

Use of Oxygen Uptake Rate (OUR) as a Tool to Start Up, Predict Process Instability, Perform Rapid Process Optimization, and Monitor Nitrifier Population Dynamics in Biological Nitrogen Removal (BNR) Systems – Teaching an Old Dog New Tricks

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Abstract

Oxygen Uptake Rate (OUR) measurements have been initially used in wastewater treatment plants to monitor biological activity of conventional BOD removal systems. The most common use of OUR measurements by plant operators has been to determine if the organisms are alive/ viable. The latter predominant use has relegated the potential of this powerful tool to mediocre use. Emerging needs to monitor, optimize, and trouble shoot BNR systems has led to the advent of many other advanced and complicated microbial techniques such as Fluorescent In Situ Hybridization (FISH), 16 sRNA/DNA-DNA hybridization using Polymerase Chain Reaction (PCR), etc. These advanced tools have provided eyes into the microbial systems to better understand process conditions and identify potential instabilities of BNR systems. Although these advanced technologies have provide the needed information, they are expensive, require highly specialized staff (typically not present at most wastewater facilities), complex and time consuming. Often the information obtained from these advanced tools is not available in time to adjust process controls when required or alter the physiological state of organisms and are not reflective of physiology/ capability of the organisms in the full scale system.

Unlike the advanced tools above, OUR testing is a simple, readily available, and familiar tool that can deliver similar information (to that of the more advanced methods) to monitor, optimize and trouble shoot BNR systems. Unlike the advanced methods, OUR use provides quick turn around (2-3 minutes) and is non invasive and thereby provides the closest physiology/ capability of organisms as those present in the full scale systems. The purpose of this paper and presentation is to highlight and promote the use of simple and quick OUR testing to manage/optimize/ operate/ troubleshoot/ start up BNR systems.

Some of the aspects that will be discussed in the paper and presentation include

- 1) Early prediction and correcting sludge settleability instabilities
- 2) Measuring and predicting nitrification capacities
- 3) Monitoring and predicting nitrifier population shifts
- 4) Heterotrophic health/ toxicity prediction
- 5) Feast/ famine determination and RAS Control
- 6) Aeration basin optimization

INTRODUCTION

Background

Often, when plant facilities are designed and commissioned, the operations means and methods are inherited from basic operations manuals that are written to manage these facilities around the basis of design. During design, assumptions are made to size facilities conservatively. These design assumptions are usually based on industry accepted ranges for facilities in question and are often not reflective of the live biological process that is cultivated and enriched within the facilities after they are brought online. The physiology of bacteria in activated sludge systems and its change due outside selective pressures placed on an activated sludge system is well known. The selection pressures imparted at start up and subsequent operation has a significant impact on the types organisms cultivated and their ability/stability to perform the treatment reactions (physiology) that are required.

By optimizing operations of facilities within a peak physiological state (peak ability) boundary/envelope provides the owner with the ability to maximize the use of existing facilities and reduce operations costs because the most efficient/ stable process reactions are promoted, implemented, and maintained. By having the appropriate tools to measure physiological state of bacteria, it is possible to develop operations strategies and guidelines to maintain the activated sludge system within the peak physiological boundary/ envelope.

Historically, plant operations have been controlled using global system parameters such as flow, BOD removal, ammonia removal, dissolved oxygen, solids retention time, return activated sludge flow rate, etc. Based on these global parameters, operations staff try to obtain some indirect snapshot and understanding of the biological processes occurring in the activated sludge system. In addition, operations staff often tries to infer the physiological state (reaction potential and stability/ instability) of bacteria from these global system parameters. Using these indirect approaches provide some insight into the ability can be inferred but they does not provide as definitive understanding of bacterial health, populations, their treatment ability, and their stability.

Process optimization performed based on biological system physiology is the next level of system operations that are required to maximize the use of existing facilities. One of the main reasons that has limited the use of this approach has been the lack of proper tools to obtain insight into organism physiology from which operational guidelines can be developed.

Over past decade, there has been an advancement of microbiological tools to meet emerging needs to monitor, optimize, and trouble shoot BNR systems such as Fluorescent In Situ Hybridization (FISH), 16 sRNA/DNA-DNA hybridization using Polymerase Chain Reaction (PCR), etc. These advanced tools have provided eyes into the microbial systems to better understand process conditions and identify potential instabilities of BNR systems. Although these advanced technologies have provided

information, they are expensive, require highly specialized staff (typically not present at most wastewater facilities), complex and time consuming. Often, the procedures used to derive results from these tests often impart environmental conditions that can change the physiology of organisms such that they are not reflective/ representative of the physiology in the full scale system that they are being evaluated. In addition, the information obtained from these advanced tools is not available in time to make timely operational decisions.

