Initial Testing of Aeration Facility
Capacity and Efficiency

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Acronyms and Abbreviations

Cfs	cubic feet per second
DES	Division of Environmental Services
DO	dissolved oxygen
DWR	California Department of Water Resources
DWSC	Deep Water Ship Channel
Facility	Stockton Deep Water Ship Channel Demonstration Dissolved Oxygen Aeration Facility
ft/sec	feet per second
ft^2	square feet
Hr	hour
Lbs	pounds
lbs/ft^3	pounds per cubic foot
mg/l	milligrams/liter
mm	millimeters
Psia	pounds per square inch absolute
RRI	Rough and Ready Island
scfm	standard cubic feet per minute

Initial Testing of Aeration Facility Capacity and Efficiency

Summary

Initial testing of the California Department of Water Resources (DWR) Stockton Deep Water Ship Channel Demonstration Dissolved Oxygen Aeration Facility (Facility) was performed March 13, 2008 and March 18, 2008. The testing was done to evaluate the facility oxygen delivery capacity and oxygen transfer efficiency.

Test results showed that the best measured oxygen delivery capacity at full water flow and an oxygen gas supply rate of about a 4% gas/water ratio was about 8,000 pounds (lbs)/day. This is less than the design capacity of 10,000 lbs/day. The facility full water flow was about 45 cubic feet per second (cfs), which is less than the design rate of 50 cfs. The measured dissolved oxygen (DO) concentration range in the facility U-tube discharges was about 41 to 43 milligrams/liter (mg/l). The inflow DO from the Stockton Deep Water Ship Channel (DWSC) was about 9 mg/l; therefore, the DO increment added at the full water flow of about 45 cfs (22.5 cfs in each U-tube) was about 32 to 34 mg/l. The initial oxygen transfer efficiency of the facility U-tubes was about 60%. The design efficiency for oxygen gas transfer (i.e., dissolution) in the U-tubes is up to 90%, so it was anticipated that about 25% more oxygen gas would be supplied to the U-tubes than would be dissolved and discharged into the DWSC. There may be changes in the U-tube gas injection apparatus that will allow more oxygen gas and smaller bubbles to be injected. These modifications to the spargers (gas injectors) of the U-tubes may increase the capacity and the oxygen transfer efficiency of the Facility. Potential modifications to increase the full water flow rate of the Facility are not considered in this report.

Introduction

The Facility is located at Dock 20 near the western end of Rough and Ready Island (RRI) (i.e., Port of Stockton West Complex) in the DWSC. The facility design followed the basis of design prepared by HDR Engineering and Jones & Stokes (now ICF Jones & Stokes) in 2005 (HDR Engineering 2004). The Facility includes two 200-foot-deep concentric U-tubes (i.e., one pipe within the other), allowing oxygen to be dissolved or transferred into water that is pumped from the DWSC. The oxygen is injected as gas bubbles at the top of the down-flow U-tubes (tubes A and B), and the gas bubbles are dissolved under relatively high hydrostatic pressure (maximum of 7.25 atmospheres, 100 pounds per square inch absolute (psia) at the bottom of the U-tubes). This design was based on the description and field test results of two similar U-tubes located at paper pulp mills along the Tombigbee River in Alabama (Speece 1996). This report presents a summary of the testing procedures, measurements, design parameters and the estimated capacity and oxygen transfer efficiency for various operating conditions tested on March 13, 2008 and March 18, 2008.

Test Procedures, Measurements, and Conditions

Field Testing Procedures

The initial testing followed the general testing plan developed for DWR (Jones & Stokes 2004) and the initial testing procedures (Jones & Stokes 2007). The goal of this testing was to measure the increase in DO concentration from the inlet to the outlet of the U-tubes under normal operation of the Facility and to calculate the capacity and efficiency. The secondary goal was to gain confidence in the accuracy of the measurements from the DO sensors and the accuracy of the oxygen gas flow rates. The basic steps were to:

1. Operate pumps to provide maximum flow (22.5 cfs) to each U-tube,
2. Add oxygen gas at full rate of about 4% gas to water flow (volume ratio),
3. Measure the change in DO concentration between inlet and outlet,
4. Calculate the oxygen discharged per day to the DWSC, and
5. Calculate the gas transfer efficiency for the U-tubes.

Measurements

The RRI mid-depth DO sensor was used for the inflow DO measurements. The inflow DO was about 9 mg/l on March 13, 2008. Because the final U-tube DO sensors (OxyGuard) have not been installed, YSI 6600 sensors were placed in flow-through chambers attached to the outlet ports of each U-tube to obtain DO measurements. The YSI sensors were calibrated and placed in the flow-through cells and connected with hoses from the outlet ports on each U-tube. Water samples were collected from the outlet ports for modified Winkler titrations to verify and adjust the DO sensor measurements.

