Evaluation of Oxygen Transfer Efficiency via Off-gas Testing at Full Scale Integrated Fixed film Activated Sludge Installation

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ABSTRACT

A study was conducted to investigate the impact of plastic carrier media used in processes such as integrated fixed film activated sludge (IFAS) in a full-scale wastewater treatment plant. Off-gas analysis was performed on a full-scale IFAS train and compared with a parallel conventional activated sludge (CAS) train. On the basis of tests performed in both the IFAS and CAS systems, a reasonable comparison was established and the average process water standard oxygen transfer efficiency (SOTEpw) for the IFAS and CAS systems were computed. An alternative comparison of SOTEpw values within the IFAS system between cells without any carrier media and cells with carrier media yields values that are comparable suggesting that carrier media have little or no affect on oxygen transfer efficiencies when the aeration systems are operated identically.

KEYWORDS: Oxygen transfer efficiency, off-gas, integrated fixed film activated sludge.

INTRODUCTION

A significant aspect of biological wastewater treatment process aeration design is the estimation of process water alpha (α) value, which is defined as the ratio of process water and clean water oxygen mass transfer coefficients. In order to accomplish this, information regarding both the standard clean water oxygen transfer efficiency as well as process water oxygen transfer efficiency are required.

Standard Clean water Oxygen Transfer Efficiency (SOTE) for an aeration system is measured in large-scale tests conducted in accordance with guidelines prescribed by American Society of Civil Engineers (ASCE Standard Guidelines). Typically, this value is obtained from manufacturers of aeration systems. Process water Oxygen Transfer Efficiency (SOTEpw) is usually determined by employing an off-gas analysis in a full-scale plant (Redmon et al., 1983). Empirical data is available from numerous conventional activated sludge processes; however, established values for processes such as Integrated Fixed film Activated Sludge (IFAS) or Moving Bed Biofilm Reactor (MBBR) are uncommon.

Manufacturers of aeration systems typically quote performance based on clean water oxygen transfer efficiencies. This allows aeration equipment manufacturers to provide estimates of clean
The objective of this study was to estimate the process water standard oxygen transfer efficiency (SOTEpw) and in turn the alpha value of wastewater with carrier media ($\alpha_m$) for an IFAS process operating with plastic carrier media and fine bubble diffusers in a full-scale plant. The data obtained was compared to both literature values for alpha and with data obtained from a simultaneous off-gas analysis in an adjacent conventional activated sludge (CAS) process train. This information is valuable towards supporting the design of full-scale IFAS plants, particularly with the estimation of process air requirements.

**METHODOLOGY**

**Site Description**

The Lakeview Wastewater Treatment Plant in the Region of Peel, Ontario, Canada was designed to treat an average flow of 110 MGD. A full-scale IFAS demonstration train was built in parallel to the existing CAS trains to test the nitrification efficiencies of the IFAS process. The demonstration train (tank #4) is a three-pass plug flow type activated sludge reactor as schematically shown in Figure 1 and was equipped with ceramic disc fine bubble diffusers.

The passes 2 and 3 of this train was upgraded to an IFAS design by addition of plastic carrier media and in-basin screens. The fine bubble diffusers in pass 1 (no carrier media) are arranged in full-floor coverage with all laterals in use. However, passes 2 and 3, which contain the carrier media, were each divided into two cells that are separated by in-basin screens, coarse bubble air-knives located at each screen and fine bubble diffusers operated in partial floor coverage by eliminating three rows of laterals on each side (lengthwise) of the tank that facilitates media roll.

![Figure 1. Schematic of Lakeview WWTP IFAS demonstration train.](image-url)
Process air flow is controlled using a network of steel pipes and needle valves. The air flow rates were neither flow-paced nor adjusted based on influent pollutant load. Table 1 lists the number of laterals and diffusers in each cell. The IFAS system was not optimized prior or during this study, some of the variability within the data may be due in part to the operating strategy employed for each of the process trains.

Table 1. Details of Laterals and Diffusers.

<table>
<thead>
<tr>
<th>Cell ID</th>
<th># L laterals</th>
<th># Diffusers/ Lateral</th>
<th>Diffusers in use/ Lateral</th>
<th>Number of Diffusers</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0</td>
<td>0</td>
<td>0</td>
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<td>6</td>
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<td>15</td>
<td>9</td>
<td>198</td>
</tr>
</tbody>
</table>

Sampling Method
The off-gas analysis was conducted using a Ewing Engineering Mark V Off-gas Analyzer shown in Figure 2 employing carbon dioxide and water vapor stripping. A floatable wooden hood, fabricated on site, was used to collect gas exiting the aeration basins. The study involved determining and analyzing off-gas measurements from both the IFAS system (tank #4 - shown in this picture) and a conventional activated sludge train (tank #3).

