Respirometry – A Valuable Tool in Wastewater Treatment

Presented By:

John Hoffman, President of Alloway

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Respirometry - Introduction

Respirometry in Control of the Activated Sludge Process. *Water Science and Technology*. Spanjers, Vanrolleghem, Olsson, and Doldt. Volume 34, 3-4, P. 117-126

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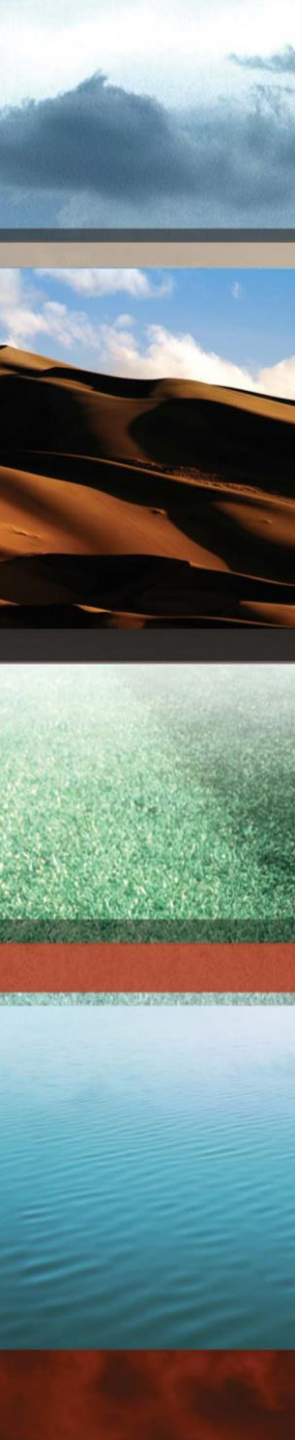

Respirometry - Introduction

- Respirometry is a general term that encompasses a number of techniques for obtaining estimates of the rates of metabolism of vertebrates, invertebrates, plants, tissues, cells, or microorganisms.... *(Cited from Wikipedia and others)*

- Today: Respirometry is the measurement and interpretation of the respiration rate of activated sludge.

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Respirometry – Introduction

A respirometer is a device used to measure the rate of respiration of a living organism by measuring its rate of exchange of oxygen and/or carbon dioxide.

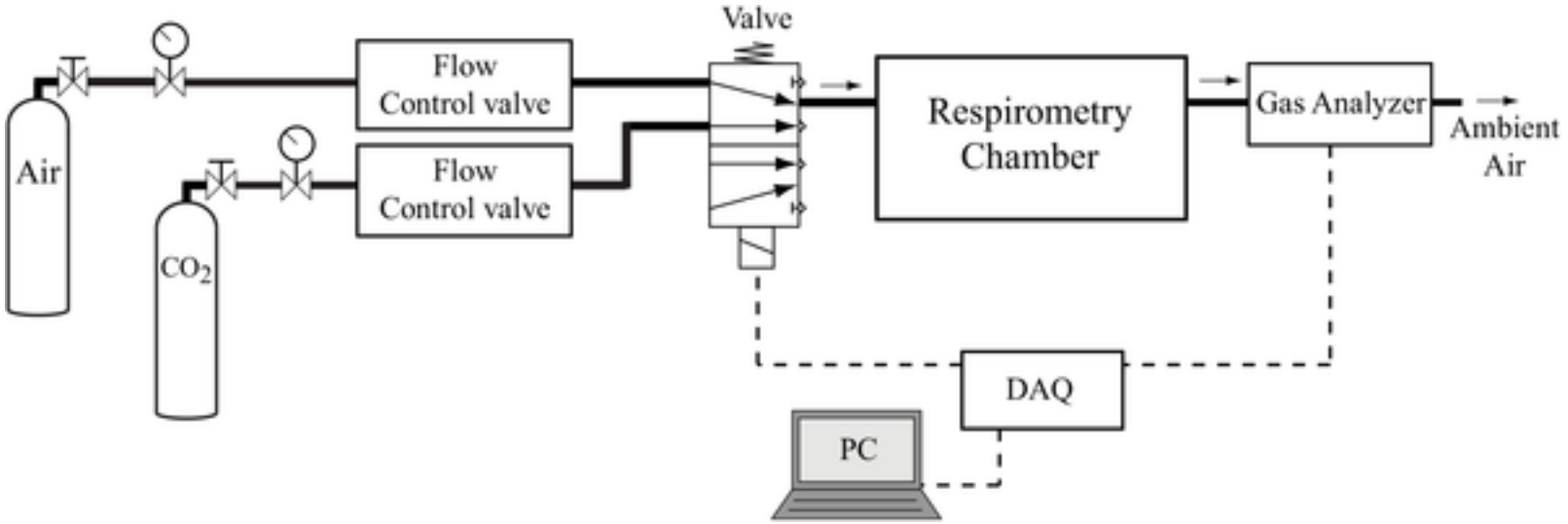

Image From: Estimation of Instantaneous Gas Exchange in Flow-Through Respirometry Systems: A Modern Revision of Bartholomew's Z-Transform Method. Pendar H, Socha JJ (2015) *Estimation of Instantaneous Gas Exchange in Flow-Through Respirometry Systems: A Modern Revision of Bartholomew's Z-Transform Method*. PLOS ONE 10(10): e0139508.

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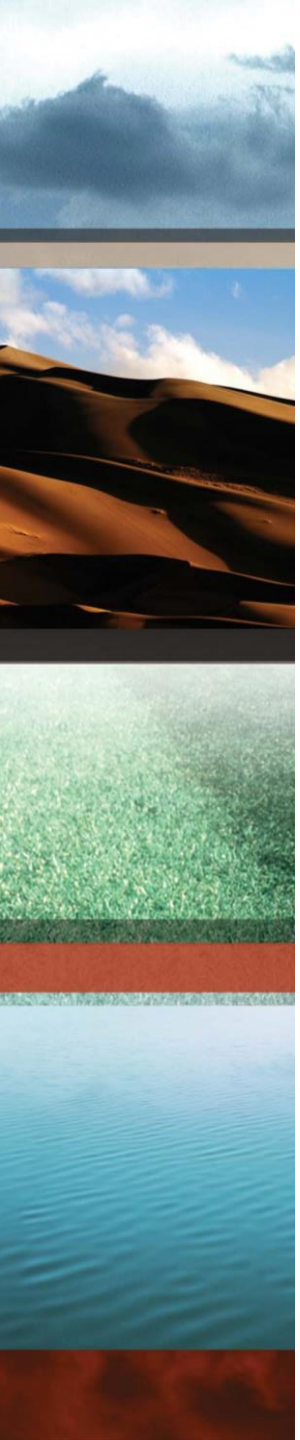

Respirometry – Introduction

- The respiration rate = amount of oxygen per unit of volume and time that is consumed by microorganisms

- Two important processes that must be controlled in a wastewater treatment plant:
  - Biomass Growth
  - Substrate Consumption

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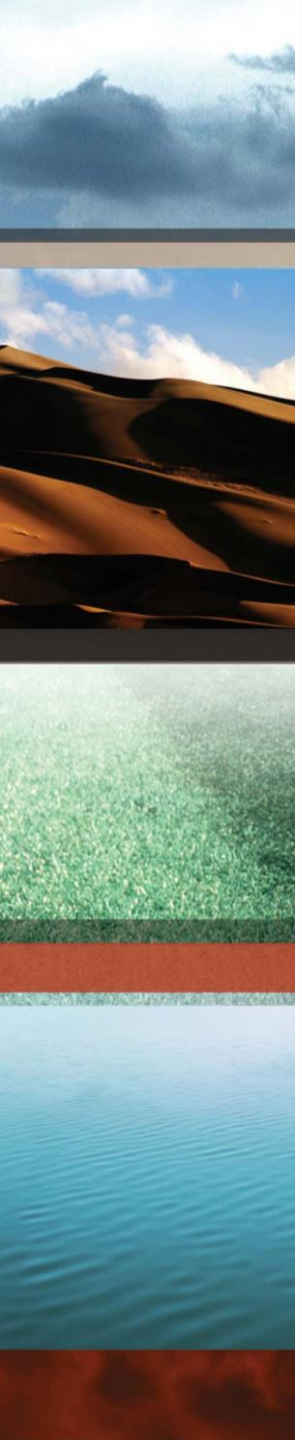

Respirometry – Introduction

DO concentration-based control is <u>not</u> similar to respiration rate-based control

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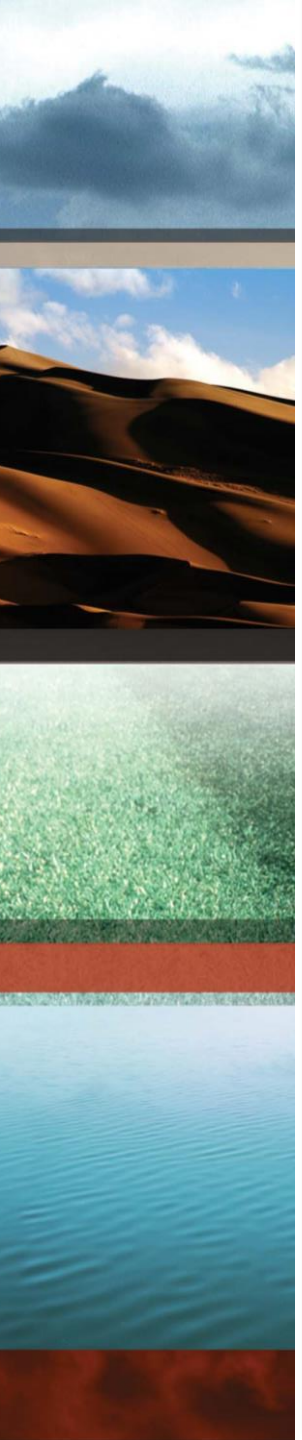

Respirometry – Introduction

The primary objective in a wastewater treatment system (usually): Meet regulatory objectives by the removal of carbonaceous material through the growth of heterotrophic bacteria. Nitrification by autotrophic organisms may account for about 40% of the oxygen demand.