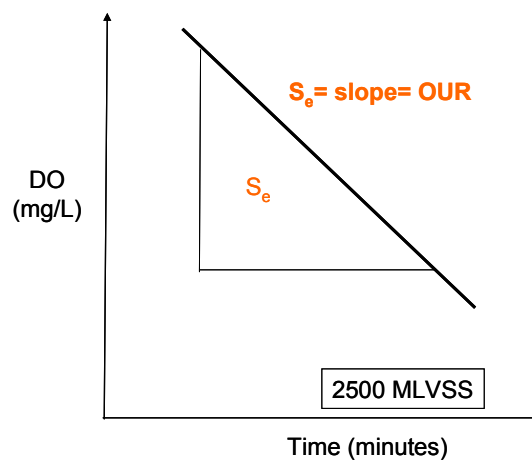
Unlike the advanced tools above, Oxygen Uptake Rate (OUR) testing is a simple, readily available, and familiar tool that can deliver similar information (to that of the more advanced methods) to monitor, optimize and trouble shoot BNR systems. This paper will highlight a few of the many ways OUR testing can be used to to manage/optimize/ operate/ troubleshoot/ start up BNR systems based organism physiology.

OUR EQUIPMENT AND DETERMINATION

Equipment

The OUR equipment (also known as respirometers) can range from a basic system that requires manual data collection and calculation to a more advanced commercial systems that is computerized where calculations are automated. Regardless of the level of automation the OUR equipment has essential components which include a test chamber to add aerated mixed liquor/ substrate, a stirring mechanism, a dissolved oxygen probe, and a dissolved oxygen analyzer.

Figure 1 – Typical OUR Determination



Methodology

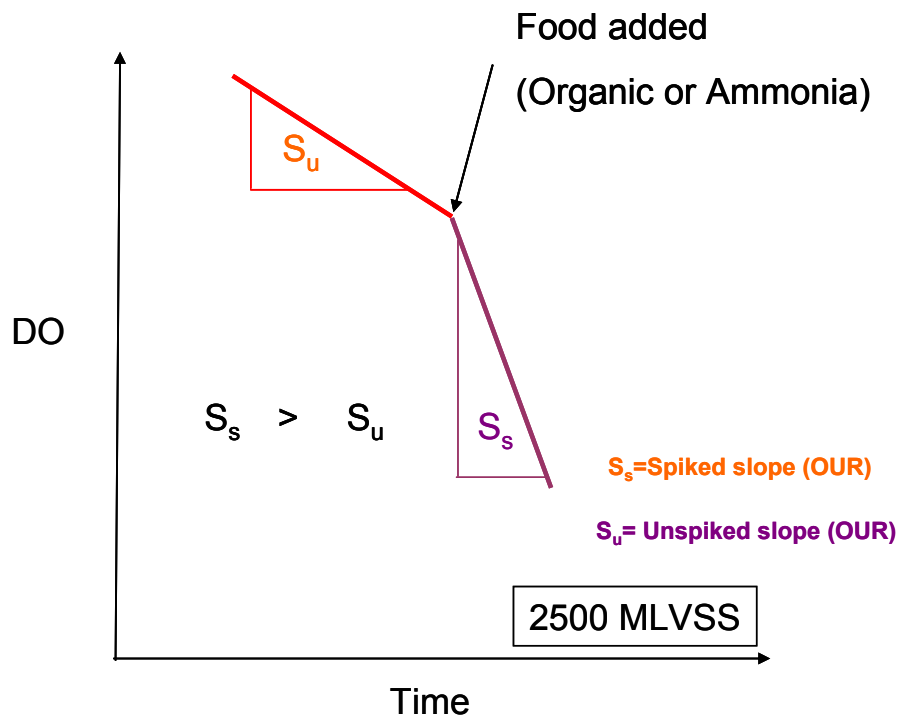
The OUR test essentially consists of adding an aerated sample of mixed liquor (collected from a desired location in a full scale system) to the test chamber, placing the DO probe into the chamber and monitoring the decline in dissolved oxygen over time. Figure 1

below shows a typical profile from a test run. The slope of the linear portion of the DO profile with time is the OUR and has the units mg O₂/ L-h. If the OUR is divided by the MLVSS of the sludge sample that was used to perform the test, a value known as the SOUR (Specific Oxygen Uptake Rate) can be determined which is the oxygen consumption rate per gram of MLVSS (mg O₂/ g-MLVSS-h). The SOUR normalizes the response to the “mass of organisms” and allows comparison of oxygen response for different mixed liquors for each gram of “organisms”.