Start-up Procedures

Prior to beginning system operation, all system components were visually inspected for structural integrity, leaks, and proper lubrication levels. The first step in normal system startup procedures was to clean the fish screens that surround the pump intakes by engaging the two-step airburst cleaning mechanism. The air discharge valves were opened sequentially to allow the airburst system to discharge into the fish screen cylinders. Water flow totalizer (cumulative volume) readings were recorded for flow meters A and B prior to startup. To initiate the testing, the vertical turbine pump for U-tube A was turned on and allowed to operate for a period of 1 minute until water flow reached a steady state. During this time the system was monitored for unusual noises, vibrations, leaks, and any other signs of equipment malfunction. This was followed by the startup and subsequent monitoring of the vertical turbine pump for U-tube B. Once both pumps were running at full capacity, flow rates and water velocity readings were checked and recorded to verify proper operation at maximum water flow.

Prior to supplying any oxygen gas to the system, the liquid oxygen level and pressure in the storage tank were recorded, as were the totalizer readings for the two oxygen gas flow meters. Then all appropriate valves were opened, with the exception of the valves that control oxygen flow to the U-tubes. Gas pressure was checked for oxygen lines A and B and set to the 45 psi design pressure by adjusting the pressure regulators. Then the supply valves were opened halfway to establish gas flow to the U-tubes. This was followed by the engagement of the "Oxygen Start" buttons in the control shed for U-tubes A and B, thereby introducing oxygen flow to the air injection apparatus at the top of the U-tubes. The supply valves were opened completely, and the gas pressure was readjusted to 45 psi.

Test Conditions

A total of five tests with unique test conditions were conducted. The first test was conducted with both water and oxygen at full flow capacity. Water and oxygen flow rates were varied for the four subsequent tests. Independent DO concentrations were monitored using sampling ports on each U-tube outlet pipe. DO concentration measurements were collected each second using two YSI 6600 sondes placed upside down in flow-through cells to minimize interference from oxygen bubbles on the membranes. Two samples from each water port were collected for each test condition in biochemical oxygen demand (BOD) bottles with chemicals added for "fixing" the DO for subsequent titration using a modified Winkler procedure (Standard Methods) for high DO concentrations.

DWR Division of Environmental Services (DES) staff operated the RRI monitoring station with an increased frequency (1-minute interval) for the surface (1-meter depth) and the mid-depth and bottom probes. These measurements were used to estimate the background (inlet) DO concentration of about 9 mg/l during the testing period. The testing period was not long enough to add DO during the entire tidal cycle (25 hours), so the influence of the added oxygen at the RRI monitoring location is difficult to detect. There is almost always a diel (daytime) increase in the RRI DO concentration caused by surface stratification and algae photosynthesis. A full day operation of the Facility to evaluate the direct effects at the RRI station is planned.

Capacity and Efficiency of the Aeration Facility

The aeration capacity of the Facility depends on the pumped water flow, the supply rate of oxygen gas (measured in standard cubic feet [scf] of gas at atmospheric pressure and 70^{o}F), and the gas transfer fraction (efficiency) that is dissolved into the water as it flows through the U-tubes. The gas flow supply rate is often expressed as a percentage of the water flow rate (standard cubic feet [scf] of oxygen gas per second to water flow [cfs]). For every 1% of oxygen gas flow (scf per second per water flow [cfs]) added at the top of a U-tube, the added DO concentration increment at a U-tube discharge if all the oxygen gas were dissolved in the water (100% efficiency) would be about 13 mg/l (because water weighs about 62.25 pounds per cubic foot [lbs/ft^3] and oxygen gas weighs about 0.0831 lb/ft^3). Accordingly, a 2% gas flow/water flow would add a maximum of about 26 mg/l of DO to the water if all the oxygen gas were dissolved. However, not all of the gas would be completely dissolved even in the 200-foot-deep U-tube. The efficiency of the gas transfer will be determined by comparing the calculated added incremental DO concentration (i.e., DO in the U-tube outlet minus DO in the U-tube inlet) with the maximum possible DO increase.

The two independent U-tubes were constructed so that field tests with different water flows (i.e., water velocities and travel times) and gas supply ratios can be conducted. Each U-tube has a maximum pumped flow of about 22.5 cfs (when both are operating), with a valve to reduce the flow to about 50% of maximum for testing performance at slower velocities. Slower velocities (longer residence times) are assumed to increase the gas transfer efficiency of the U-tubes but will lower the delivered capacity (because of lower flows) of DO to the DWSC. Lower gas supply rates may allow smaller initial bubbles with increased gas transfer efficiency but also will reduce the delivered capacity of the Facility. The delivered capacity of the Facility may be a more important operating parameter than the overall gas transfer efficiency.