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Respirometry – Introduction

Respiration rate is usually measured with a respirometer.

Photo by: Aragón, C., M.D. Coello, J.M. Quiroga
(http://www.sciencedirect.com/science/article/pii/S0263876209002706)

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Oxygen Uptake Rate (OUR)

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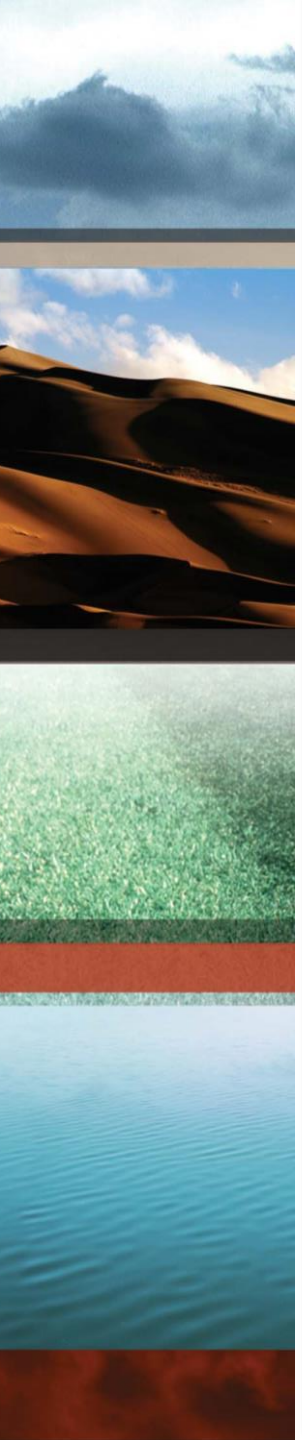

Oxygen Uptake Rate (OUR)

The rate of oxygen used by microorganisms in a biological system

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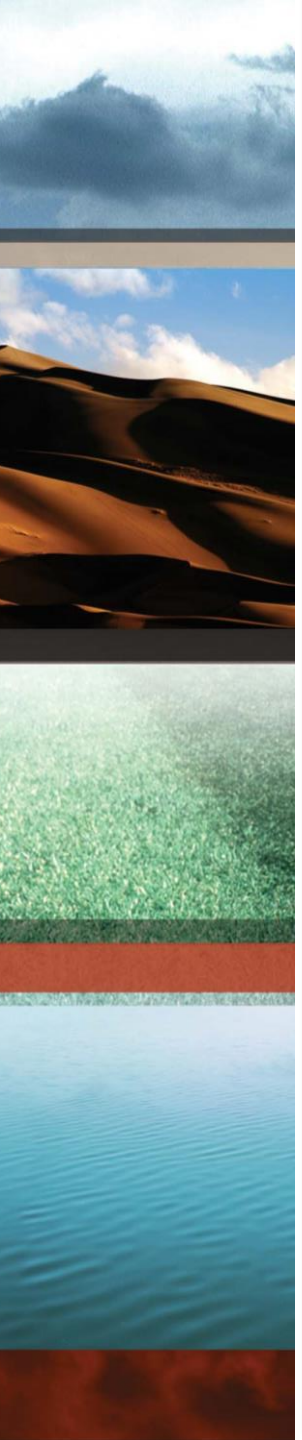

Oxygen Uptake Rate (OUR)

- High OUR values
  - Organic load is too high (**Excessive F**:M) and/or
  - MLVSS concentration is too low (**Insufficient** F:**M**) and/or
  - The bioreactor is too small and/or
  - Low DO condition exists in the bioreactor

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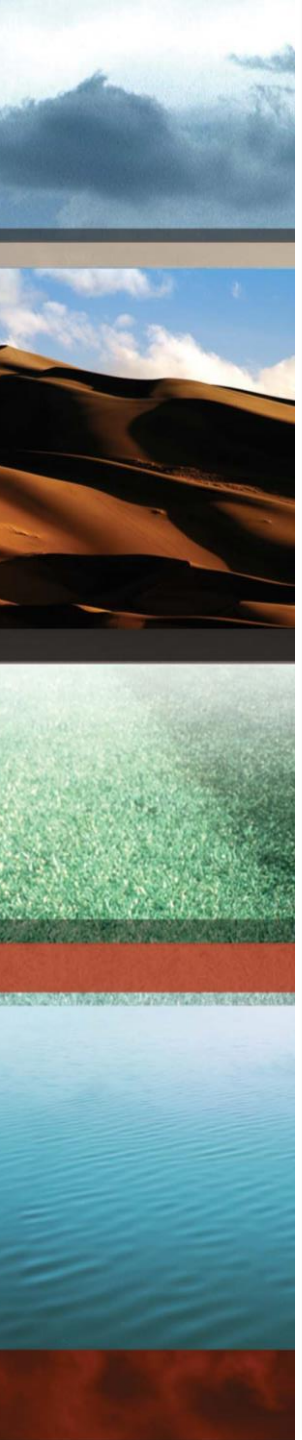

Oxygen Uptake Rate (OUR)

Test Procedure:

1. Collect the MLSS sample as it is leaving the bioreactor
2. Aerate the sample (either by pouring or shaking) to get the DO above 5 mg/L
3. Put the sample in a BOD bottle containing a magnetic stir bar and insert a DO probe
4. While stirring, record the DO at one minute intervals for up to 15 minutes

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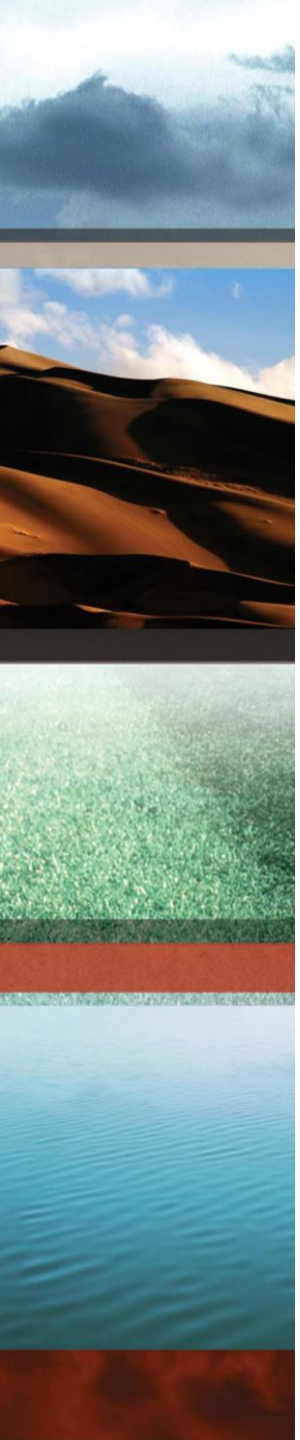

Oxygen Uptake Rate (OUR)

When Is Treatment Complete?

