ACTIVATED SLUDGE PROCESS CONTROL USING IN BASIN OXYGEN RELATED PARAMETERS

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ABSTRACT

The removal of degradable substrates in the activated sludge process is rate dependent on the fraction of active mass in the sludge and the concentration and relative degradability of those substrates. Biomass floc-former biological selectivity is assisted by accumulation regeneration mechanisms relative to carbon substrate removal velocity and biomass metabolic activity and applied substrate gradients imposed on the biomass. Substrate removal velocity and intracellular storage can be measured by biomass respiration rate, which includes endogenous or maintenance respiration and the uptake rate for readily degradable substrate. In basin measurements of dissolved oxygen concentration, mixed liquor suspended solids concentration, with reference to oxidation reduction potential, can be used to minimize energy use and to assist with the formation of a predominantly floc-forming biomass in full-scale treatment plants. Oxygen related biomass parameters, specific oxygen utilization rate (SOUR) and potential oxygen utilization rate (POUR) can be used for automatic control of the activated sludge process to ensure high removal performance and to control the promotion of good solids - liquid separation through operation of the process within a specific envelope of SOUR. This method of control in a complete-mix fed-batch reactor configuration (C-TECH) which operates with sequences of fill-aeration, settle and decant, is described.

KEYWORDS

Biorate control, Cyclazur, Cyclic activated sludge technology, Filamentous sludge bulking control, Nutrient removal, Potential oxygen utilization rate, 2A2O, Specific oxygen utilization rate.

THE PROCESS

Biorate control, through in-basin respiration rate measurement, is simplified in variable volume activated sludge variants which are essentially operated as fed-batch complete-mix reactors. This feature, together with an initial admixture reactor, in fluid communication with the complete-mix reactor volume, differentiates cyclic activated sludge technologies from generic sequencing batch reactor technology. This basic activated sludge variant, invented by Goronszy circa 1978, maintains all of the benefits of generic batch reactor processing, with interrupted inflow operation during settling and decant, together with configuration for positive self regulating filamentous sludge bulking control that is derived through the initial admixture reactor, operated under self-mixed anoxic or anaerobic reaction conditions. Energy use and nutrient removal are also optimized through the application of Biorate control.

THE REACTOR BASIN AS A RESPIROMETER

Dissolved oxygen is a necessary requirement for the oxidative reactions that take place in aerobic dispersed growth treatment. Residual dissolved oxygen occurs as a result of transferred oxygen that is not used by the biomass. Too much residual dissolved oxygen is wasteful of energy and may be harmful to the production of the natural microbial flocculant glycocalyx and to the biologically mediated nitrogen and phosphorus removal mechanisms that can also take place. Over aeration (exposure of the biomass to aerated conditions in the substantial absence of substrate) typically upsets the kinetic selection of floc-formers over a number of filamentous micro-organism species which results in a turbid effluent and or generation of a poorly settling biomass and or erratic biological phosphorus removal. Experience has shown that to prevent micro-organism filamentous growth caused by oxygen deprivation it is necessary to provide oxic conditions within the biological floc with the proviso that low organic loading species have not been allowed to proliferate through unfavourable So/Xo or nutrient limitation. Mean floc oxygen utilization rate, and floc particle size can provide diffusional limitation to oxygen penetration and the liquid phase dissolved oxygen concentration that is sufficient to ensure a complete oxic environment within the floc particle.

Measurement of DO and end of cycle oxygen utilization rate are used to minimize the energy use in mixing and aerating during a process cycle. DO is monitored and recorded continuously. Uptake rate at the end of a cycle is determined via the slope of the oxygen depletion curve, measured over a set (but short) time interval. A representative rate is effectively determined within 3 minutes of shutting the blower(s) off. The rate of aeration is previously set to be less than or equal to the average oxygen demand expectation in the cycle. This has a set point measurement for rate of increase in dissolved oxygen concentration versus time of aeration. During the cycle, achievement of the set point, (an indicator of supply sufficiency) causes a reduction in air flow rate (the supply function) to keep supply less than the demand.