The DWR aeration Facility U-tubes have an inside tube diameter of 20 inches (area of 2.2 square feet [ft^2]), so the velocity is about 10 feet per second (ft/sec). The 200-foot-deep U-tube with a 10 ft/sec velocity has a design transfer efficiency of about 80–90% (travel time of 40 seconds), as simulated by a gas transfer model with the smallest likely initial bubble size of 2 millimeters (mm) in diameter (HDR Engineering 2004). The gas transfer efficiency depends on the initial bubble diameter, which ranged from about 2 mm to 4 mm during the Alabama U-tube tests. A 200-foot-deep U-tube with a velocity of 10 ft/sec has a simulated efficiency of about 70% if the initial bubble size is 4 mm in diameter. The initial bubble size for the U-tubes is unknown, but the spargers used for these tests each had two rows of five 1/8” (3.125 mm) - diameter holes. A slower water velocity will allow higher gas transfer efficiency but will reduce the capacity of the device to deliver DO to the DWSC.

Oxygen Gas Supply Rate

The oxygen gas supply rate in standard cubic feet per minute (scfm) can be calculated from the water flow rate (cfs) and the desired gas/water volume ratio as:

Oxygen gas supply (sfcm) = 0.6 x gas/water volume ratio (%) x water flow (cfs)

Because each scf of oxygen weighs 0.0831 pounds (atmospheric pressure and 70°F), the oxygen gas supply per day can be calculated as:

Oxygen gas supply (lbs oxygen/day) = 0.0831 lbs/scf x gas flow (scfm) x 1,440 minutes/day ~ 120 x gas flow (scfm)

Each oxygen gas supply meter is actually reading units of scf per hour (hr), so the daily oxygen gas supply rate for each oxygen gas supply meter is:

Oxygen gas supply (lbs oxygen/day) = 0.0831 lbs/scf x gas flow (scf/hr) x 24 hr/day~ 2 x gas flow (scf/hr)

Delivered Capacity and Efficiency

The Facility delivered capacity (lbs oxygen/day) can be calculated by determining the added DO increment achieved with a certain gas supply rate and a measured water flow rate. The delivered capacity equation is:

Delivered capacity (lbs oxygen/day) = 28.317 l/cf x (lbs water/4.536 x 10^5 mg water) x 86,400 sec/day x added DO increment (mg/l) x water flow (cfs) ~ 5.4 x added DO increment (mg/l) x water flow (cfs)

Where added DO increment = [measured U-tube outlet DO concentration – measured RRI mid-depth DO concentration]

The Facility efficiency as a percent will be calculated as the delivered capacity divided by the daily supply:

Efficiency (%) = 5.4 x DO increment (mg/l) x flow (cfs)/[2 x gas flow (scf/hr)] x 100

Table 1 shows how the maximum capacity varies with the gas supply rate and the water flow rate (for 100% oxygen gas transfer efficiency). The maximum possible DO increment with 100% gas transfer efficiency is given at the bottom of the table. The water flow rate is about 22.5 cfs in each U-tube, compared with the design flow of 25 cfs in each U-tube. The range of gas/water ratios (2%–6%) that were tested in the Alabama U-tubes is given in Table 1. A 2% gas ratio would give a maximum DO increment of 26 mg/l, and a 6% gas ratio would result in a maximum DO increment of about 78 mg/l. The gas transfer efficiency likely would decrease at higher gas ratios because of larger initial bubbles with less surface area per gas volume (based on the Alabama testing).

The measured DO concentration in the U-tube discharge should be maintained at less than the saturated DO concentration for oxygen gas, which is about 60 mg/l at 25^{o}C at a depth of about 17 feet. This depth corresponds to the average depth of the facility discharge diffuser. This operation limit on the outlet DO concentration will minimize the potential release of oxygen gas from supersaturated water in the diffuser pipe.

Testing Results

As noted above, a total of five tests with different test conditions were conducted. The first test was conducted with both water and oxygen gas at full flow capacity. The water and oxygen flow rates were varied for four subsequent tests. The test results are summarized in the following paragraphs. The general results of capacity and efficiency for full water and gas flow testing of the Facility conducted on March 18, 2008, are also presented for comparison.

The Test 1 conditions were maximum water flows in both U-tubes with maximum oxygen gas supply rates with an oxygen gas/water ratio of about 4%. The measured and calculated results for this test are presented in Table 2. Test 1 results show that the individual U-tube performances were similar. The average gas transfer efficiency for this test was about 62%, with a total delivery capacity of 8,104 lbs, and a total combined oxygen gas supply rate of about 13,000 lbs oxygen/ day. This oxygen gas supply rate would provide the planned design delivery capacity of 10,000 lbs oxygen/day if the gas transfer efficiency could be increased to about 80%.

