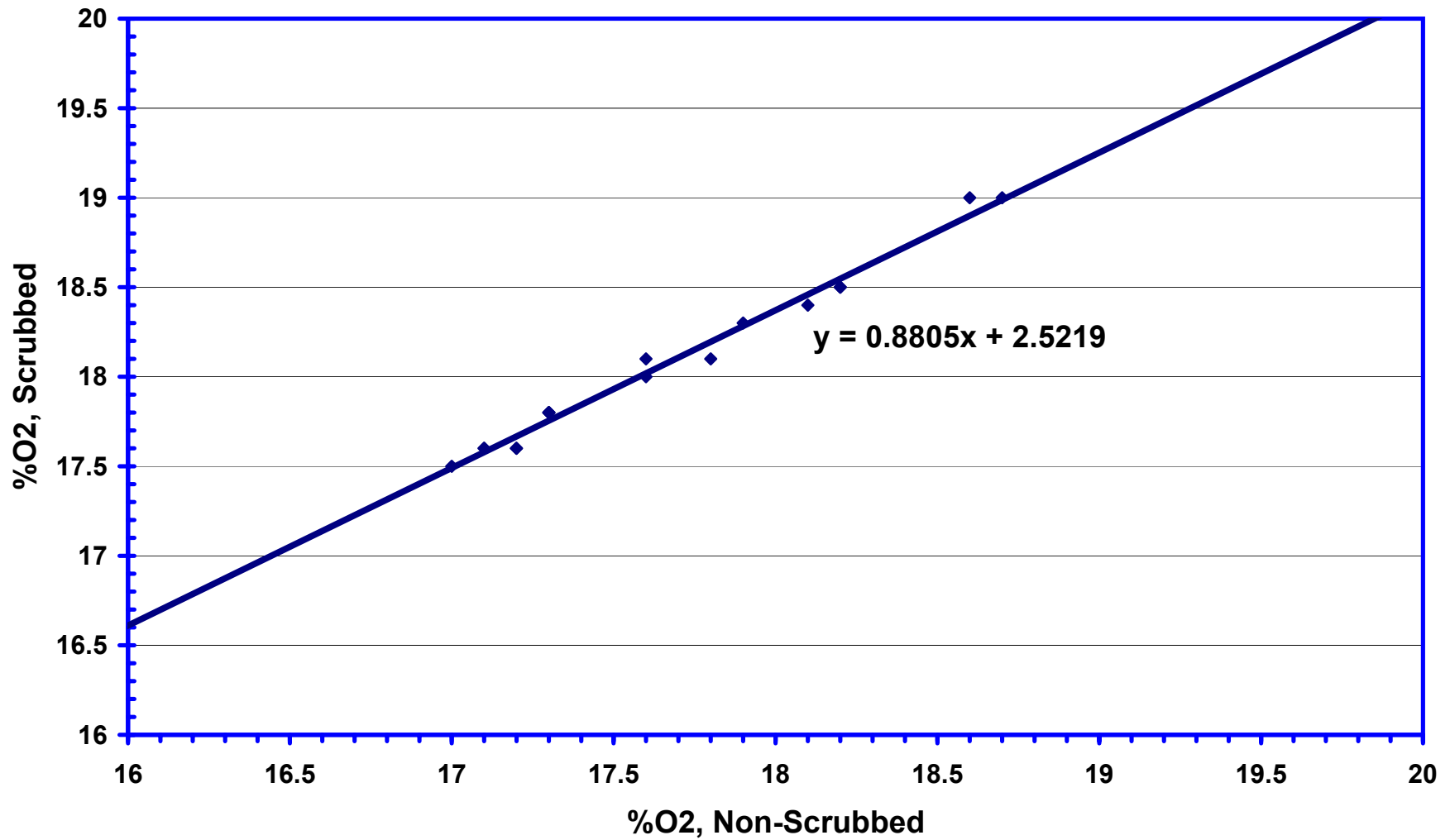
Alpha Test Results 10.0 PSI operation 09/22/03