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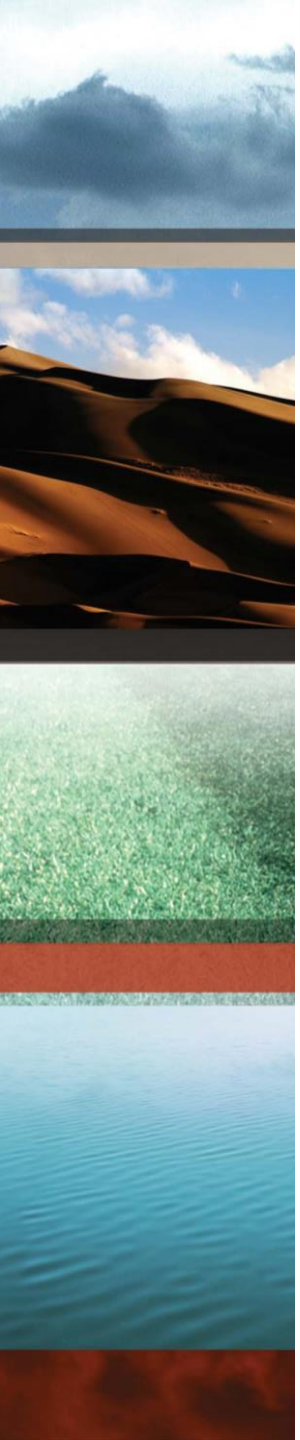

Oxygen Uptake Rate (OUR)

- Method 1683 – Specific Oxygen Uptake Rate in Biosolids
  - Performance-Based Method
  - SOUR is calculated using OUR and solids*
    - SOUR=OUR/MLVSS
  - Optimum Range 8-20

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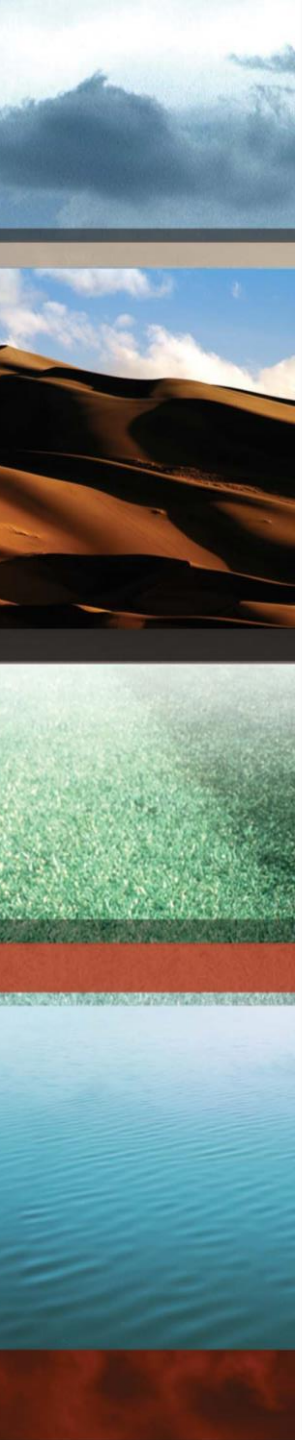

Oxygen Uptake Rate (OUR)

- OUR = The slope of DO (mg/L) versus time (minutes)

  line of the best fit* is the oxygen consumption rate

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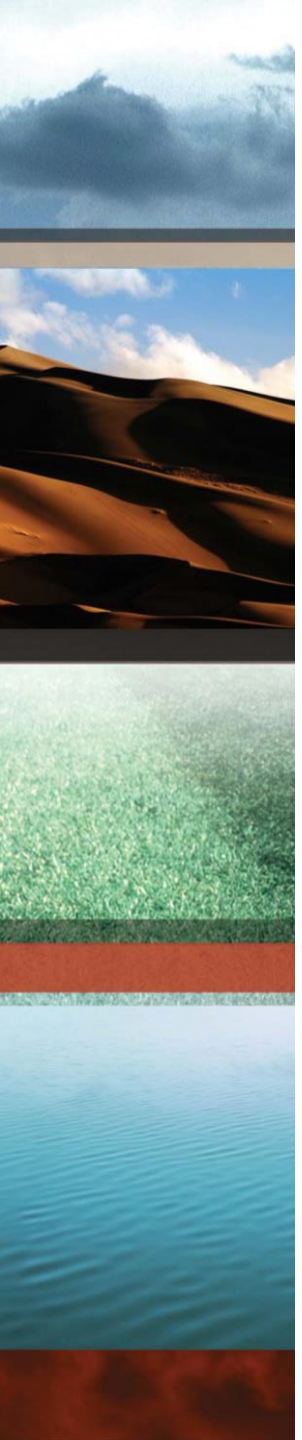

Oxygen Uptake Rate (OUR)

- Specific oxygen consumption rate in milligrams per gram per hour =

$$\frac{\text{Oxygen consumption rate, (mg/L) / min.}}{\text{Volatile Suspended Solids, g/L}} \times \frac{60 \text{ min.}}{\text{h}}$$

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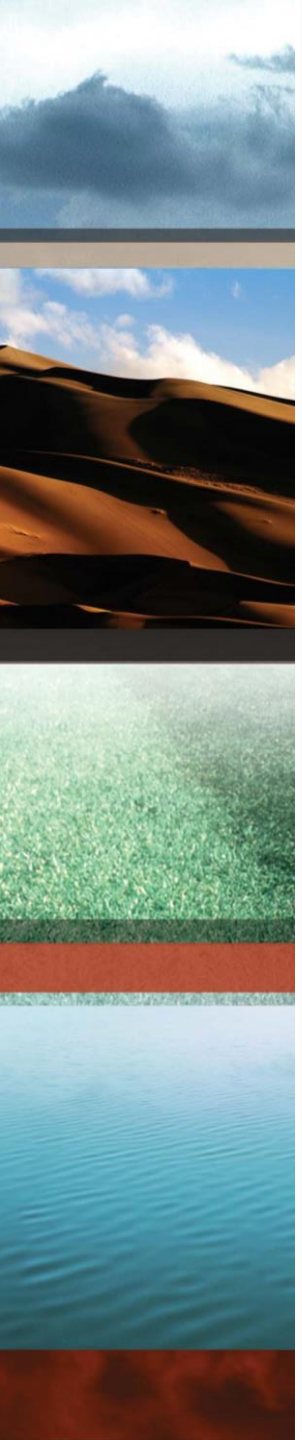
Endogenous Respiration



Endogenous Respiration

"A situation where living organisms oxidize some of their own cellular mass instead of new organic matter they adsorb or absorb from their environment."

- *California State University, Sacramento, Volume II*

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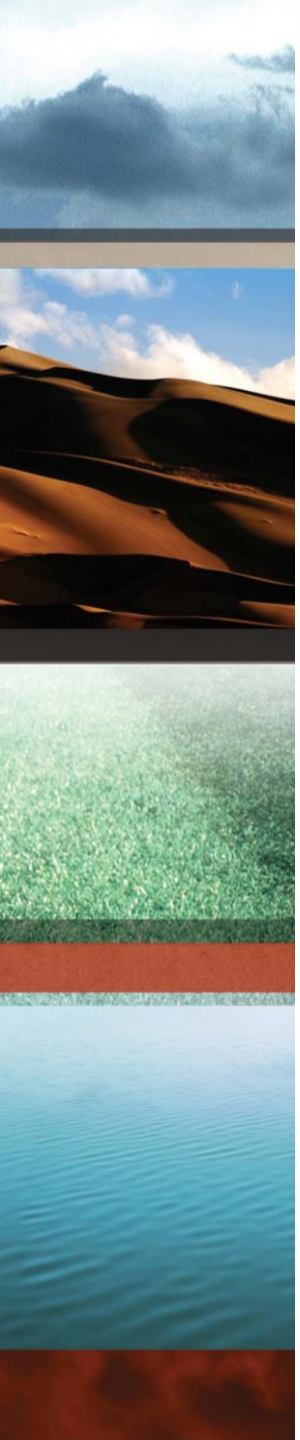

Endogenous Respiration

Treatment is complete when endogenous respiration occurs.

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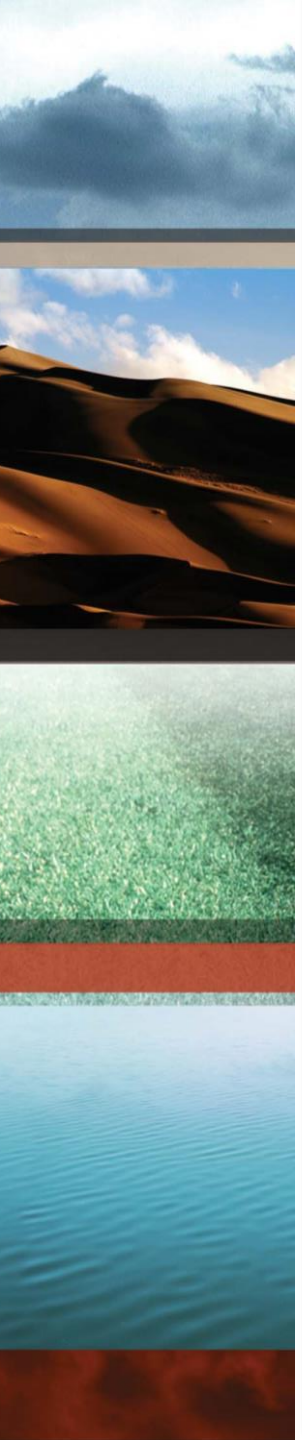

Endogenous Respiration

- The “Time to Endogenous” respiration can be determined by repeated OUR tests on a MLSS being aerated. This may take several hours. An endogenous state should be reached within the detention time of the bioreactor.