The Test 2 conditions were maximum water flows in both U-tubes with a reduced oxygen gas/ water ratio of about 3%. The measured and calculated results for this test are presented in Table 2. Test 2 results show an improved gas transfer efficiency of about 65%, but the total delivery capacity dropped to about 6,388 lbs oxygen/day. The most likely cause for the slight efficiency increase was smaller average gas bubble size (less coalescing) in the U-tubes.

The Test 3 conditions were full water flow with a further reduced oxygen gas/water ratio of about 2%. The water flows in tubes A and B remained the same as for Test 2. The average gas transfer efficiency for this test improved to about 71%, but the total delivery capacity dropped to 6,320 lbs. Lower gas supply rates might give a slightly higher efficiency, but the total delivery capacity would be reduced further. The measured and calculated results for Test 3 are presented in Table 2.

The Test 4 conditions were full water flow with maximum oxygen gas supply (repeat of Test 1). The average gas transfer efficiency for this test was about 60%, with a total delivery capacity of 8,000 lbs. These results are slightly less than for the Test 1 because the measured gas supply rate was slightly higher but resulted in the same added DO increment. The measured and calculated results for Test 4 are presented in Table 2.

The Test 5 condition attempted to reduce the water flow by partially closing the inlet valve while the oxygen gas was supplied at a maximum rate (of about 4% of full water flow). However, as the flow rate was reduced to about 18 cfs, the water pressure at the inlet was reduced, because the U-tube was draining faster than the pumped flow rate. The gas flow safety switch was triggered when the water pressure dropped below about 3 psi (indicating a loss of water flow condition). This testing revealed that the outlet valves, rather than the inlet valves, would need to be used to reduce the water flow. The Test 5 conditions involved full gas supply rate with a reduced water flow. The outlet valves were partially closed to reduce the water flow to 11.8 cfs in U-tube A and 11.4 cfs in U-tube B. This increased the water pressure at the gas injection tube from about 5 psi to about 25 psi. The gas flow rate apparently was reduced because of the higher water pressure (less pressure difference at the air injection tube). The average gas transfer efficiency for this test was very low at 31% with a delivery capacity of only 2,998 lbs oxygen/day. The measured and calculated results for this test are presented in Table 2.

One additional test of the full operation capacity and efficiency was obtained on March 18, 2008, during near-field measurements of DO and dye at the diffuser to test the performance of the diffuser. The U-tubes were operated at full capacity with a combined water flow of 45 cfs and a gas supply rate of 6,800 scf/hr (13,600 lbs oxygen/day) with a measured DO increment of 36.4 mg/l, measured with a YSI probe in a flow-through cell on the combined outlet pipe leading to the diffuser. The combined delivery of DO to the DWSC was 8,845 lbs oxygen/day, with an efficiency of about 65%.

Table 2 presents a summary of the testing conditions and basic results for all tests performed March 13, 2008 and March 18, 2008. Figure 1 shows the YSI probe measurements from the outlets of U-tube A and U-tube B during the testing. Figure 2 shows the adjustments that were made to the measurements to match the modified Winkler DO titrations. Figure 3 shows the YSI DO measurements from the combined outlet pipeline during the full operation testing of the diffuser mixing conditions on March 18, 2008.

Comparison with Original Design

The maximum range of calculated DO delivery capacities of 8,000 to 8,800 lbs oxygen/day during the testing (Tests 1 and 4 on March 13 and March 18 test) was less than the target design capacity of 10,000 lbs oxygen/day. These delivery capacities were obtained at a maximum water pumping rate of 45.5 cfs. This pumping rate is less than the design target flow rate of 50 cfs. The measured oxygen gas transfer efficiency ranged from 52% to 63% for these same tests, while the design efficiency was simulated to be 80% to 90%. It is possible that some changes in the oxygen gas injection apparatus (sparger) may increase the oxygen gas transfer efficiency and therefore the DO delivery capacity. These changes could include increasing the number or size of openings or their orientation on the sparger. An efficiency of 75% would provide a delivered capacity of 10,000 lbs oxygen/day with the oxygen gas ratio of 4% (oxygen gas supply of 6,480 scf/hr) at the measured water flow of about 45 cfs.

Recommendations

The oxygen gas flow rate is currently a maximum of about 4% of the water flow (about 3,240 scf/hr of oxygen gas) for each U-tube. This maximum gas flow rate is controlled by the regulated gas line pressure of about 45 psi (3 atmospheres) and also may be controlled by the oxygen gas injection sparger (1-inch diameter tube having 10 drilled 1/8-inch-diameter holes) in each U-tube down-flow pipe. Modifications of the oxygen gas injection spargers to evaluate more holes (e.g., 20 or 40) or different designs (such as an open-ended oxygen gas flow tube extending into the water flow) should be planned to increase the maximum oxygen gas flow rate to 5% or 6%. A higher oxygen gas line pressure (of 60 or 75 psi) could be investigated also, but this might require adjustments in the gas supply line plumbing and would require the oxygen gas flow rate meter to be recalibrated for the increased oxygen gas density.