	Beta	Omega	Sat DO C20	Barometric Pressure, PSIA	Csw	Css	
	0.99	1	10.6	14.37	8.90	10.52	
Air in Seconds	Measured Air Out Seconds	Corrected Air Out Seconds	Water Temp	DO @ Op Temp	Tau	YSI DO mg/l	Royce DO mg/l
71.95	154.55	87.6	29.5	7.69	0.85	0.86	1.53
73.46	158.92	89.8	29.5	7.69	0.85	0.29	0.98
72.88	157.24	88.9	29.6	7.69	0.85	0.16	0.09
73.45	158.89	89.8	29.6	7.69	0.85	0.15	0.02
73.12	157.94	89.3	29.6	7.69	0.85	0.14	0.01
72.39	155.82	88.2	29.7	7.69	0.85	0.14	0.01
Average DO Mg/l	Air In Temp	Air In RH %	Feed Air CFM	Air Out Temp	Off Gas CFM	Off Gas % Sat *Caustic Scrubbed	
1.20	30.6	50	2.41	32.3	1.98	18.8	
0.64	31.7	52	2.36	33.8	1.93	18.4	
0.13	33.5	45	2.38	33.0	1.95	18.4	
0.09	34.3	37	2.36	34.9	1.93	18.3	
0.08	35.6	43	2.37	35.1	1.94	18.0	
0.08	36.4	36	2.39	34.8	1.96	17.9	
OTR		SOTR (GSEE Tests) *			Alpha vs. GSEE SOTR GSEE Calculations		
0.67		0.74			1.00		
0.70		0.74			0.97		
0.69		0.74			0.89		
0.71		0.74			0.92		
0.72		0.74			0.93		
0.73		0.74			0.95		
				Average	0.95		
				STDEV	0.04		

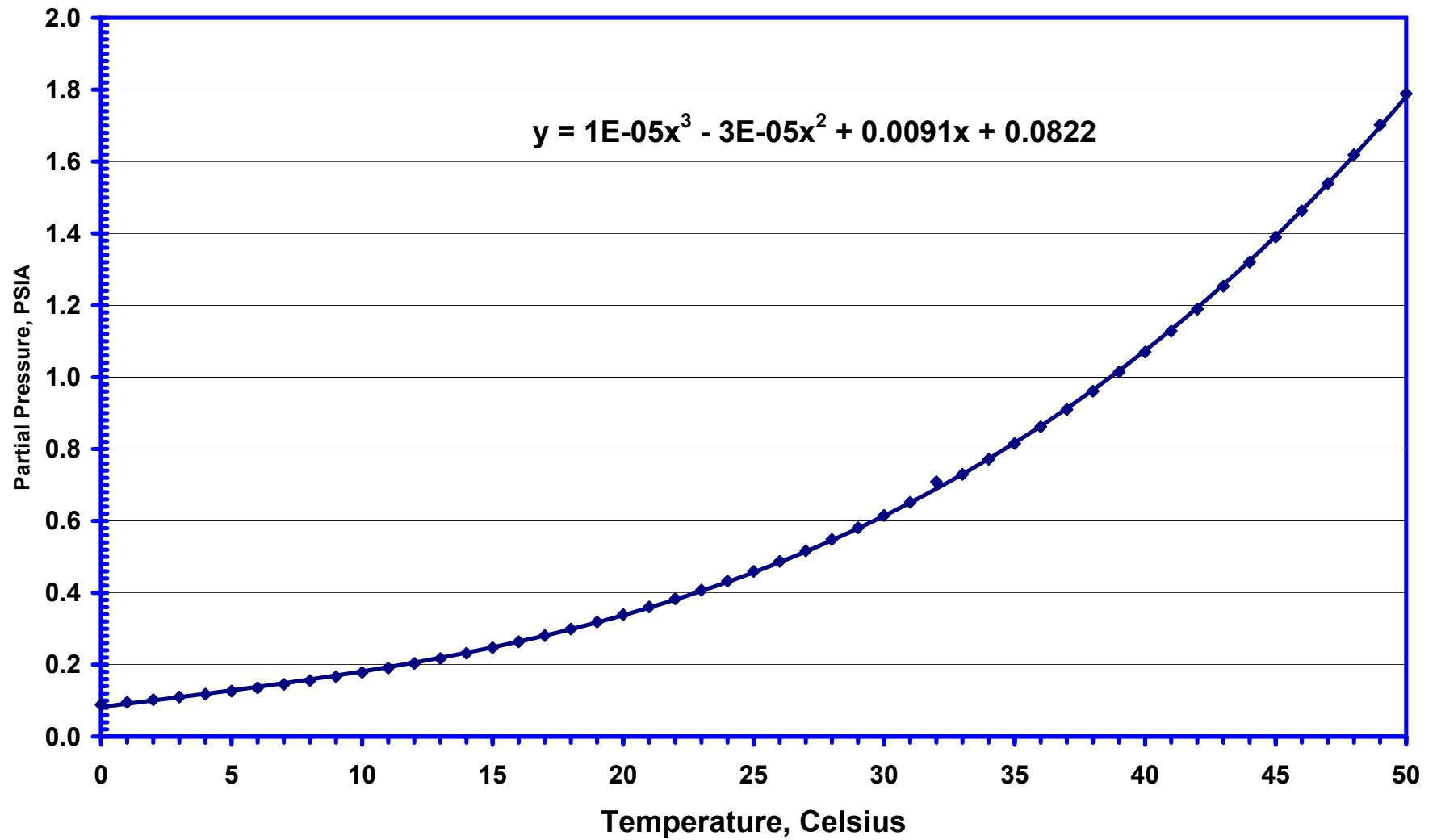
Lag Time For Depleted Feed Gas To Flush Through System Tank Off Gas % O2