Spiked and unspiked OURs/ SOURs are performed to estimate organism response/ physiology. Each of these performed unspiked OURs are typically performed to obtain the actual oxygen uptake rate of the mixed liquor sample as collected from the full scale system “as is”. If the test chamber is spiked with a known substrate, the OUR response will measure how the organisms in the mixed liquor respond to that substrate. Depending on the food “spiked” into the test chamber, different types of organisms will respond while others do not from which one can isolate a response from a certain class of organisms.

For example, if you wanted to understand the heterotrophic health, spiking with e.g., glucose, a readily assimilable substrate by most heterotrophs, one can estimate heterotrophic activity. If the substrate spiked to test chamber is ammonia, the OUR response will estimate only nitrification activity and hence the isolate the activity of nitrifiers in a mixed liquor sample. Figure 2 shows how the unspiked and spiked responses are determined during a test run.

Figure 2 – Unspiked/ Spiked OUR Determination



The OUR/ SOUR tests are performed at known MLVSS so that physiological response can be compared for sludge samples analyzed (across a basin, during times of the day, or at different days). If the unspiked OUR is determined from the end of an aeration basin where all treatment reactions are complete, this value would equate to the endogenous respiration rate of the organisms. If the unspiked OUR is determined from a sample that was collected from the influent end of the aeration basin, it would provide an estimation of organism activity in a “feast” condition.

RESULTS AND CONCLUSIONS

This section discusses how the SOUR tests can be used to monitor and optimize BNR systems.

Early Prediction of Sludge Settleability Instability

Figure 3 – SOUR/ SVI Correlation

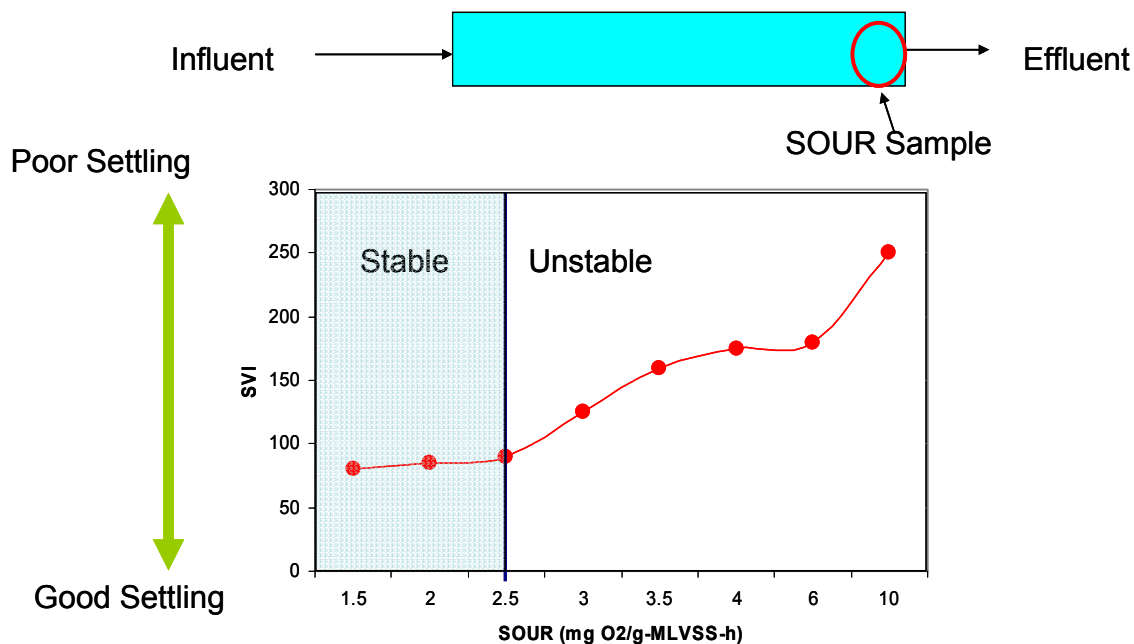
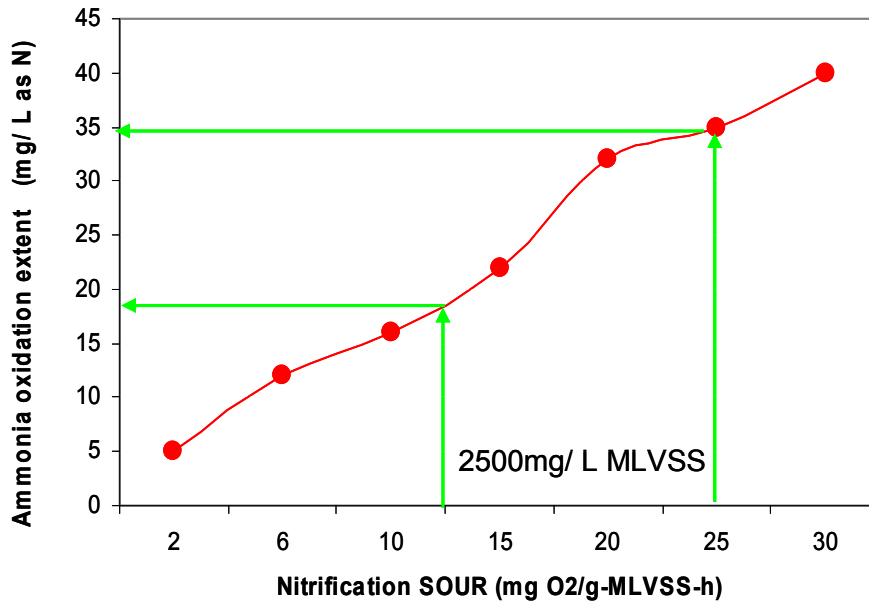