In basin measurement of biomass concentration (MLSS) provides a means for the automatic measurement of the in-basin Specific Oxygen Utilization Rate (SOUR - MLSS based). The same instrument shows the effectiveness of mixing at the operating energy input rate to the basin, the inventory of biomass in the basin (i.e. effectiveness of the wasting program) and the relative positioning of the sludge blanket interface during the air-off sequence.

Monitoring of the redox potential of the in-basin biomass affords a simple means of checking the operational set points for rate of aeration and biomass inventory. Excessive aeration and a too high biomass inventory is counter productive causing a net reduction in SOUR which effectively interferes with the rate of depletion of biomass redox during air-off sequences. Where biological phosphorus removal is employed, it is necessary for the biomass to cycle between oxic and specific anaerobic redox potentials during the cycle of operation. The depletion rate of redox is affected by SOUR, with low values not allowing anaerobic conditions, and hence phosphorus release to take place, during the air-off period in a cycle of operation. Air-of sequences are typically two hours in this process. Air-on sequences are typically two, four or six hours.

ACCUMULATION - REGENERATION MECHANISM

Actual respiration rate is the uptake rate taken near the completion of an aeration sequence; it is also a measure of the instantaneous rate exerted by the biomass during its regeneration at the time of sampling. The endogenous rate is typically a maintenance rate with no stored or available extracellular substrate i.e. the starvation or regeneration rate. An actual oxygen utilization rate results from exposure of biomass, at an initial endogenous rate, to substrate. The actual oxygen utilization rate will increase as the concentration of substrate to biomass increases i.e. the ratio of initial substrate concentration, So, to initial biomass concentration, Xo. There is a limitation on maximum oxygen utilization rate versus So/Xo, the floc forming (i.e. maximum) substrate removal velocity associated with the accumulation mechanism (feed condition). Maximum respiration rate is the uptake rate that occurs in the presence of an excess of readily biodegradable substrate. It is also a measure of the potential oxygen utilization rate (POUR) of the biomass. A maximum ratio of substrate to biomass needs to be determined in order to ensure saturated substrate conditions. A potential oxygen utilization rate can be determined for environments of high substrate concentration and limiting dissolved oxygen concentration, even zero dissolved oxygen concentration. In this work the POUR of a biomass was determined on a sample taken from the principal reactor at or near to the end of the aeration sequence. The POUR of that biomass is determined by aerated mixing of a volume of eighty percent of the mixed and aerated biomass and twenty percent of the influent sewage for a standard time before measurement.

The endogenous or basic respiration rate is defined as the uptake rate of a sludge after aeration for 1.5 hours without feeding; it is the unfed rate without exogenous or stored substrate; typically around2 $mg0_2\ g^{-1}VSShr^{-1}$. The actual respiration rate is the sum of endogenous rate plus residual rate associated with the removal of readily degradable substrate and converted storage compounds. The endogenous rate is generally independent of loading. Actual respiration rate is therefore proportional to biomass loading and is a measure of its metabolic activity. The rate of depletion of biomass oxygen utilization rate has been shown to parallel intracellular PHB depletion, where the PHB-COD equivalence is approximately 1.4.

CONTROL HYPOTHESIS

The hypothesis is presented that there is a desirable process connection between the maximum oxygen utilization rate and the actual oxygen utilization rate (measured as a ratio of POUR/SOUR) and the accumulation - regeneration performance relative to substrate removal and sludge settling (glycocalyx production). At the moment, this ratio can be determined by experiment. Set point regimes of actual respiration rate can be maintained through manipulation of air flow rate, air-on time and biomass wasting. The set point value of actual respiration rate also needs to account for the accumulation - regeneration mechanism which can be gauged by the ratio of POUR/SOUR i.e. the potential to respond to a saturated substrate environment relative to its existing regenerative state. In an ideal complete-mix reactor, for constant organic loading, the biomass oxygen utilization rate can be expected to be constant. Similar conditions occur for variable volume operation of the complete-mix reactor when the uptake rate is expressed as specific oxygen utilization rate.