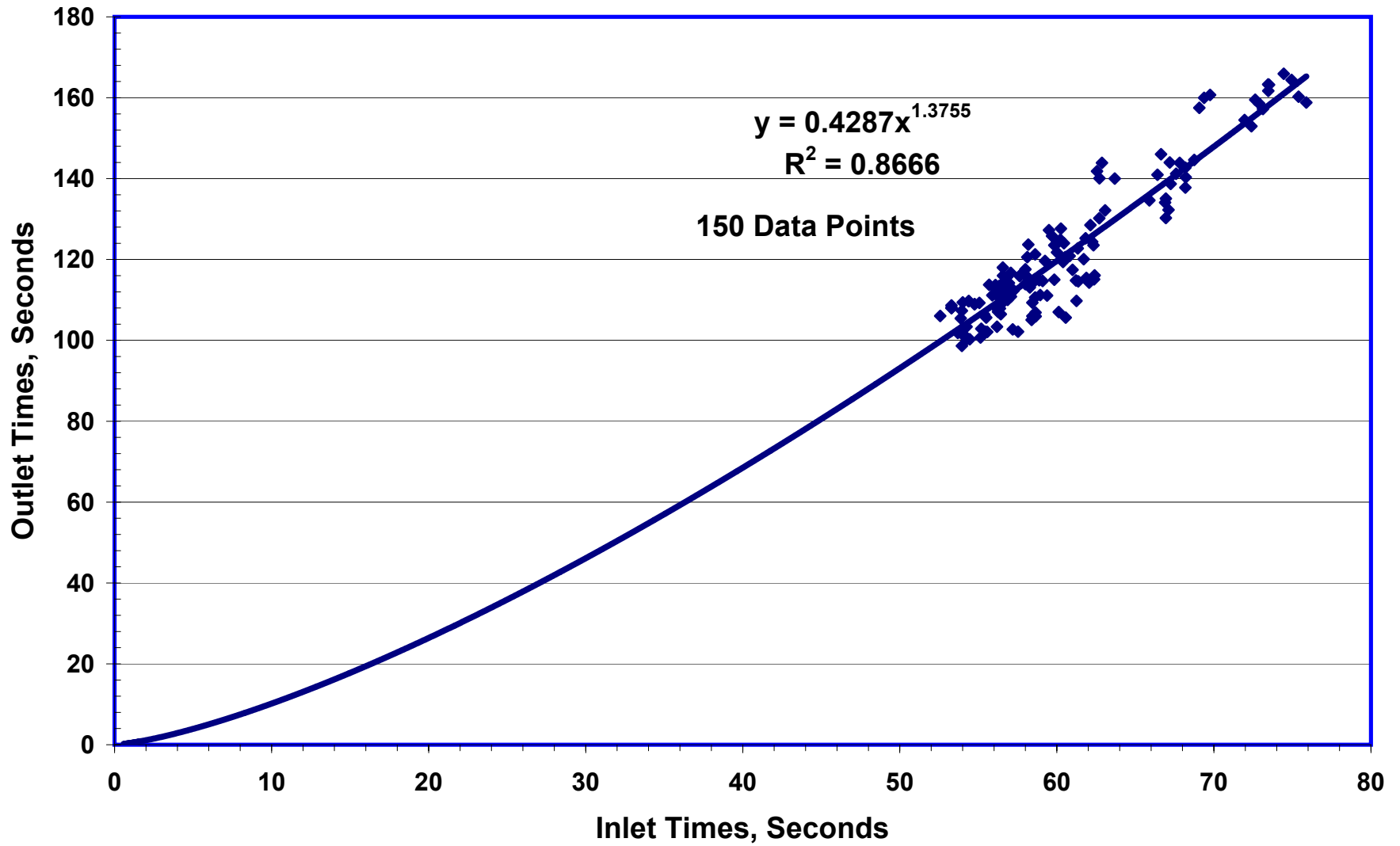
Off Gas O2 Concentration Non-Caustic Scrubbed vs. Caustic Scrubbed