Figure 3 shows the relationship between endogenous unspiked SOUR and sludge settleability for an activated sludge pilot study where the plug flow reactor was subjected to increased loading. As the loading was increased, the unspiked SOUR at the end of the reactor increased over time. SVIs were also taken routinely taken to during the increased loading study. As observed, there is a SOUR value beyond which the SVIs begin to increase. The SOUR range over which the SVIs go unstable can be used to predict sludge bulking ahead of time before it gets out of control and operational decisions can be made to bring a sludge that is on the verge of being unstable, back into the stable regime. When a rise in SOUR is observed at the end of the basin, it can be reduced in several ways (reduced load, increase basin air, or take the basin offline and aerate for a few hours) to reduce the endogenous SOUR back within the stable range.

Predicting Nitrification Capability

Figure 4 – Relationship between nitrification SOU and ammonia oxidation



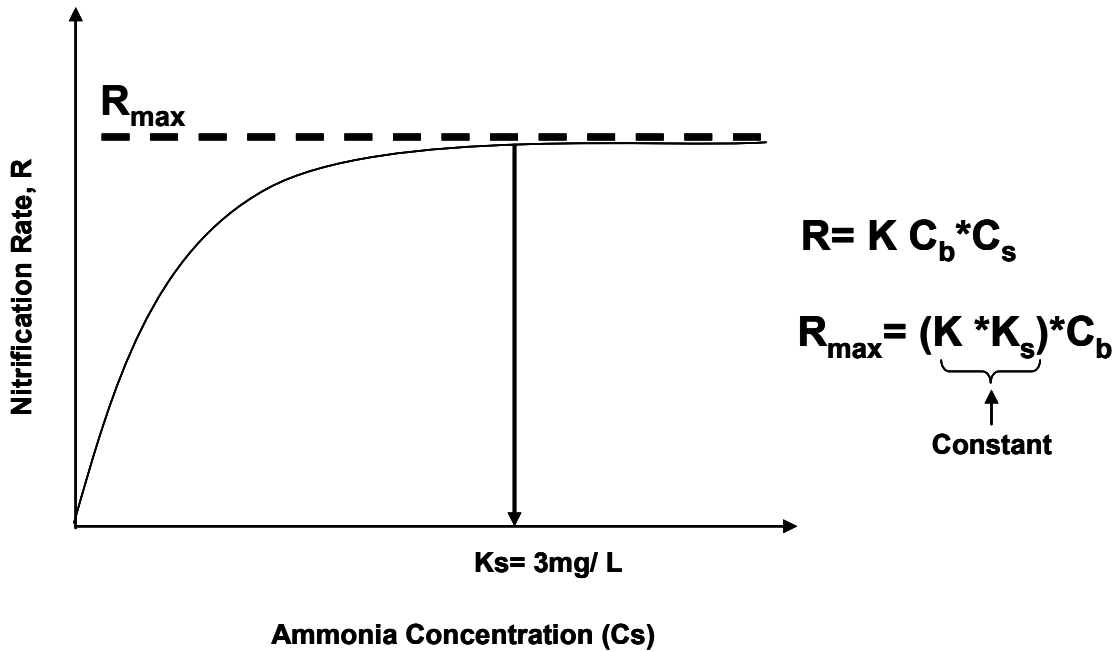
capability

Spiked SOUR data using ammonia can be used to correlate that SOUR response of a given mixed liquor's to ammonia oxidation potential for a given system. Figure 4 shows a graph of how ammonia spiked SOUR was used to predict ammonia loading for a plug flow reactor based on global operational data (effluent ammonia and nitrate). The graph shows that higher nitrification SOURs are a good indicator of higher ammonia oxidation capacity. By performing a spiked SOUR with ammonia it is possible to make decisions on ammonia loading to a system. Furthermore, as seen in the next section below, an increase in the nitrification SOUR is an indicator that the system is enriching a larger population of nitrifiers.