Biorate control uses dissolved oxygen measuring sensors within the variable volume complete-mix basin configuration which provides the elements of a full-scale process respirometer. In this way it is possible to measure directly the metabolic activity of the biomass and to use this information to automatically regulate the duration of the aeration sequence and the rate of aeration to optimize energy use and maintain set-point metabolic activity levels. For example a reduction in oxygen consuming load demand to a basin, will be reflected, after a certain lag period, as a lowering of the aeration intensity (air supply) so that excessive dissolved oxygen concentrations are avoided. On the other hand an increase in load demand will cause an increase in aeration intensity so that the metabolic activity of the biomass, as measured by its propensity to use oxygen, is matched with the requisite aeration intensity, the rate of inflow of air into the reaction basin. Further interaction with the duration of the aeration sequence is caused through comparison with successive cycle set point values of $d0_2/dt$. Continued reduction in successive cycle $d0_2/dt$ causes a change to the duration of the aeration sequence. Two additional process modifications may also be employed. The rate of oxygen supply is reduced, to accord with a directional shunt to increase the uptake rate of the biomass; hence a lowering of the mass input of oxygen during a cycle. The mass of biological solids is reduced to increase the oxygen utilization rate per unit of biomass. In simple terms, this method of process control uses a relative position in the respirogram as a set points which is near to the equivalent point of removal of intracellular storage components. The operating POUR/SOUR ratio is an indicator of these responses.

The actual SOUR is a parameter which shows exactly the reactive state of the biomass. Unlike other workers who have measured SOUR through external on-line instrumentation, use is made of in-situ measurements taken from within the main reaction basin. Appropriate corrections within the sensitivity limits of the control technique are superimposed upon the measured parameter to correct for divergence from true steady state; nonetheless the technique has proven to be most reliable within the time constants under which the process is expected to perform. Biorate control makes use of the actual oxygen utilization rate in total and makes no effort to separate heterotrophic and autotrophic activity.

MEASUREMENT AND CONTROL PRINCIPLES

By adding substrate to biomass in set proportions (So/Xo increments) and measuring the peak OUR response a pattern of behaviour can be deduced from the incremental increase in SOUR to the maximum response value and the rate of die away of the SOUR with continued aeration (Goronszy and Eckenfelder, (1986)). The shape of the curve respirogram plotted as SOUR Vs floc-load (So/XoXd) closely parallels the hyperbolic shape of the Monod batch growth curve for specific growth versus substrate concentration typically described by.

$$\mu = \frac{\mu \max S}{K_S + S} \qquad (1)$$

where μ = specific growth rate
μ max = maximum specific growth rate
K_S = substrate concentration at which $\mu = ½ \mu$ max.
S = substrate concentration (readily metabolisable).

Since growth and oxygen uptake rate are proportional, a similar equation can be described -

$$OUR = \underline{OUR \max So} \qquad (2)$$

$$K^1_s + So$$

Dividing by X_V,

$$\frac{SOUR}{POUR} = \frac{S}{K^1_s + S} \quad (3)$$

K^1_s = concentration of substrate at which SOUR = $\frac{POUR}{2}$

A value of So/Xo is reached whereby the maximum measured SOUR response equates to a capacity limitation of that biomass for substrate incorporation. A high relative ratio of POUR to actual end of cycle operating SOUR is indicative of a high selective pressure for floc-former growth. These observations relate to the feed starve (accumulation/regeneration) principal of operation and an indicative ratio of POUR/SOUR $\geq$ 2.5 as being necessary for stable and consistent good settling performance. Operational circumstances within the main reaction basin are always significantly below POUR values which indicate the process is always under substrate limitation. Excluding toxicity effects, when values of POUR/SOUR are less than two, the absorptive regeneration capacity of the biomass is deteriorating due to excessive sludge age, and a decrease in active fraction of biomass attributable to floc forming micro-organisms. Selectivity pressures for floc-forming micro-organisms can be enhanced through increasing POUR/SOUR which is functional on So/Xo. In the absence of substrate to support growth operation under aeration simply results in a depletion of stored organics in the micro-organisms and or digestion of the active micro-organism fraction that is present. If this condition continues unchecked process performance is lost both from the point of view of biomass characteristics and pollutional removal. With proper selection, SOUR and POUR can be used to promote good solids settling performance, efficient biological nitrogen and phosphorus removal and overall aeration energy savings.