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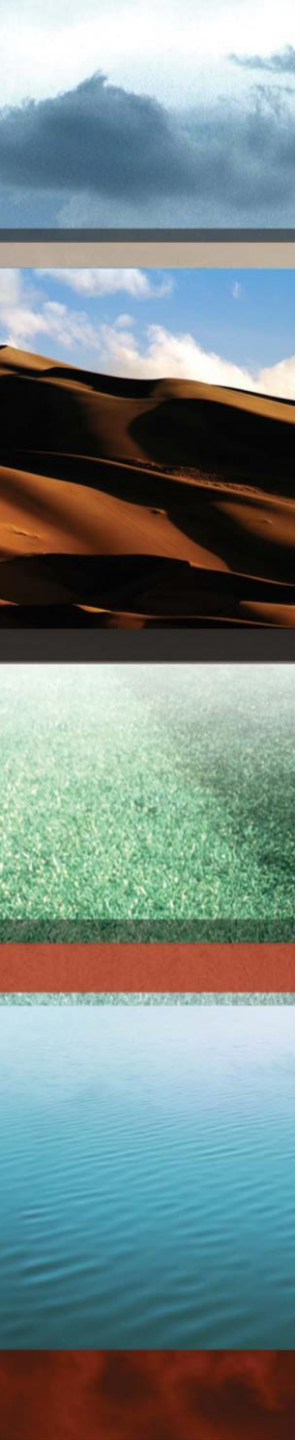

Endogenous Respiration

Long “Time-to-Endogenous” (High) OUR values:

- Organic load is too high (**Excessive F**:M) and/or
- MLVSS concentration is too low (**Insufficient** F:**M**) and/or
- The bioreactor is too small and/or
- Low DO condition exists in the bioreactor

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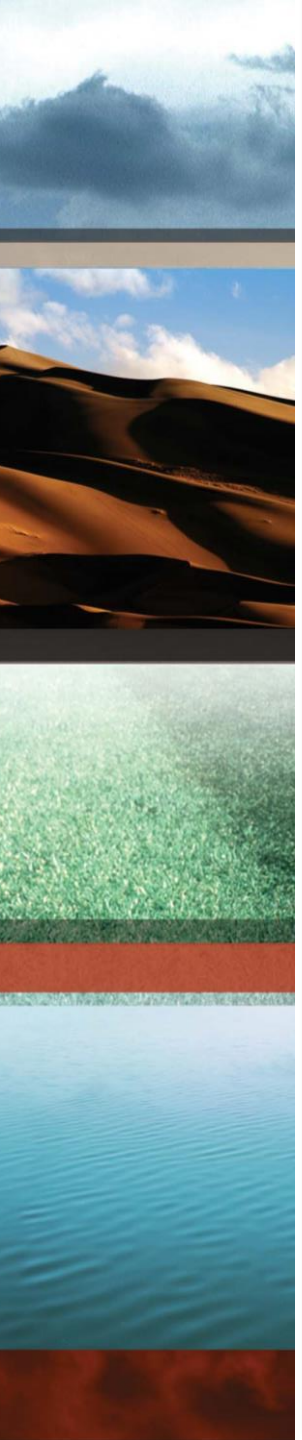

Endogenous Respiration

Test Procedure:

- Collect several gallons of mixed liquor in a pail and aerate the sample
- Determine an OUR value periodically and graph the values

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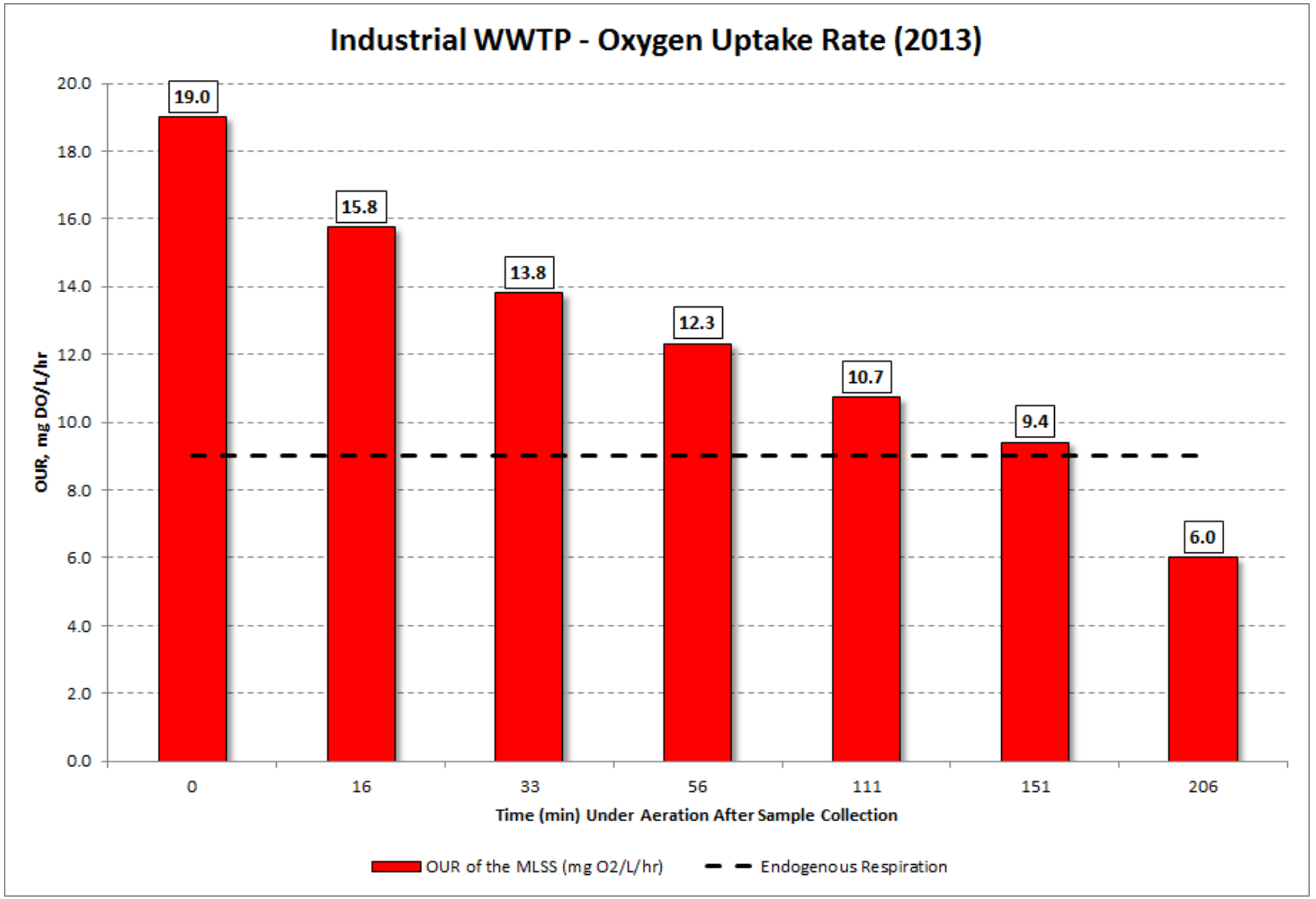

Figure From: Fuller, R. (2017, March 18). *OUR Level 2 Testing [Blog post].* Retrieved from https://www.thewastewaterblog.com/single-post/2016/12/18/OUR-Level-2-Testing.

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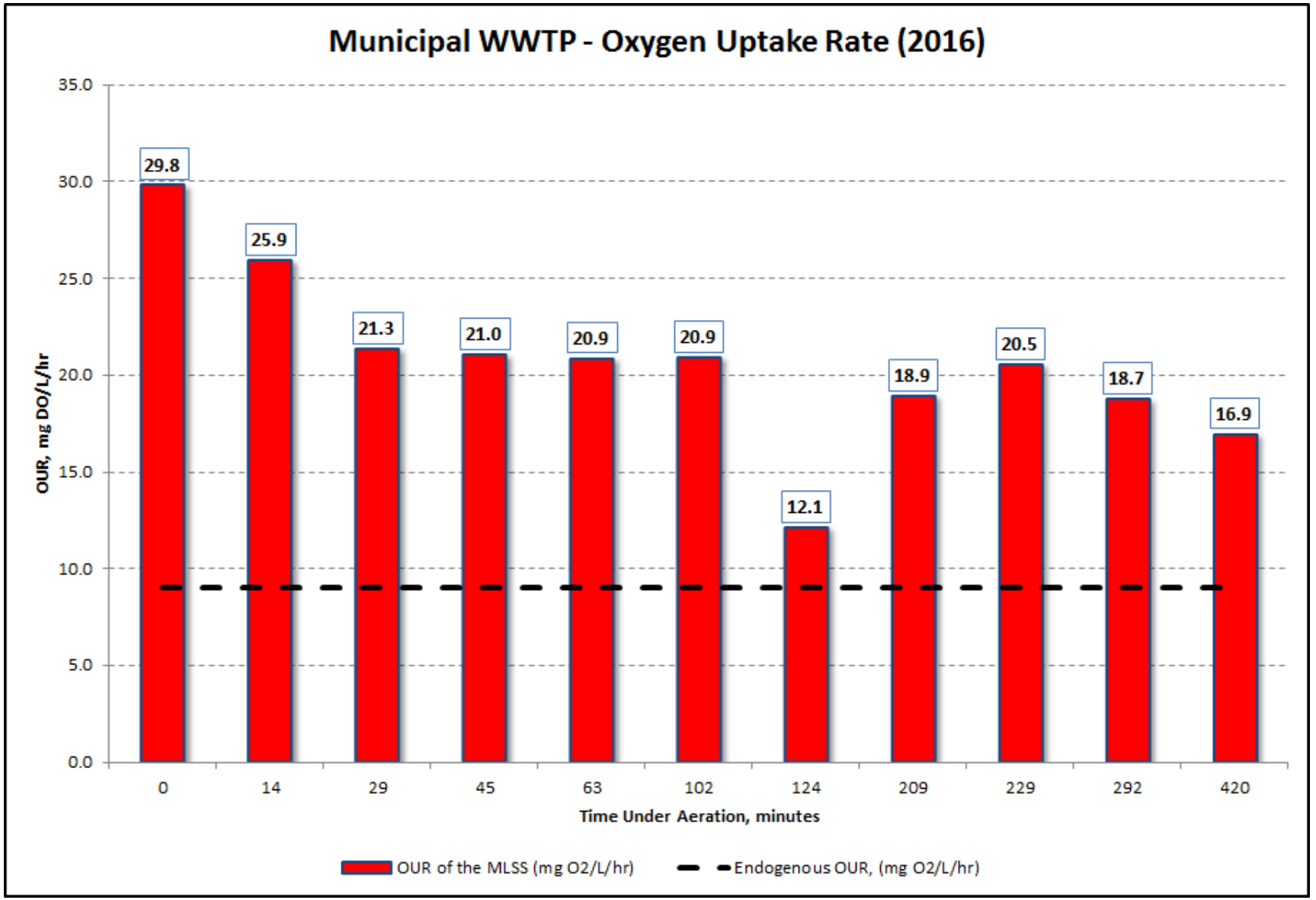