Monitoring and predicting nitrifier population shifts

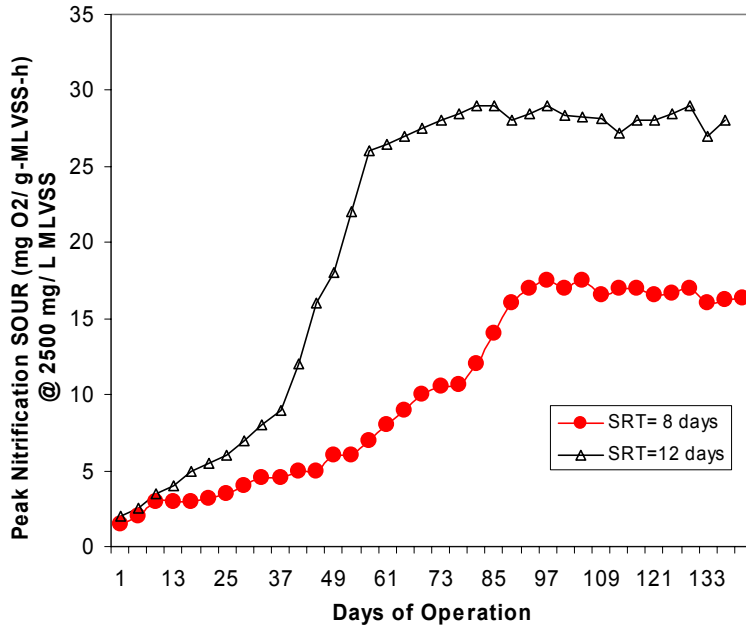
Using the peak nitrification SOUR, it is possible to track nitrifier populations in activated sludge and impacts to nitrifiers in the system due to operational changes. Based on the kinetics of nitrification, as seen in Figure 5, the peak nitrification SOUR is proportional to the concentration of nitrifiers (C_b). By adding ammonia at a dose beyond the saturation concentration (K_s which is between 2-3 mg/L) into the OUR test chamber, the resulting SOUR is proportional to the amount of nitrifiers. Hence the peak nitrification SOUR is good indicator of nitrifier concentrations.

Figure 5 – Relationship between peak nitrification rate (R) and nitrifier concentrations (Cb)



Hence, SOURs can also be used to monitor and predict population shifts due to operational changes. Figure 6 shows the peak nitrification SOURs versus days of operation for two separate basins that were operated at same hydraulic retention time and loading but operated at different solids retention times (SRT). As observed, at each SRT, there is an initial phase where there is an increase in the peak nitrification SOUR versus days of operation after which the peak nitrification rate tapers. At higher SRTs, a similar pattern is observed with the exception that the peak nitrification SOUR is always higher than the peak nitrification SOUR at the lower SRT.