Figure 2. Off-gas collection hood with extraction line to analyzer.

Off-gas testing involves the placement of a floating off-gas collection device on the liquid surface of the aeration tank at various locations and analyzing the exiting gas for the partial pressure of oxygen as compared to that of ambient air.
In addition, the rate of off-gas evolution is measured for each off-gas collection hood sampling position employed and each test condition. All data was collected and analyzed according to the procedures described in the paper, "Oxygen Transfer Efficiency Measurements in Mixed Liquor Using Off-gas Techniques" (Redmon, 1983).

The sampling hood has a 4” diameter opening on top that is attached to a 2” hose leading to the off-gas analyzer. Figure 2 shows the off-gas collection hood in operation at the Lakeview WWTP. The off-gas analyzer shown as an inset in figure 2 employs a wet vacuum to extract the exiting gas. The gas is run through a column packed with sodium hydroxide (supported within PVC pellets) and desiccant to remove carbon dioxide and humidity, respectively.

The analyzer simultaneously draws in off-gas from the hood and ambient air. The off-gas analyzer measures the partial pressure of oxygen in dried, ambient air and compares it to that of the off-gas exiting the surface of the aeration tank from which the carbon dioxide and water vapor have been stripped.

During the test, for each sample location, the instantaneous oxygen concentration of the ambient air is first determined, followed by a series of measurements of the off-gas exiting the aeration basin collected at one-minute intervals, finally followed by another instantaneous measurement of ambient air. Using the millivolt outputs observed for both off-gas (Mg) and ambient (reference) air (Mr) from the gas phase oxygen meter, a direct measure of the actual field oxygen transfer efficiency (OTEF) under prevailing conditions is calculated.

To ensure standard operating pressure, care is taken to maintain the pressure under the hood equal to that of atmospheric pressure. This is accomplished by regulating the rate of extraction of the exiting off-gas. In measuring the gas flow to the hood, the withdrawal rate of off-gas from the hood is increased to produce a slight vacuum in the hood and then the withdrawal rate is gradually reduced to produce a slight pressure or a balanced pressure condition. This procedure results in bracketing the flow between a gas flow that produces a vacuum inside the hood and a flow that produces a positive pressure within the hood. This allows for ease of deducing the oxygen concentration at standard operating conditions simply by applying a temperature correction factor.

The mixed liquor dissolved oxygen (DO) concentration was measured using a bench-top dissolved oxygen meter. The measured value is used in calculating the effective DO deficit knowing the saturation DO of the wastewater at test conditions. The mixed liquor DO concentration at the sampling location along with mixed liquor temperature and local barometric pressures permits the calculation of standard oxygen transfer efficiency under process conditions (SOTEpw).

Standard conditions are defined as zero DO, a temperature of 20°C and an atmospheric pressure of 29.92” Hg.

Since alpha is the ratio of oxygen transfer under process conditions to those in clean water, both corrected to standard conditions, the system alpha can readily be calculated as the ratio of SOTEpw to SOTEcw.
Sampling Locations

Sample location is critical in accurately determining the OTE of the process water. Caution was exercised to ensure that the hood was not located close to the air-knife in order to avoid measurements in highly turbulent zones with excessive air flow. The test tank comprised of 3 passes consisting of 6 six cells separated by coarse screens with 1 cm openings. Each pass was 144 feet in length and 20 feet wide, having a side water depth of 14 feet. The operating diffuser submergence was approximately 13.1 feet. The sample locations are indicated schematically in Figure 4.

![Figure 4. Schematic of test basin indicating sample locations.](image)

Cell 1, the pre-denitrification stage, is anoxic and the point where return activated sludge (RAS) was introduced into the system. Cell 2 was aerobic and included in the off-gas testing in order to compare OTE values for cells with and without media.

Cells 3 through 6 served as nitrification stages; they were aerated and contain approximately 45 percent media fill by volume.

The numbers assigned for each sample location indicates the tank number, pass number and location identification. For example, sample number 4.3.4 indicates tank 4, pass 3, and test hood location 4 within that pass.

For each location, seven (7) readings were recorded, two (2) of which were readings of ambient air and five (5) of the off-gas measured at 1-minute intervals. In addition, nine more samples
were collected in the adjacent CAS reactor (tank #3), with a minimum of three samples per pass.