Figure From: Fuller, R. (2017, March 18). *OUR Level 2 Testing [Blog post].* Retrieved from https://www.thewastewaterblog.com/single-post/2016/12/18/OUR-Level-2-Testing.

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Treatability Testing (OUR)

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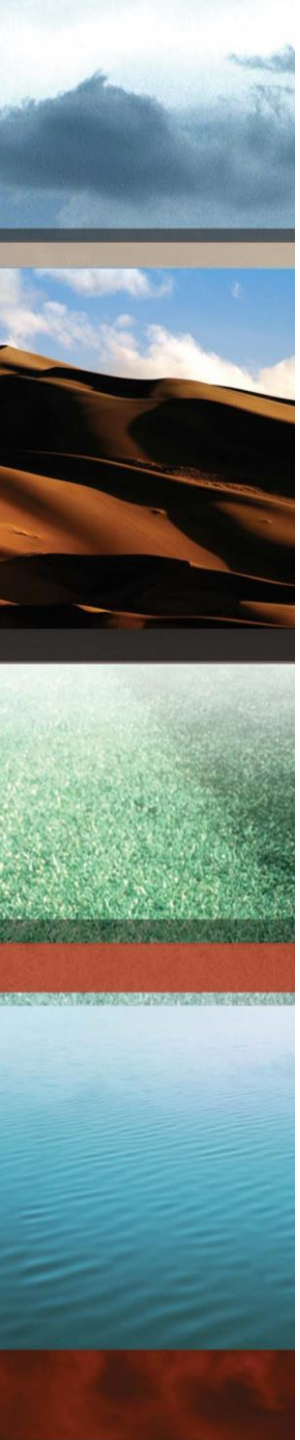

Treatability Testing (OUR)

- OUR can be used to evaluate the impact of different waste streams on biological treatment systems.
- Is a waste stream:
  - Desirable?
  - Inhibitory?
  - Toxic?

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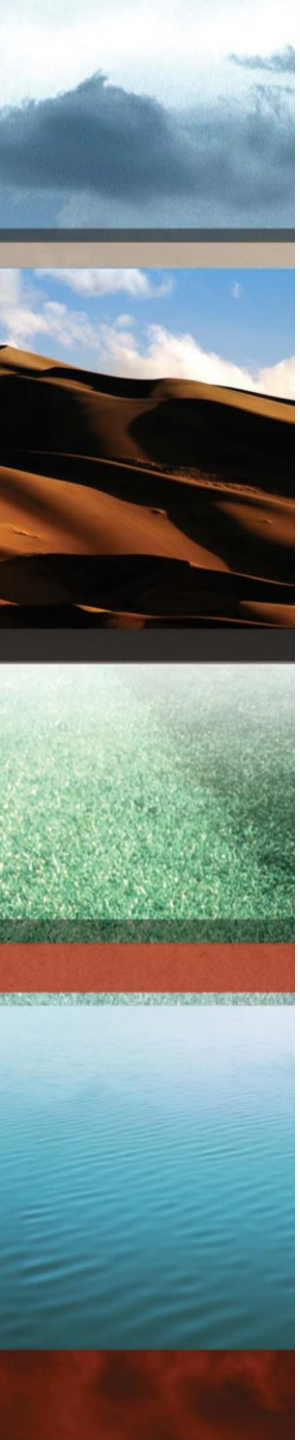

Treatability Testing (OUR)

- In this model, microorganisms should be at a state of endogenous respiration.

- All or most oxidizable organics have been consumed.

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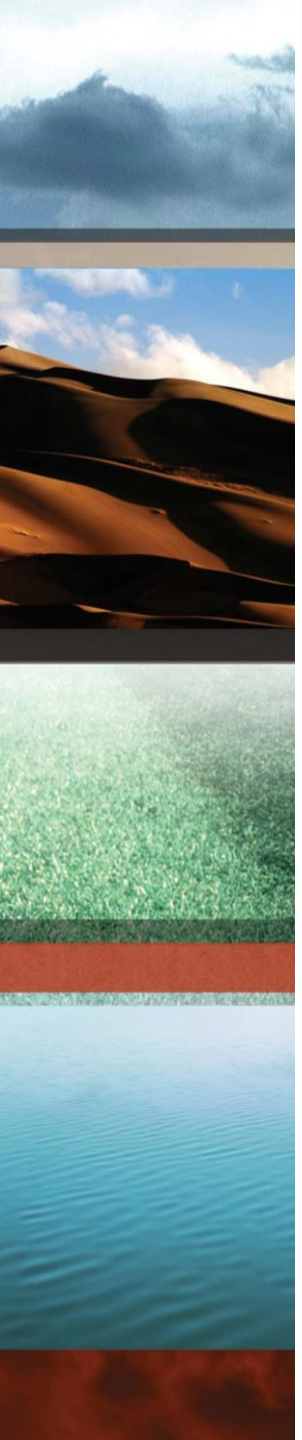

Treatability Testing (OUR)

- When has endogenous respiration been reached?
  - OUR in MLSS sample <10 mg/L/hr

"The prepared cell suspension is aerated for a 2-hour period. At the end of the period, the respiration rate is determined using respirometric or an oxygen uptake technique."

- ASTM Standard D5120 Section 4.4 (2009)

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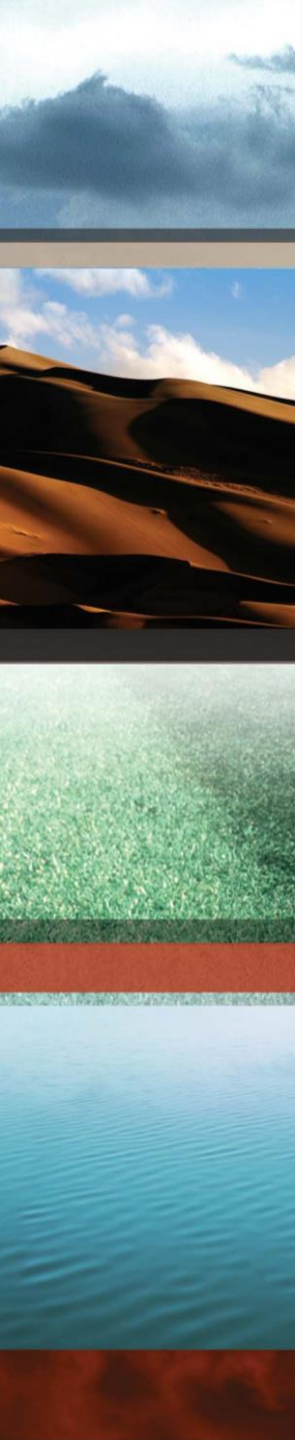

Treatability Testing (OUR)

Test Description (1):

1. Test mixtures and controls are aerated to keep oxygen concentration above 60% saturation (about 1 L/min)
2. Test mixtures and controls are stirred
3. After aeration (usually 3 hours) calculate the OUR
4. Decide how to proceed