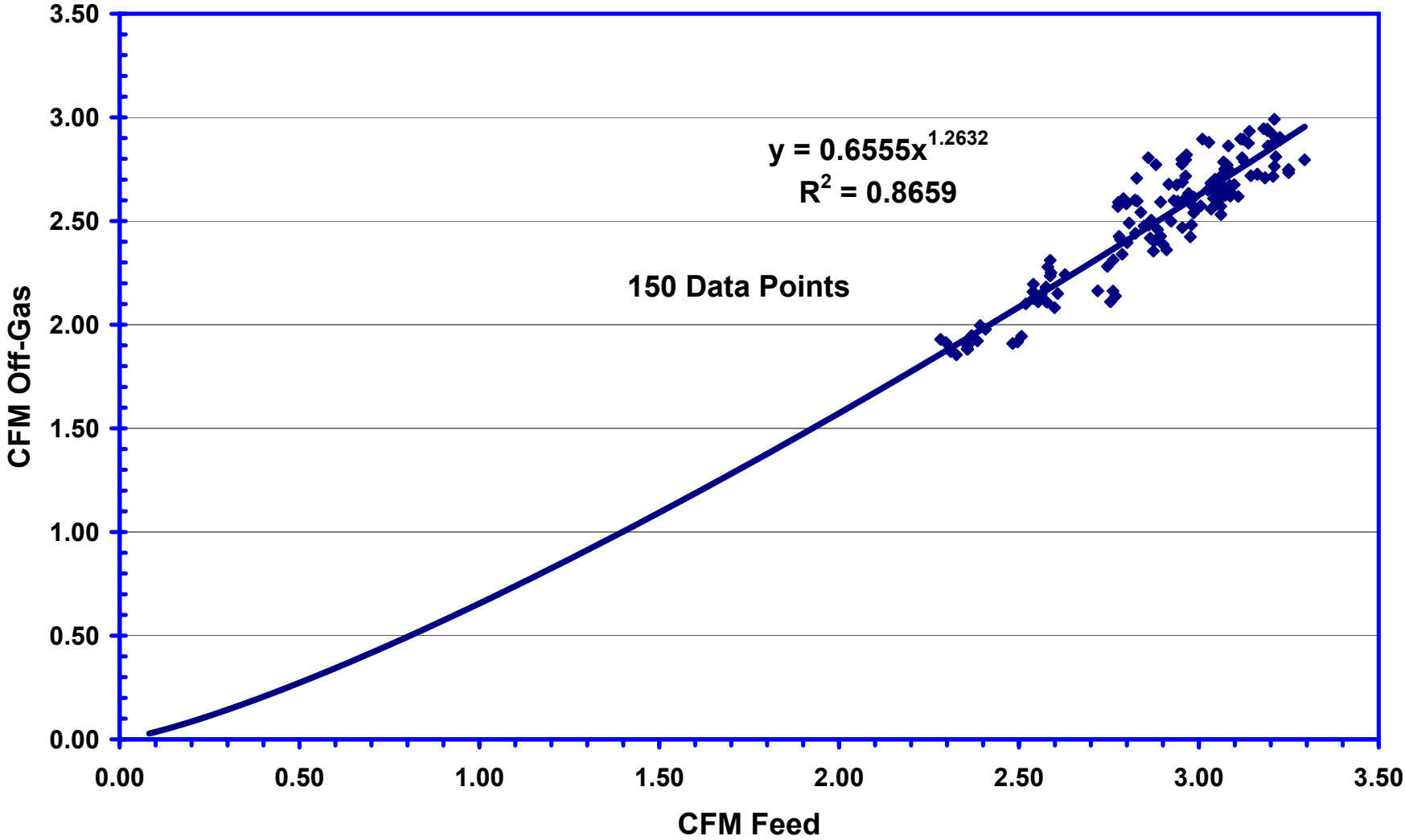
Parial Pressure of Water vs. Temperature



Inlet vs. Outlet Times (Uncorrected)



CFM Off-Gas vs. CFM Feed



Off-Gas CFM % of Feed CFM