Figure 6 – Nitrifier Population Monitoring and Control

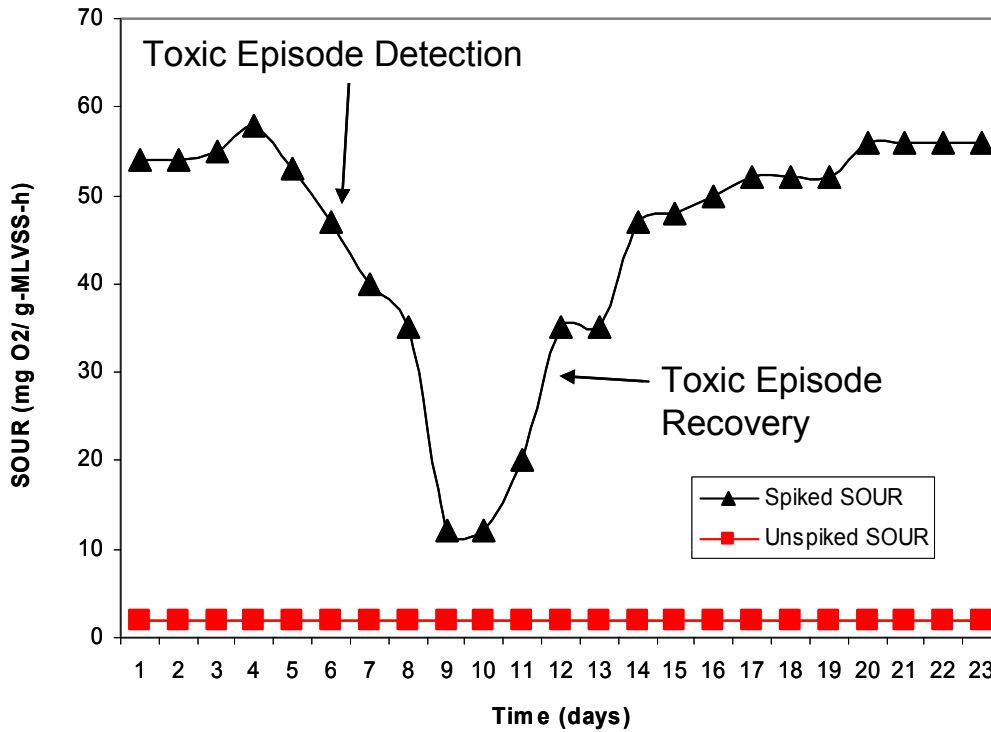


Using the above data, a correlation can be derived between SRT and nitrification capacity by combining Figures 4 and 5.

Heterotrophic Health/ Toxicity Prediction

Figure 6 shows how you can use SOUR information to predict heterotrophic toxicity early. The data shown is for a plug flow activated sludge system where spiked (with glucose) and unspiked SOUR was measured daily at the effluent end of the basin. As seen there is a declining trend in the spiked SOUR by day between day 4 and 6 indicating that there is something negatively impacting the heterotrophic health of the bacteria. The trend was picked up before the five-day BOD data was available to know that treatment is being impacted. Based on the SOUR data, a decision was made to reduce flow to the basins and increasing the aeration capacity. A bench scale aeration study was also initiated of the impacted sludge where it was aerated without additional feed to determine its recovery potential. The bench scale aeration studies also tested SOURs (spiked and unspiked) over the course of the test. The bench scale tests indicated that the heterotrophic activity recovered in 2 days. Based on the combination of full scale and bench scale SOUR data, informed operational decisions were made possible that resulted in a predicted recovery of heterotrophic activity.