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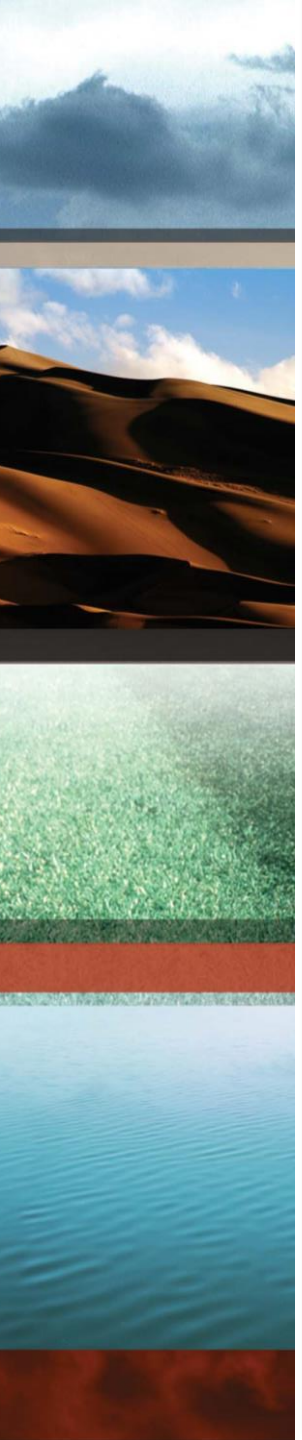

Treatability Testing (OUR)

Test Description (2)

1. Set up a series of BOD bottles containing MLSS. Add incremental amounts of the stream to be evaluated (i.e., 0.2 mls, 0.4 mls, 0.6 mls).
2. When the sample is not toxic, OUR should increase with increasing aliquots of the sample. Decreasing OUR with increasing aliquots indicates toxicity.
3. Treatability Testing (OUR)
4. Case Study - A study using similar test procedures showed that antifreeze (ethylene glycol) was not toxic to mixed liquor in doses up to 5000 mg/L and doses over 10,000 mg/L showed toxicity.

Respirometry-based evaluation of the fate and possible effects of antifreeze on activated sludge Fall, Cuenca, Ba, Solis. *Journal of Environmental Management*. 2004.

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Respirometry – Control Concepts

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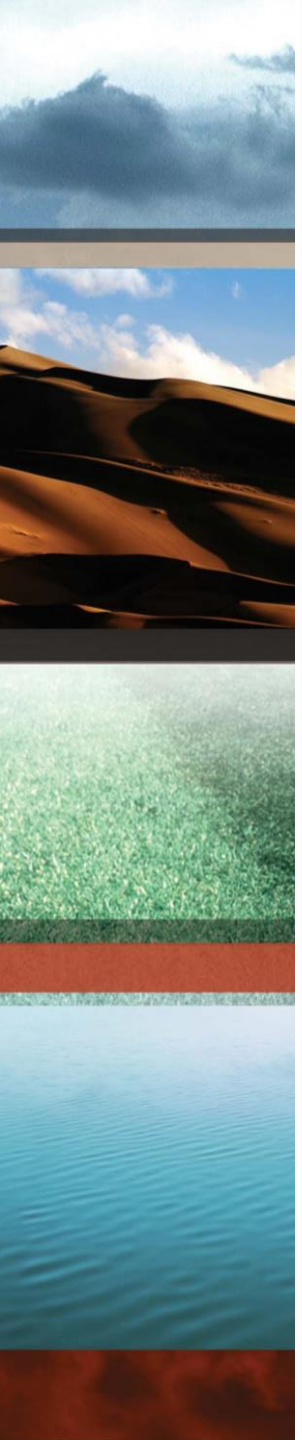

Respirometry – Control Concepts

A wastewater treatment plant is never at a steady state.

- It is continually subject to disturbances.

The basic objective:

- Keep the plant running consistently despite disturbances!
- Meet the effluent standards!

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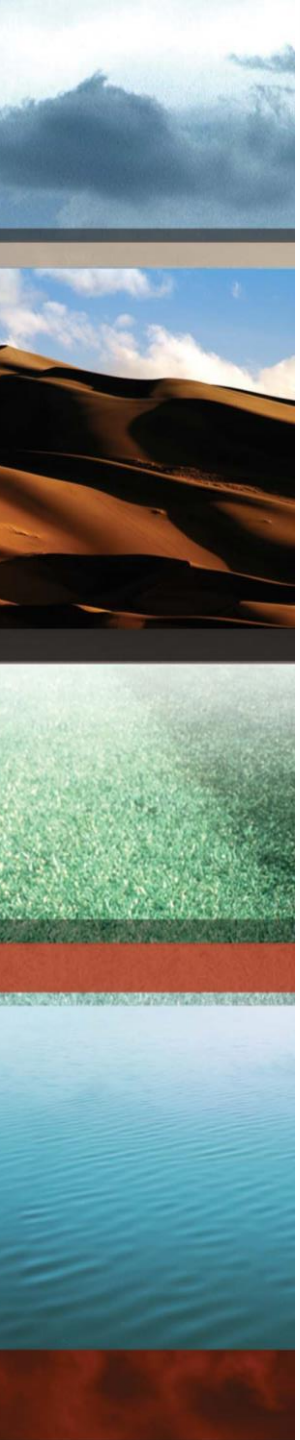

Respirometry – Control Concepts

Disturbances beyond our control:

- Influent flow rate
- Influent composition
- Influent concentrations
- Internal streams are purposefully or unintentionally changed

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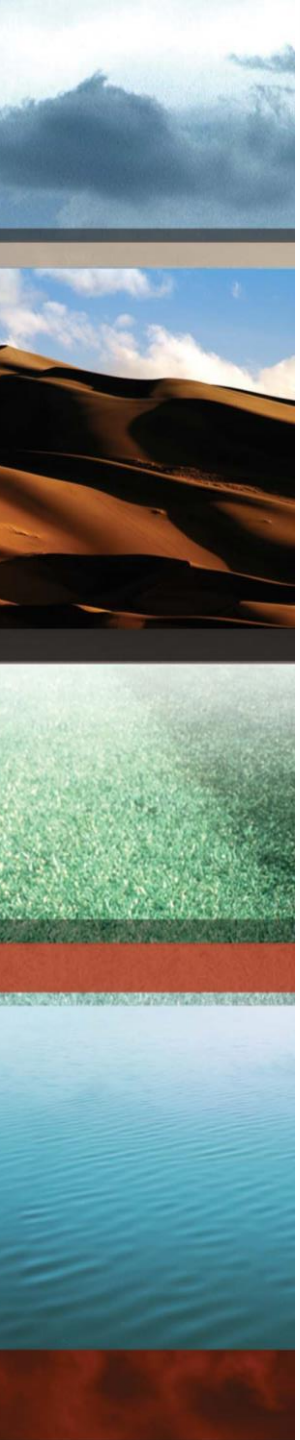

Respirometry – Control Concepts

Operational Objectives:

- Grow the right biomass population
- Maintain good mixing where appropriate
- Maintain adequate loading and DO concentration
- Maintain adequate airflow
- Favor good settling properties
- Avoid clarifier overload

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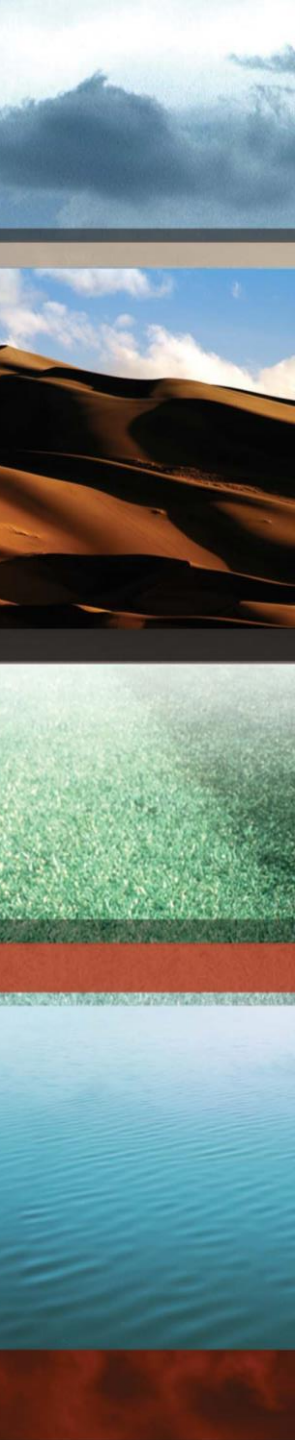

Respirometry – Control Concepts

- Many operational problems are related to fundamental biochemical microbiological behavior.
- Manipulated variables available often seem to be too limited to control the plant to some desired operating state.

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Respirometry – Control Concepts

Manipulated Variables

- Airflow rate
- Chemical dosage rate
- Waste flow rate
- Recycle flow rate

Disturbances

- Influent flow
- Influent composition
- Influent concentrations
- Others*

*Example: Filter backwashing

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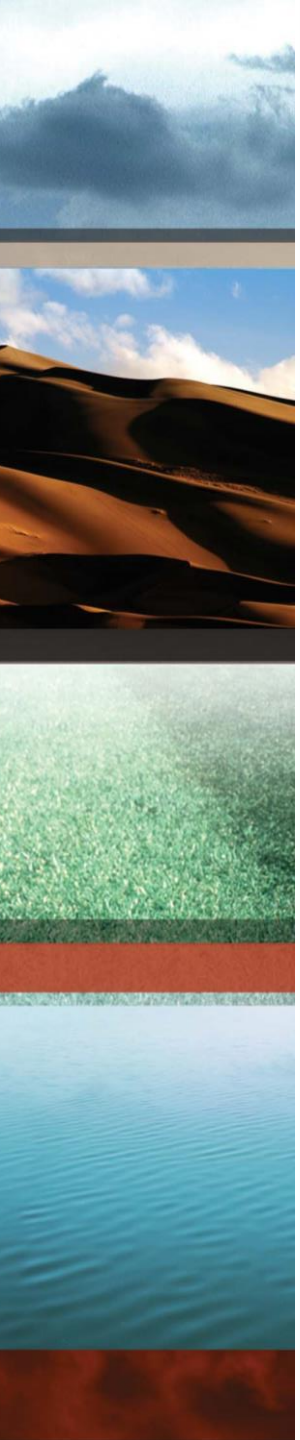

Respirometry – Control Concepts

Standard Feedback

- Through the use of set points, variables can be controlled.
  - Example: establish a DO range in the aeration tank with some type of a control mechanism
  - Problem: This does not recognize a toxic occurrence. The system does not take the respiration rate into consideration.