The modification to the oxygen gas injector sparger should be accompanied by the use of an underwater video camera that can be inserted from the opposite 4-inch port that was constructed for the original U-tube design. Some way of positioning and moving the camera and light within the U-tube needs to be fabricated (i.e., a pivot device). The water velocity is 10 ft/sec, so the pivot device will need to be relatively strong. The goal of the video is to observe the bubbles forming at the gas sparger holes (size and spreading) and also to observe the possible bubble breakup (smaller bubbles) or merging (larger bubbles) in the U-tube device. Each modification of the injector sparger should be photographed to determine how the bubble dynamics and average bubble sizes are modified.

The ability to measure the performance at reduced water flow rate with increased travel time of water in the U-tubes is currently limited by the resulting increased water pressure (of about 25 psi) at the gas injection location (top of the U-tubes) that apparently reduced the gas flow rate. The gas supply flow meter is calibrated for a specific gas pressure of 45 psi. At reduced water flow, the gas pressure was increased slightly (to 50 psi), and the gas flow meter indicated that much less gas was being injected. More testing is needed to understand the gas injection rate at the higher water pressure and higher gas pressure. Operating one of the U-tubes at maximum water flow and maximum gas flow is perhaps the best plan for periods when the delivered capacity needed to increase the DO in the DWSC is less than the 10,000 lbs oxygen/day design capacity.

The full tidal day (25-hour) operation of the Facility with dye injection should be conducted as soon as possible to determine the performance of the Facility for delivering an added increment of DO concentration to the DWSC. This test should be conducted as soon as the gas injection sparger apparatus has been recorded on video and modified to provide the highest gas transfer efficiency at the highest gas supply ratio of 4% to achieve the design capacity of 10,000 lbs oxygen/day. The DWR monitoring stations upstream and downstream from the diffuser, as well as the RRI station DO measurements at 3 feet depth and mid-depth and bottom, should be compared to evaluate the DO increase achieved with the Facility. Longitudinal surveys at mid-depth should be performed with the UOP monitoring boat during the higher-high and lower-low slack tides before and after the testing period to evaluate the tidal mixing and movement of the incremental DO (and dye) released from the diffuser during the 25-hour testing.

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Table 1. Maximum Possible DWR Aeration Facility Dissolved Oxygen Delivery Capacity (lbs/day) for 100% Assumed Efficiency

	Oxygen Gas/Water Volume Ratio (%)									
	2%		3%		4%		5%		6%	
Flow (cfs)	Gas Flow (scf/hr)	Oxygen Delivery Capacity (lb/day)	Gas Flow (scf/hr)	Oxygen Delivery Capacity (lb/day)	Gas Flow (scf/hr)	Oxygen Delivery Capacity (lb/day)	Gas Flow (scf/hr)	Oxygen Delivery Capacity (lb/day)	Gas Flow (scf/hr)	Oxygen Delivery Capacity (lb/day)
25	1,755	3,510	2,633	5,265	3,510	7,020	4,388	8,775	5,265	10,530
30	2,106	4,212	3,159	6,318	4,214	8,424	5,265	10,530	6,318	12,636
35	2,457	4,914	3,686	7,371	4,914	9,828	6,143	12,285	7,371	14,742
40	2,808	5,616	4,212	8,424	5,616	11,232	7,020	14,040	8,424	16,848
45	3,159	6,318	4,739	9,477	6,318	12,636	7,898	15,795	9,477	18,954
50	3,510	7,020	5,265	10,530	7,020	14,040	8,775	17,550	10,530	21,060
Maximum DO increment (mg/l)	*26*		*39*		*52*		*65*		*78*	

Table 2. Initial Testing of DWR Aeration Facility in the DWSC on March 13, 2008 and March 18, 2008