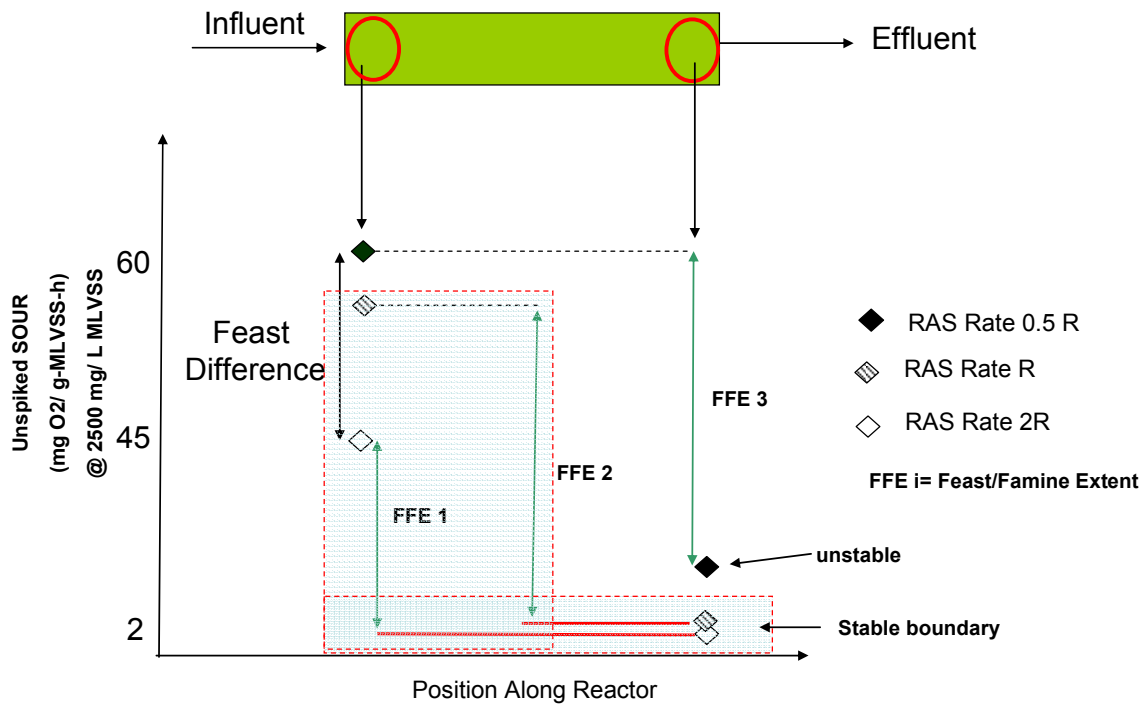
Figure 6 – Early Toxicity Prediction



Feast/ Famine Determination and RAS Control

Figure 7 shows unspiked SOUR measurements at the influent and effluent end of a plug flow reactor for two return activated sludge rates (RAS). For a given RAS rate, the unspiked SOUR is higher at the influent end compared to the effluent end as is expected as there is more food available at the beginning of the reactor compared to the effluent end of the reactor. At the influent end, the unspiked SOUR is higher at the lower RAS rate than at the higher RAS rate. The difference between the influent and effluent unspiked SOURs for a given RAS rate defines the feast/ famine extent (FFE). As seen, the FFE under the lower RAS rates is higher than the FFE under the higher RAS rate. SOURs were used to develop a range of RAS rates for a range of influent flow rates that maintained the end of basin SOURs below the sludge bulking threshold similar to that identified for sludge in Figure 3. Understanding the impact of RAS on FFE allows the operator to work within the stable envelop. Based on the correlation, operational decisions could be made to better match the RAS rate with the influent flow and loading. Working in the envelope area that provides the best FFE with balanced basin MLSS is desired. With reduces basin MLSS maximum treatment occurs with reduced clarifier loading and RAS pumping rates, all of which impact operations significantly.

Figure 7 – Feast/ Famine Tracking



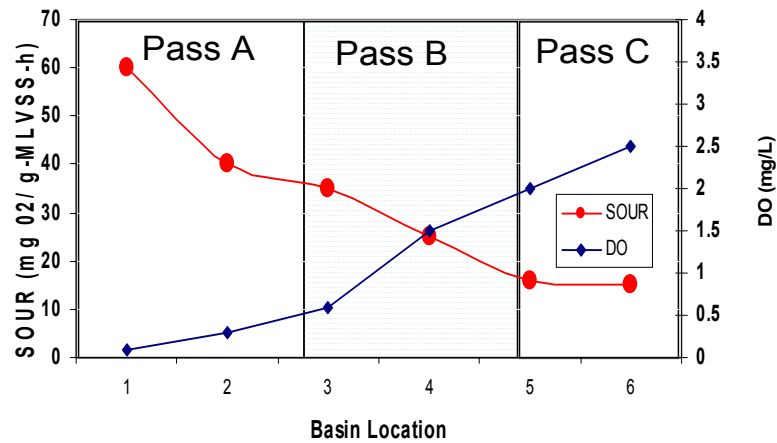
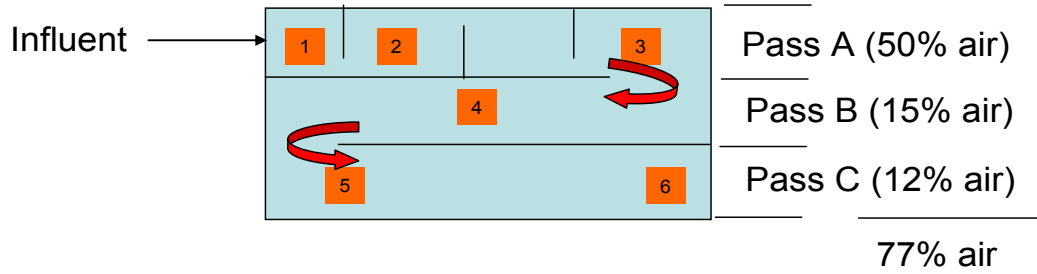
Using SOUR analyses, it is possible to monitor deviations from the stable boundary and make operational decisions on returning to the stable/ optimum zone. For the end of basin SOURs exceeding the stable zone, increasing the RAS rate, increasing aeration to the basin (if possible), or taking a basin offline and aerating a little longer are operational decisions that can be made to move the physiological state of the activated sludge back into the stable zone.

