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January 27, 2016

Mr. Christopher Wunz
Mr. Charles Wunz
76 Heatherbloom Drive
Lewisburg, PA 17837

Re: Report of the Clean Water Test Results of the Maelstrom Test Unit – November 2011

Dear Chris and Chuck,

Redmon Engineering Company conducted a series of clean water oxygen transfer tests on the Environmental Solutions Maelstrom test unit located on Jim Oliver's property November 1-3, 2011.

Following your review of the attached report, should you have any comments or questions, please let me know.

Best regards,

REDMON ENGINEERING COMPANY

David T. Redmon, P.E.

**CLEAN WATER OXYGEN TRANSFER TEST
OF THE
ENVIRONMENTAL SOLUTIONS, LLC
MAELSTROM TEST CELL**

November 1-3, 2011

INTRODUCTION

Redmon Engineering Company was engaged by Christopher Wunz to conduct a series of clean water tests on the Environmental Solutions, LLC Maelstrom oxidizer/aerator unit in order to observe the oxygen transfer performance characteristics of the unit over a range of airflows and power inputs.

This document includes all the information regarding the tests conducted, the testing equipment and procedures followed, and the final results for the different conditions tested.

The tests were conducted by David Redmon, of Redmon Engineering Company on November 1 to 3, 2011 with the assistance of Jim and Don of Environmental Solutions, LLC and Chuck Wunz.

DESCRIPTION OF TESTING PROCEDURES AND EQUIPMENT

The Clean Water Oxygen Transfer Tests presented in this document have been carried out by Redmon Engineering Company following the procedures described in the ASCE Standard "A Standard for the Measurement of Oxygen Transfer in Clean Water,"

(ASCE/EWRI 2-06).

Summary of Method

The test method is based upon removal of dissolved oxygen from the water volume by sodium sulfite followed by reaeration to near the saturation level. The dissolved oxygen inventory of the water volume is monitored during the reaeration period by measuring dissolved oxygen concentrations at several determination points selected to best represent the tank contents.

The data obtained at each determination point are then analyzed by a simplified mass transfer model to estimate the apparent mass transfer coefficient, K_La, and the steady state dissolved oxygen saturation concentration, C^*_∞. The basic model is given by

$$C = C^*_\infty - (C^*_\infty - C_0)\ \exp(-K_La_t)$$

Where:

C = dissolved oxygen concentration, mg/l

C^*_∞ = determination point value of the steady DO concentration at time approaches infinity, mg/l,

C_0 = DO concentration at time zero, mg/l, and

K_La = determination point value of the apparent volumetric mass transfer coefficient, 1/hr.

The differentiated form of the above equation, known as the Log Deficit Method, was used to determine the value of K_La for each probe for each test.

$$K_La = Ln ((C^* - C_1)/(C^* - C_2))/(t_2 - t_1)$$

Where:

Ln = is the natural log

C* =. is the saturation value measured at the end of the test

C_1 & C_2 = the dissolved oxygen concentration at times 1 and 2

t_1 & t_2 = times 1 and 2

The above equation yields a linear regression of the natural log of the DO deficit versus time. In this test, DO data representing approximately 20% to 90% of the DO saturation value was employed to fit the above equation at each determination point during reaeration period. In this way, estimates of K_La are obtained at each determination point. These estimates are adjusted to standard conditions (20°C water temperature, zero DO concentration and one atmosphere – 29.92 inches mercury) and the standard oxygen transfer rate (SOTR) is obtained as the average of the products of the adjusted determination point K_La values, corresponding adjusted determination point C^*_∞ values, and the tank volume.

SOTR = K_La_{20} ($C^*_{\infty 20}$) V

Where

K_La_{20} = determination point value of KLa corrected to 20°C;

$C^*_{\infty 20}$ = determination point value of steady-state DO concentration corrected to 20°C and a standard barometric pressure of 1.00 atmospheres;

V = liquid volume of test water in the test tank when the aerator(s) is turned off.