**Principle of Computation**

To estimate the oxygen transfer efficiency under actual operating conditions in municipal wastewater treatment applications, the following equation is used (ASCE, 1992):

\[
\text{OTE}_{\text{F}} = \alpha (\text{SOTE})(\Theta ^{T-20})(Y \Omega \beta C^*_{b20} - C) / C^*_{b20}
\]

Where
- \( \text{OTE}_{\text{F}} \) = Wastewater oxygen transfer efficiency (decimal fraction).
- \( \alpha \) = Alpha (decimal fraction).
- \( \Theta \) = Mass transfer coefficient temperature correction factor (dimensionless).
- \( T \) = Process water temperature (°C).
- \( Y \) = Temperature correction factor (dimensionless)
- \( \beta \) = Ratio of steady state DO saturation concentration in process and clean water (dimensionless)
- \( \Omega \) = Pressure correction factor (\( \text{Pb}/\text{Ps} \)) for the steady state DO saturation concentration (dimensionless)

Where
- \( C^*_{bST} \) = Tabulated DO surface saturation value (mg/L) at temperature \( T \).
- \( C^*_{b20} \) = Tabulated DO surface saturation value (mg/L) at 20°C

\( \beta \) = Ratio of steady state DO saturation concentration in process and clean water (dimensionless)

\( \Omega \) = Pressure correction factor (\( \text{Pb}/\text{Ps} \)) for the steady state DO saturation concentration (dimensionless)

Where
- \( \text{Pb} \) = Local barometric pressure for the site (inches of Hg).
- \( \text{Ps} \) = Standard barometric pressure; 29.92 inches of Hg (101.3 k Pa).
- \( C \) = Dissolved oxygen concentration (mg/L).

Averaged over process water volume being evaluated.

All of the factors involved in the conversion from clean water to wastewater, except alpha, can be specified or reasonably estimated from published, assumed or measured values. To obtain a reasonable estimate of alpha, it was necessary to perform the tests described within this paper.

**RESULTS**

A summary of the calculated process water SOTEpw for critical sample locations are presented in Table 2.

On the basis of tests performed in both the IFAS and CAS systems, a reasonable comparison was established only between passes 2 of both tanks for the reason that the operating conditions in the remainder of the tanks were not sufficiently optimized. The average SOTEpw in pass 2 of the IFAS system was calculated to be 11.7 percent, in comparison, the average SOTEpw for pass 2 of the CAS was 14.7 percent. The variance in OTE is likely due to the air flow rates that each
process were operating under. For example, the air flow rate applied to IFAS pass 2 was 0.34 SCFM/ft² as compared to 0.13 SCFM/ft² in pass 2 of the CAS system. It is common knowledge in the industry that fine air diffusers operated at low air flow rates yield greater OTE values, which could be the likely explanation for higher OTE measured for the CAS system.

An alternative comparison of OTE values within the IFAS system (tank #4) between cells without any carrier media and cells with carrier media yields values that are comparable suggesting that carrier media have little or no affect on oxygen transfer efficiencies when the aeration systems are operated identically. Results are presented in Table 3. The average SOTEpw in cell #2 of tank #4, operating without any carrier media, was calculated to be 12.6 %, while the SOTEpw for cells with carrier media was found to be 11.7%.

Further explanation for this slight difference in OTE may be due to:
- Addition of media reduces the liquid volume, although it is not a significant reduction of volume, it might change the bulk liquid velocity, resulting in lower oxygen transfer.
- With reduced bulk liquid volume in cells with media, the calculated OTE/unit volume will be lower as compared to a cell with no media.
• Media aids in bubbles coalescence, resulting in coarse bubble formation, and ultimately lowering OTE slightly.

Based on data from the diffuser manufacturer, the clean water standard oxygen transfer efficiency (SOTEcw) for the ceramic disc diffuser used at Lakeview WWTP was determined to be 19.5% during standard testing. The ratio of SOTEpw to SOTEcw yields alpha-media ($\alpha_m$) values of 0.6 for the IFAS system and alpha ($\alpha$) value of 0.646 for the CAS process. These alpha values are within the typical ranges used in designing a full-scale IFAS system.

CONCLUSIONS

Off-gas evaluation of the full-scale IFAS installation at the Lakeview WWTP yielded an alpha-media ($\alpha_m$) value of 0.6. This value is within the reported design range for fine bubble diffusers, suggesting that the impact of the plastic carrier media on SOTEpw is not significant. Comparison of data between the IFAS and a neighboring CAS process suggests that the SOTEpw is slightly higher in the conventional activated sludge train as compared to the IFAS system. However, this is likely explained by the significant difference in process air flow rates for the two systems, with fine bubble diffusers known to yield a higher OTE under conditions of reduced air flow rates such as was the case with the CAS process.

The inherent variability in the operating conditions, diffuser layout and the fact that we lacked control of parameters such as air and wastewater flow rates could be responsible for the observed differences in SOTEpw. Further studies are planned to investigate effects of these parameters on the computed SOTEpw.

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REFERENCES