	Water Flow (cfs)	Gas Flow (scf/hr)	Gas Supply (lbs oxygen/day)	Gas Ratio (%)	Outlet DO (mg/l)	DO Increment (mg/l)	Delivery (lbs oxygen/day)	Efficiency (%)
A. Test 1 with full gas supply rate of about 4%				**Time: 0945 to 1015**			**Inlet DO = 9.0 mg/l**	
U-tube A	23.1	3,230	6,460	3.9%	41.0	32.0	3,992	62%
U-tube B	22.4	3,270	6,540	4.1%	43.0	34.0	4,113	63%
Combined	45.5	6,500	13,000	4.0%	42.0	33.0	8,104	62%
B. Test 2 with gas supply of about 3%				**Time: 1030 to 1045**			**Inlet DO = 9.0 mg/l**	
U-tube A	23.1	2,450	4,900	2.9%	35.0	26.0	3,243	66%
U-tube B	22.4	2,440	4,880	3.0%	35.0	26.0	3,145	64%
Combined	45.5	4,890	9,780	3.0%	35.0	26.0	6,388	65%
C. Test 3 with gas supply of about 2%				**Time: 1100 to 1115**			**Inlet DO = 9.0 mg/l**	
U-tube A	23.1	1,620	3,240	1.9%	27.5	18.5	2,308	71%
U-tube B	22.4	1,540	3,080	1.9%	27.0	18.0	2,177	71%
Combined	45.5	3,160	6,320	1.9%	27.3	18.3	4,485	71%
D. Test 4 with full gas supply of about 4%				**Time: 1115 to 1145**			**Inlet DO = 9.0 mg/l**	
U-tube A	23.1	3,400	6,800	4.1%	41.0	32.0	3,992	59%
U-tube B	22.4	3,400	6,800	4.2%	43.0	34.0	4,113	60%
Combined	45.5	6,800	13,600	4.2%	42.0	33.0	8,104	60%

	Water Flow (cfs)	Gas Flow (scf/hr)	Gas Supply (lbs oxygen/day)	Gas Ratio (%)	Outlet DO (mg/l)	DO Increment (mg/l)	Delivery (lbs oxygen/day)	Efficiency (%)
E. Test 5 with full gas supply				**Time: 1315 to 1330**			**Inlet DO = 9.0 mg/l**	
Flow reduced with outlet valve				Water pressure at inlet increased from 5 psi to 25 psi				
U-tube A	11.8	2,210	4,420	5.2%	29.0	20.0	1,274	29%
U-tube B	11.4	2,560	5,120	6.2%	37.0	28.0	1,724	34%
Combined	23.2	4,770	9,540	5.7%	32.9	23.9	2,998	31%
Operation of the DWR U-tube Oxygenation Device on March 18, 2008 to observe near-field diffuser DO profiles								
F. End of day measurements with full gas supply of about 4%					**Time: 1530 to 1800**		**Inlet DO = 9.1 mg/l**	
Combined	45.0	6,800	13,600	4.2%	45.5	36.4	8,845	65%