The standard aeration efficiency (SAE), or rated of oxygen transfer per unit of power input, is often of interest and is computed by the following expression

SAE = SOTR / Power Input.

Oxygen transfer efficiency (OTE) refers to the fraction of the mass of oxygen in an injected air stream dissolved into the test fluid under given conditions. The standard oxygen transfer efficiency (SOTE) is the oxygen transfer efficiency corrected to standard conditions (20°C water temperature, zero DO and 1.00 atmospheres) and may be calculated for a given flow of air by

SOTE = SOTR / W_{02}

Where:

W_{02} = mass flow of oxygen in the air stream, mass/time (lbs/hr).

Description of the Test Basin

The clean water testing of a single cell of the Maelstrom oxidizer/aerator unit was conducted on the premises of Jim Oliver at 255 Camp Horne Road in the metropolitan area of Pittsburgh, PA on November 1 to 3, 2011. The outside dimensions of the test unit were 40 inches by 20 inches by 44 inches tall. The inside aeration portion is 18 inches by 19 inches by 24 inches tall. A schematic drawing of the test setup is shown as Figure 1.

Airflow, airline pressure and airline temperature were observed and recorded several times during each test run. Power measurement were made using a “Kill-A-Watt EZ,” monitor. These readings were used to compute the applied airflow for each test in standard cubic feet per minute (scfm) and the power draw in kilowatts.

TEST PROCEDURE

The tests have been conducted following the procedures described in the ASCE Standard ASCE/EWRI 2-06, “A Standard for the Measurement of Oxygen Transfer in Clean Water.”

Public supply drinking water obtained from the local utility was used for the clean water tests. The quality of the public water used satisfies all the requirements of the ASCE Standard.

Deoxygenation

Deoxygenation of the test water was achieved by the addition of anhydrous sodium sulfite (Na_2SO_3) in excess of the stoichiometric amount required for the removal of all dissolved oxygen present in the test water, using cobalt chloride hexahydrate ($CoCl_2 \cdot 6H_2O$) as a catalyst. In order to assure uniform distribution of the cobalt catalyst, the technical grade cobalt chloride hexahydrate was dissolved in water an added to the test basin with the aeration system on at least one hour before the first addition of sodium sulfite. Sufficient cobalt chloride hydrate was added to yield a cobalt ion concentration of about 0.35 mg/l. The ASCE Standard requires that the cobalt ion concentration be in the range of 0.10 to 0.50 mg/l.

The sodium sulfite was dissolved in water and added to the test unit in solution form. Sufficient excess sodium sulfite was added to allow adequate time for the airflow rate to be set prior to the dissolved oxygen concentration beginning to rise. In all cases, a dissolved oxygen concentration of less than 0.50 mg/l was achieved in all areas of the test volume for at least three minutes.

Measurement of Oxygen Transfer

Determination of dissolved oxygen concentration in the different areas of the test tank was done using four Yellow Springs Instruments (YSI) Model 52 dissolved oxygen meters and membrane probes. All DO probes were fitted with 1.0 mil membranes.

The probes were suspended at different depths within the 1500 gallon accumulation tank. The dissolved oxygen meters and probes were calibrated using the

"In Vitro Calibration Adjustment," method (Paragraph D.2.2, page 19 of the 1992 ASCE Standard). The probes are placed in a vessel of saturated drinking water that was being aerated. The DO in the vessel is calculated knowing the local barometric pressure and water temperature.

The DO versus time data for each non-steady state test run was logged automatically to an Excel spreadsheet. The four dissolved oxygen meters were connected to the laptop computer by four RS-232 adapters. The DO data were logged on various time intervals depending on the applied airflow rate.

TEST PROGRAM

A total of sixteen (16) test runs were conducted on the Maelstrom test cell. Test runs 11 and 12 had problems with the data logging system and the dissolved oxygen versus time data for these two runs was lost. Tests were conducted using a blower horsepower of 1.0 and 0.25 horsepower over a range of airflows using one and two pumps. The Maelstrom test cell was operated in the normal forward flow manner and also with the flow direction through the test cell reversed.