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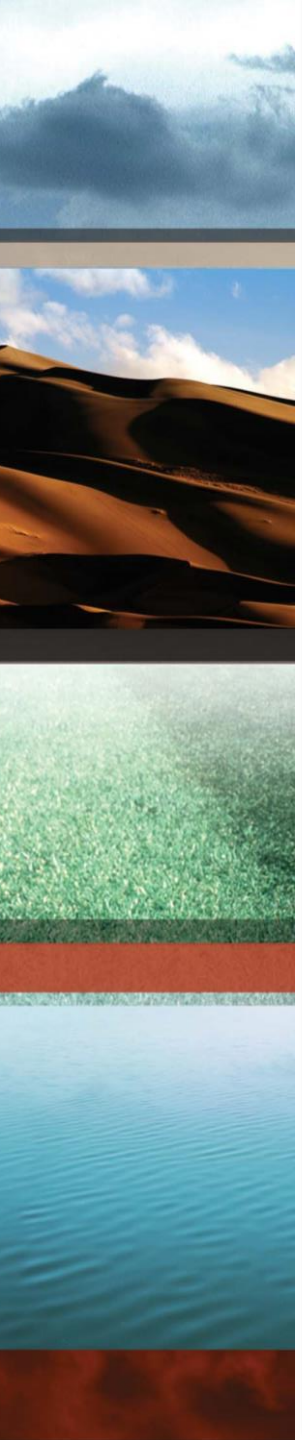

Respirometry – Control Concepts

Feed Forward

- The respiration rate is measured and compared with a desired set point! Airflow is manipulated so the set point is reached.
- Obviously, other analysis is required but results are best when obtaining feedback and looking ahead are combined (FB and FF).

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Respirometry – Case Studies

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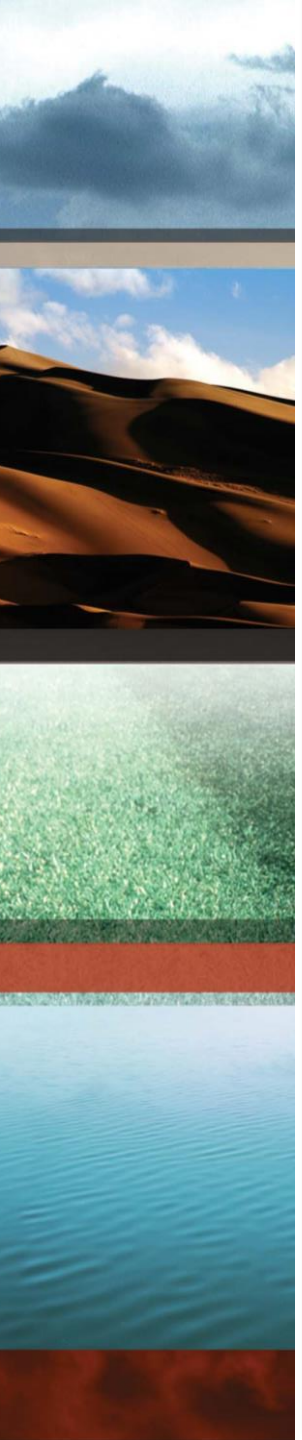

Respirometry – Case Studies

- A respirometric technique was used to study the NaCl and O&G effects on aerobic biological treatment of fish canning industrial wastewaters: No inhibition from NaCl at concentrations below 17.5 mg/L.

Cristóvão, R. O., V. M.S. Pinto, R. J.E. Martins, J. M. Loureiro, and R. A.R. Boaventura. (2016). Assessing the influence of oil and grease and salt content on fish canning wastewater biodegradation through respirometric tests. *Journal of Cleaner Production*, 127, 343-351. http://www.sciencedirect.com/science/article/pii/S095965261630325O

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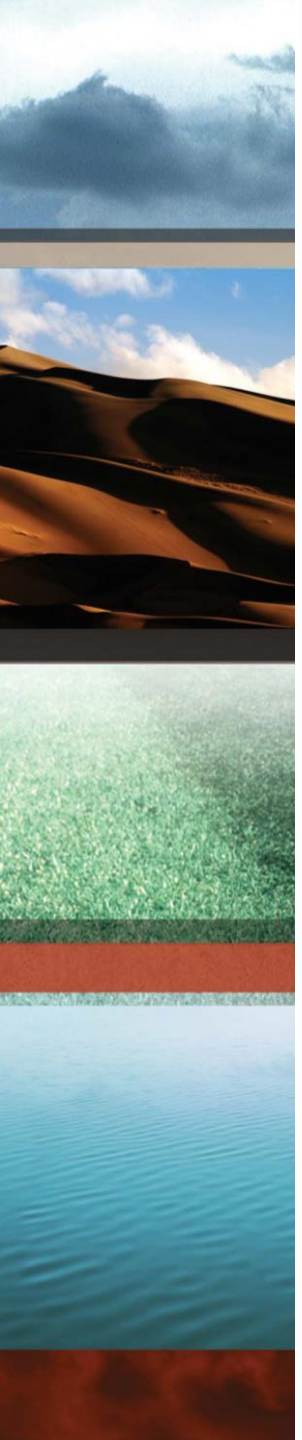

Respirometry – Case Studies

- On-line measurements of the activity of activated sludge biomass may allow for more efficient operation of treatment plants… Samples from the five activated sludge plants were assayed and showed, as expected, that the MLSS and MLVSS levels were a poor measure of activity of the sample determined by OUR….

Guwy, A.J., H. Buckland, F.R. Hawkes, and D.L. Hawkes. (1998). Active biomass in activated sludge: Comparison of respirometry with catalase activity measured using an on-line monitor. *Water Research*, *32*(12), 3705-3709. http://www.sciencedirect.com/science/article/pii/S0043135498001572

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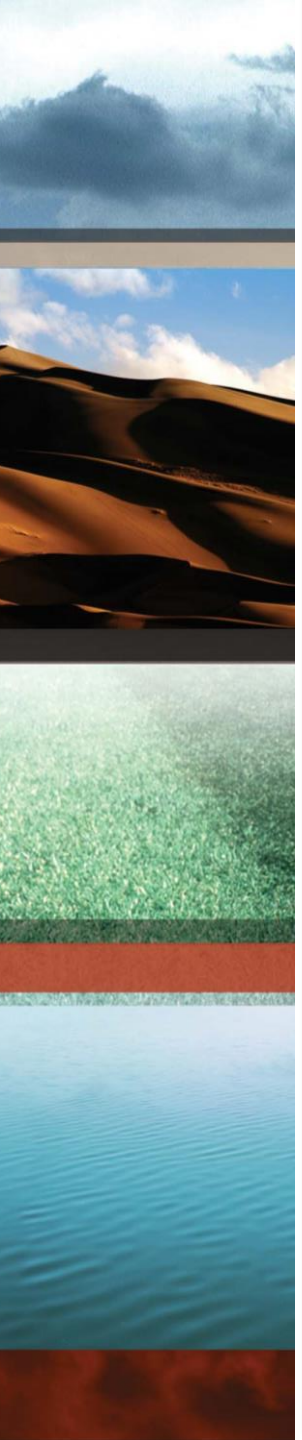

Respirometry – Case Studies

- An investigation demonstrated that in situ respirometry was an effective tool to manage the removal of an inhibitory substrate in a sequencing batch reactor (SBR)…It was possible to select an optimum operating cycle using the oxygen uptake rates as an indicator for the removal of phenol….