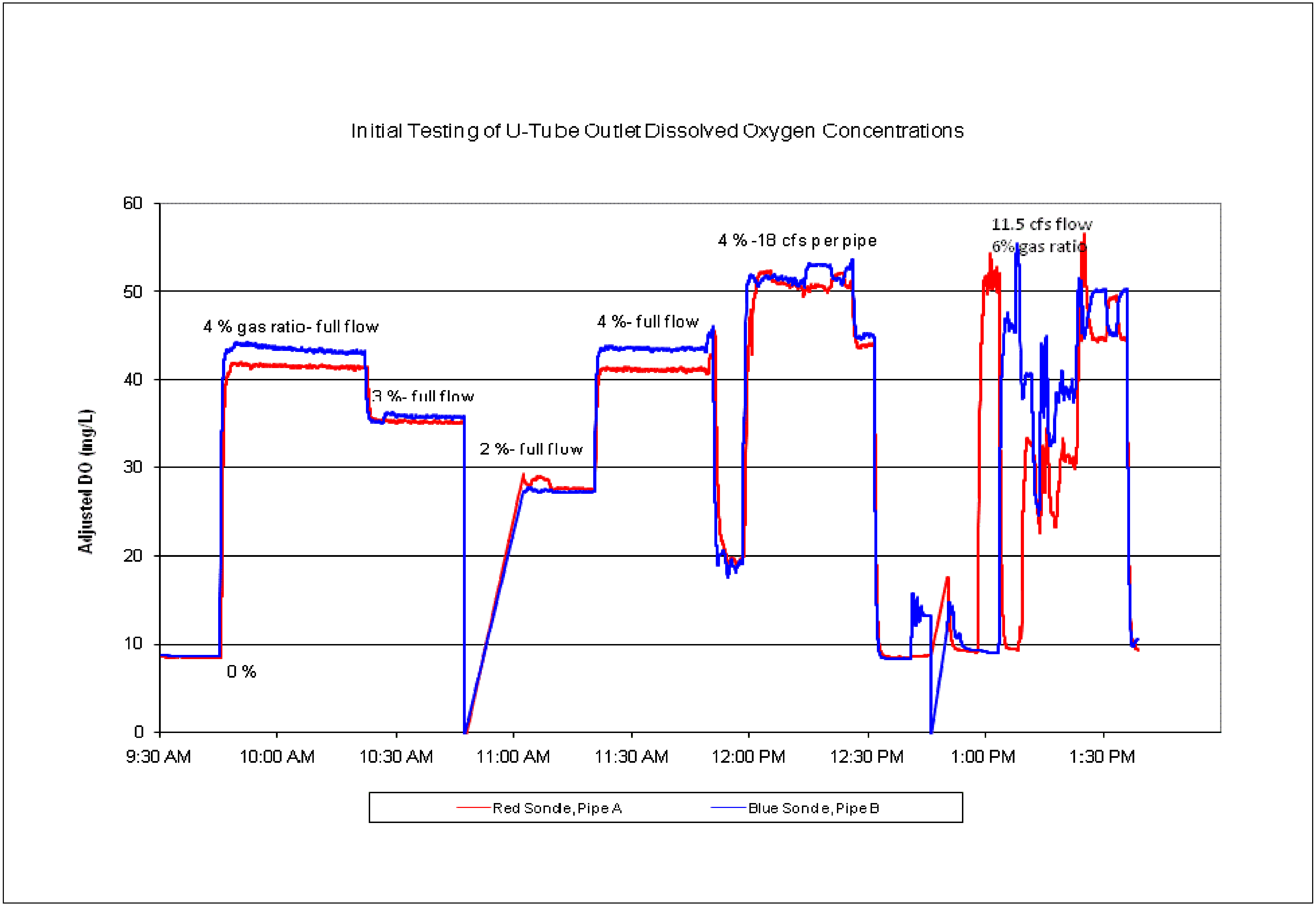

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Figure 1

Adjusted (to Match Modified Winkler) YSI Probe Dissolved Oxygen Measurements in the Outlet of U-Tubes A and B on March 13, 2008