Test Conditions and Results

Table 1 summarizes the results for each of the test runs. The DO versus time data, as well as the log-deficit analysis of the data is contained in Appendix I. In each case, the DO-time data were averaged prior to analysis using the log deficit method. Included in Table 1 is the aerator description, the run number, liquid flow direction, the blower horsepower, the airflow, the water flow, the water temperature, the total dissolved solids concentration, K_La_{20}, C^*_{20}, SOTR, liquid volume, SOTE, air to water ratio, line power, and the SAE. The Kla 20 values listed in Table 1 have been corrected to a total dissolved solids concentration of 1000 mg/l.

In Table 1 the parameters of greatest interest are the direction of liquid flow, the SOTE, the applied airflow, the liquid flow rate, the line power, and the standard aeration efficiency (SAE). These parameters define the performance of the Maelstrom test cell. Upon inspection of Table 1, it is readily apparent that the test cell operates more efficiently when the liquid flow is in the reverse direction to the normal liquid flow direction. Another observation is that the Maelstrom unit performs in a manner very similar to jet aeration systems commonly employed in municipal and industrial wastewater treatment systems. In the case of jet aerators, air and liquid are mixed together in overlapping nozzles (one supplying liquid and one supplying air) and intimately mixed within the outer nozzle prior to discharge to the bulk liquid in the reactor. When using jet aerators, the efficiency of the unit is related to the air to water ratio in the jet nozzles. At a fixed pumping rate (fixed liquid flow through the nozzles), as the airflow is increased (increasing air to water volume ratio) the oxygen transfer efficiency steadily decreases. The same affect was observed with the Maelstrom test unit.

Figures 2 and 3 are plots of standard oxygen transfer efficiency (SOTE) as a function of the air to water ratio. Figure 2 is for the reverse flow data and Figure 3 is for the forward flow data. In both cases there is a very strong correlation between the air to water ratio and the oxygen transfer efficiency. The most efficient condition was when the Maelstrom test cell was operating in the reverse flow direction using a 0.25 horsepower blower at the lowest airflow rate tested (approximately 21 scfm) with two pumps operating. In this case the SAE was observed to be 3.75 pounds of oxygen per horsepower. Under the same operating condition, except with the liquid flow in the forward or normal direction the SAE was 2.63 pounds of oxygen per horsepower. When the airflow rate is increased above the 21 scfm level the air to water ratio significantly increases resulting in substantially less efficient performance.

Discussion

In light of the test results it is apparent that the air to water ratio needs to be kept low to maximize the efficiency to the Maelstrom unit. At an air to water ratio of approximately 0.67 the most efficient operation was observed. The combination of running the Maelstrom unit at a low air to water ratio and having the liquid flow countercurrent to the airflow, results in the most efficient performance of the test unit. The 3.75 pounds of oxygen per horsepower clean water oxygen transfer is greater than that typically observed from a jet aeration systems commonly used in municipal and industrial biological wastewater treatment plants. As typically applied in these systems, the SAE for normally applied jet aeration systems is somewhere between about 2.1 and 3.4 pounds of oxygen per wire horsepower per hour.

CLEAN WATER OXYGEN TRANSFER TESTS
OF THE
ENVIRONMENTAL SOLUTIONS MAELSTROM TEST CELL
IN
PITTSBURGH, PENNSYLVANIA

PERFORMED ON BEHALF OF:

CHRISTOPHER WUNZ

CONDUCTED

November 1 to 3, 2011

PERFORMED BY:

REDMON ENGINEERING COMPANY

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A P P E N D I X   I

DO-TIME DATA
AND
LOG DEFICIT ANALYSIS
AND
OVERALL SUMMARY

A P P E N D I X   I I

FIELD DATA SHEETS