Yoong, E.T., P.A. Lant, and P.F. Greenfield. (2000). In situ respirometry in an SBR treating wastewater with high phenol concentrations. *Water Research, 34*(1), 239-245. http://www.sciencedirect.com/science/article/pii/S004313549900142 6

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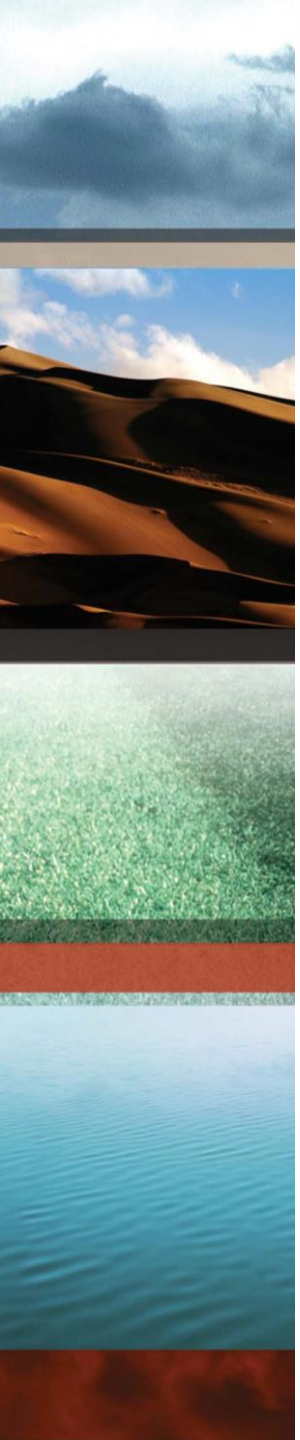

Respirometry – Case Studies

- … In this study respirometry has been used as a relatively quick and efficient means to detect the effect of the presence of a salt of up to 5 g/l (low salt stress) on the degradation of carbon and nitrogen pollution and on bacterial floc aggregation….

Zerdazi, R., M. Boutraa, A. Melizi, M Bencheikh lehocine, and A.-H. Meniai. (2012). Use of Continuous Aeration Respirometry Method for the Prediction of Slightly Saline Waste Water Biodegradation. *Energy Procedia*, *18,* 1361-1371. http://www.sciencedirect.com/science/article/pii/S1876610212009228

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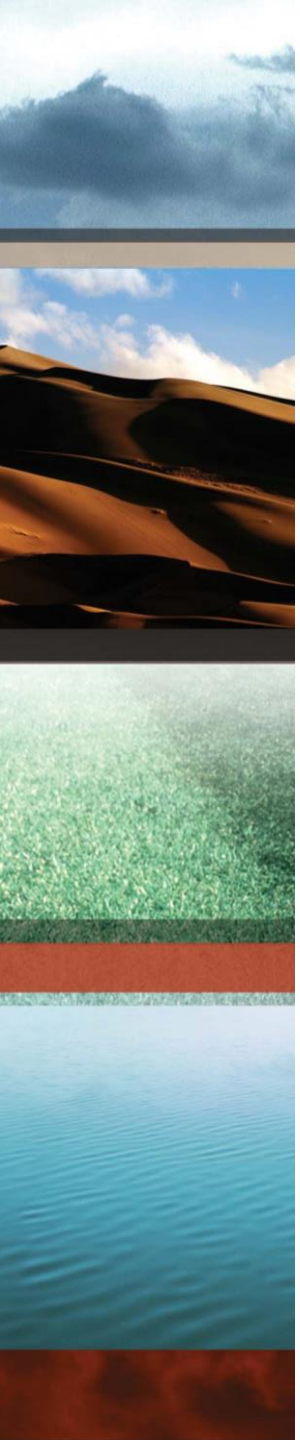

Respirometry – Case Studies

- … This study described a new respirometric technique to monitor the transient response of activated sludge systems to individual synthetic organic compounds…The fed batch reactor was oxygenated…to meet the steady-state oxygen demand…Mathematical descriptions of the transient profiles were derived and the… profiles were subsequently compared to profiles predicted…for SOC removal…

Smets, B. F. , S. M. Fehniger, and C. P. Leslie Grady Jr. (1996). Development of a respirometric assay to measure the transient load response of activated sludge to individual organic chemicals. *Water Science and Technology, 33*(6), 49-55.
http://www.sciencedirect.com/science/article/pii/027312396002843

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Respirometry – Making Sense of It

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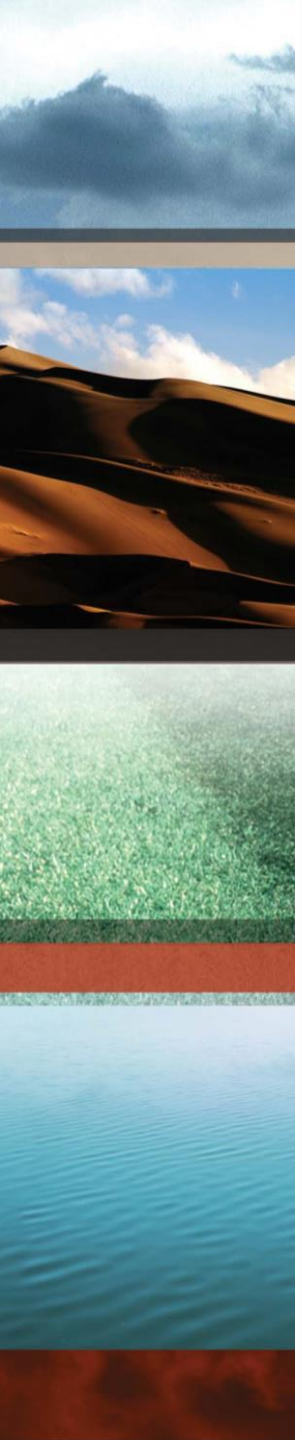

Respirometry – Making Sense of It

- Using a mathematical model to help predict the OUR and potential microbiological inhibition in an activated sludge plant

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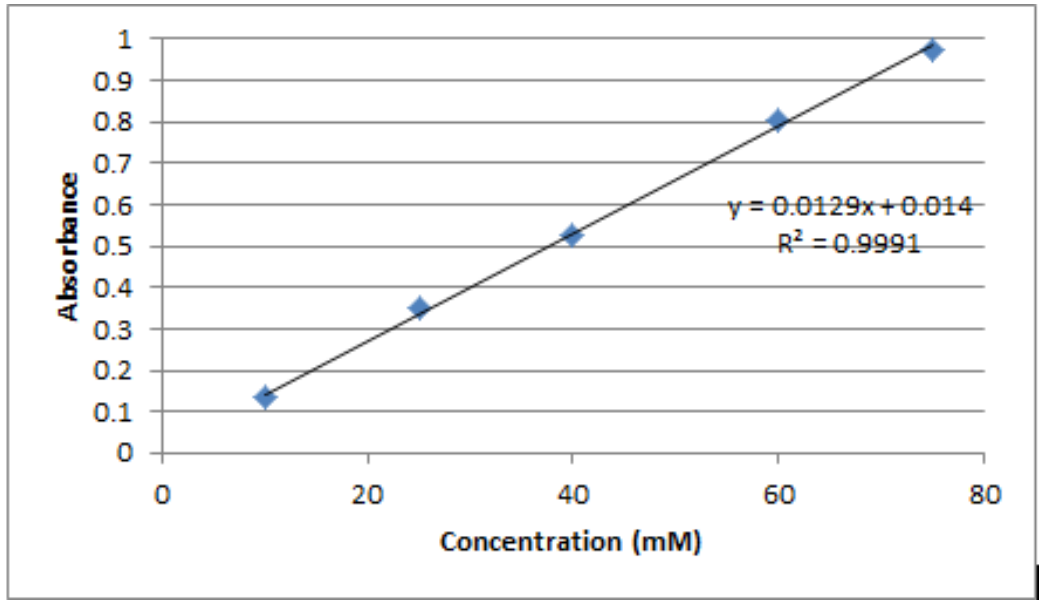
Respirometry – Making Sense of It

- Simple Linear Regression - a statistical method that allows us to summarize and study relationships between two continuous variables. One variable (x) is regarded as the predictor, or independent variable.



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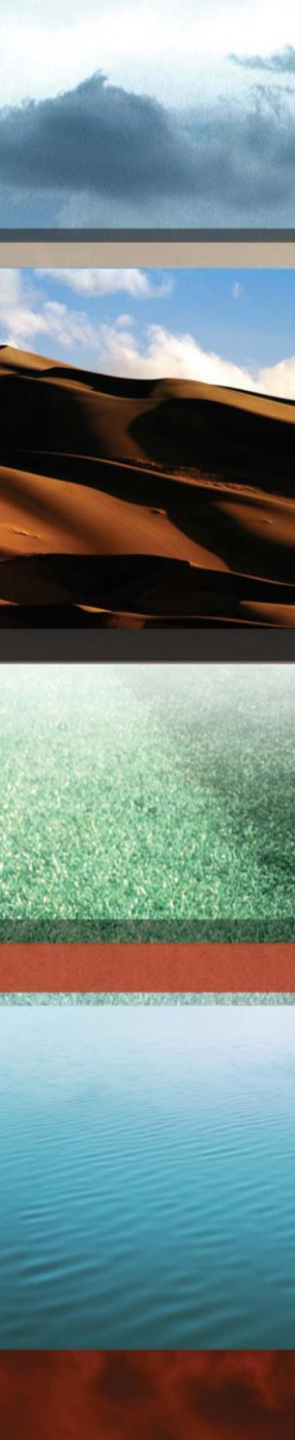

Respirometry – Making Sense of It

- Multiple Linear Regression (MLR) - attempts to model the relationship between several variables to predict the outcome of a response variable (the respiration rate)

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Thank you!

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