Aeration Basin Optimization

SOUR data is also useful in optimizing aeration basin operation. Figure 8 shows the DO and unspiked SOUR profile for a 3 –pass aeration basin. The basin was operated based on DO control so that compliance is met while attempting to lower the end of basin DO levels at location 6 in the basin. As seen in Figure 8, the aeration system was tapered to about 77% of design flow to target an end of basin DO of 2.5 mg/ L. Evaluation of DO and global system compliance parameters (BOD, ammonia) alone it would appear that the that the aeration system has been optimized and that stable operation has been achieved.

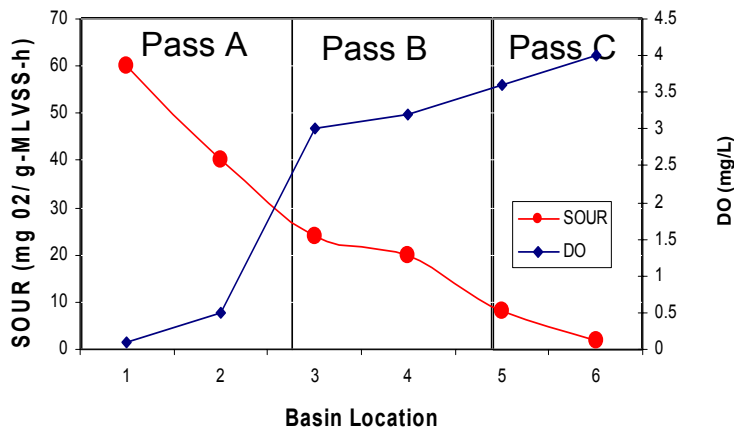
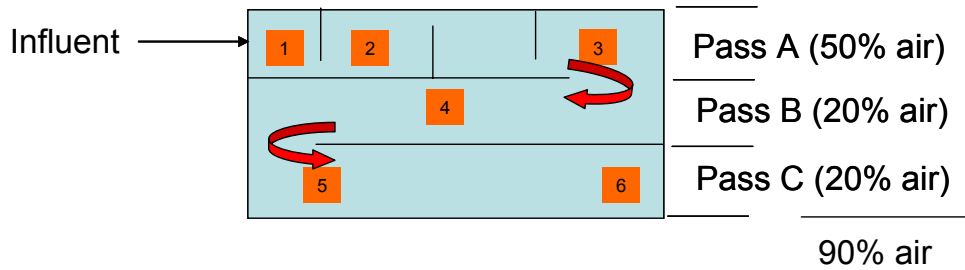
However, the SOUR profiles taken across the same basin indicates that although compliance parameters and DO profiles appear to be reflect proper aeration and stable operation (compliance data), the SOUR at the end of the basin is high ($10 \text{ mg O}_2/\text{g-MLVSS-h}$). This indicates that that organisms are storing food intracellularly and do not have enough reaction time under aeration to return to an endogenous respiration rate. If this operation is prolonged, it is possible that the end of basin OUR will continue to rise and result in a bulking sludge as per Figure 3.

Figure 8 – DO and SOUR profiles at 77% of design air flow



The SOUR provides insight about the physiology of the organisms to indicate that additional aeration time is required to consume intracellular storage products. Figure 9 shows that by increasing the tapered air flow to about 90% of the design flow, compliance is achieved with a mixed liquor that has been allowed to consume its intracellular storage products and allowed to return to a stable physiological state. The air flow is increased gradually using SOUR information to achieve target end of basin SOURs with a slight increase in end of basin DO (from 2.5 to 4.0 mg/L). Instead of intuitively turning the air to 100%, the SOUR tests were used to increase it to the amount necessary which was only 90% of the design air flow.

Figure 9 – DO and SOUR profiles at 90% of design air flow



SUMMARY

As observed in the previous pages, there are numerous ways in which SOURs can be used to determine the physiology and population dynamics in mixed liquor of BNR systems. It is a simple yet versatile tool that can be used to obtain near real time information on:

- Overall/ collective status (endogenous rate, peak ability, health) of organisms in activated sludge
- Separate status of major BNR populations (heterotrophs and nitrifiers)
- Relative changes in microorganism populations and treatment ability due to system operational changes
- Decision set points to maintain operation within an envelope where peak performance is maintained with efficient use of the activated sludge system facilities (blowers, clarifiers, RAS pumps, etc.).
- Optimize aeration basin air flow based on organism physiology.

The presentation will go into additional detail on the summary uses of the SOUR tests described above.