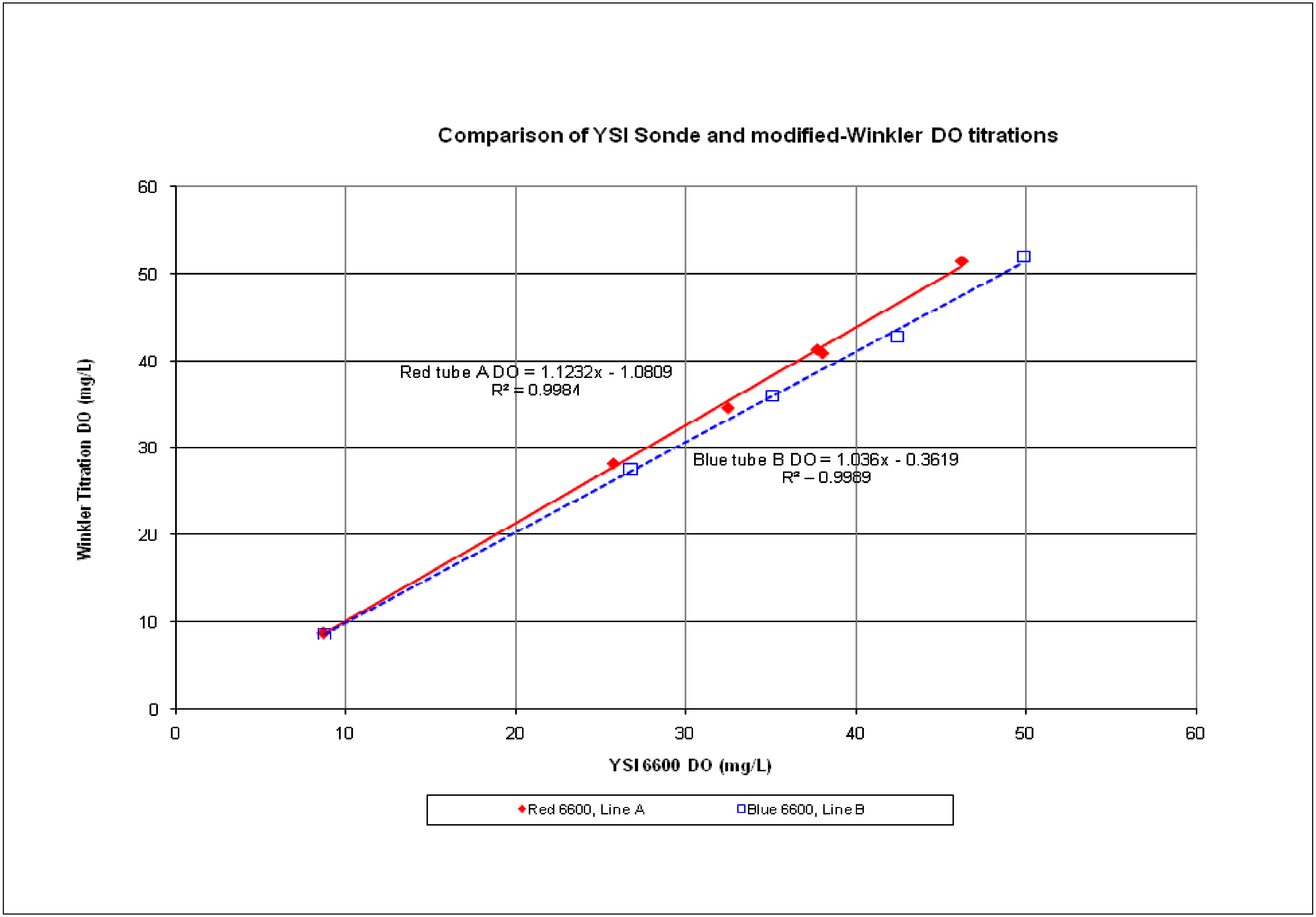

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Figure 2

Comparison of Modified-Winkler Dissolved Oxygen Titrations and YSI Sonde Measurements during March 13, 2008, Initial Testing of U-Tubes Capacity and Efficiency

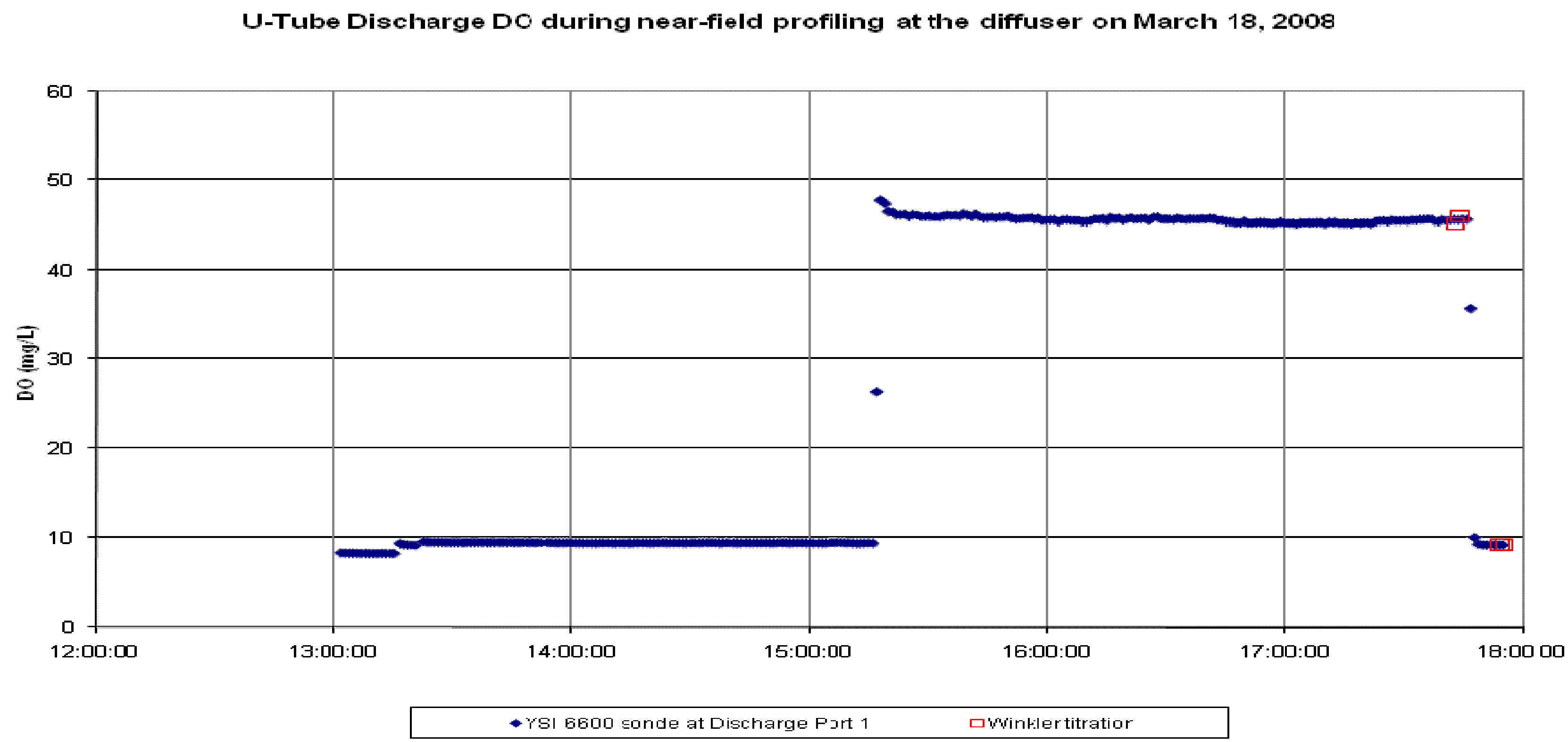

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Figure 3

Measured Dissolved Oxygen Concentration in the Combined Outlet Pipe from the DWR U-Tube Oxygenation Device on March 18, 2008