MATERIALS AND METHODS

To confirm the POUR/SOUR control hypothesis oxygen supply of a two basin facility was periodically adjusted (rate and mass) through determination of SOUR and POUR and adjustment of the aeration sequence time, aeration rate and mixed liquor solids inventory. Actual oxygen uptake rates (SOUR) were monitored for each basin at two times in an aeration sequence; at the end and at the selected time before the end. At the end of an aeration sequence there is continued but diminishing mixing taking place in the basin for around five minutes. In-basin measurement of the rate of uptake of dissolved oxygen invariably generated a straight line relationship for around five to eight minutes. The slope of this graph was used as the actual oxygen uptake rate of the biomass at the end of the aeration sequence. Manually extracted samples of mixed liquor were also used for bench measurement procedures and for comparison. Available on site wet chemistry was limited to suspended solids.

The potential oxygen utilization rate (POUR) for the biomass in each basin was determined on a sample taken near to the end of the air-on sequence. Additional in-basin measurements of SOUR were also taken by manually increasing the dissolved oxygen concentration, thence by interrupting the air supply, monitoring the resultant dissolved oxygen depletion rate as sensed by the in-basin, self-cleaning, dissolved oxygen sensor. By this means up to four in-basin measurements were made for selected cycles on selected days. Cycle decant volume and daily water use were recorded. Representative samples of treated effluent were analyzed on-site for total suspended solids. Mixed liquor suspended solids concentration was determined for each basin; sludge settling tests were conducted for each basin for one and two hour periods in a two litre wide diameter settleometer. In-basin temperatures were recorded. Sludge settling as percent settled volume, was used as the main response parameter indicator to uptake rate manipulation for filamentous sludge bulking control. Composite samples of influent and effluent were taken two to three times per week for analyses of BOD, COD, TSS, (influent) and BOD, TSS, NH_3-N, oil and grease. The results of these analyses were generally made available some eight weeks after sampling.

Maximum dissolved oxygen and final SOUR values were routinely assessed relative to solids settling trends. A number of diluted settling tests were conducted using a fifty percent effluent dilution and the standard wide mouth two litre settleometer. The two basin plant is sized to operate on a 17 day sludge age. Effluent quality is typically less than 10 mg/L TSS, 10 mg/L BOD, 10 mg/L total nitrogen and 1.5 mg/L total P for influent concentrations which average 350 mg/L BOD, 100 mg/L TSS, 55 mg/L NH_4-N and 30 mg/L of total P. The nominal fill aeration sequence of 180 minutes was manipulated as required.

RESULTS AND DISCUSSION

Prior to March 1995 aeration input was operated on upper and lower set points with no regard to the actual biomass metabolic activity with aeration taking place over the full four hours of the six hour cycle. Set point limits were 3.8 mg/L (upper) and 1.2 mg/L (lower). The sensor was frequently not in contact with biomass, hence process oxygen demand within a cycle was not routinely sustained. Consequently periods of filamentous sludge bulking occurred due to oxygen starvation and inadequate kinetic bioselection. Plant operation was modified to establish a calibration for effective use of the POUR/SOUR ratio. An assessment of basin performance showed a close similarity in alternating cycles of each basin. A series of data for one basin is presented in the paper to illustrate the year data base that was obtained. The relationship between the ratio of POUR/SOUR and biomass settled volume (SVI) is quite dramatic. As POUR/SOUR is also a measure of the operational selective pressure this is not surprising.

Best plant performance occurred for an aeration sequence of 120-140 minutes (total cycle of 360 minutes), MLSS of 2800-3200 mg/L, POUR/SOUR ratio in excess of 4, ramped dissolved oxygen concentration profile with approximately 30 minutes generating a liquid phase environment of 2.5 to 3.5 mg/L, producing a biosolids settled volume of 15 to 22 percent and an effluent TSS of around 10 mg/L.

Proper selection of blower speed control settings provided the ramped supply of dissolved oxygen totally negating the use of upper and lower DO set point control. The ramp slope (velocity was based on the determination of the in-basin SOUR value at the end of the aeration sequence. The close values and profile of the POUR/SOUR ratio taken at the end and within the aeration sequence simply confirms the near steady state operation of the principle regeneration reactor in this configuration. By design it is a variable volume complete mix reactor and as such should exhibit an approximate process steady state behaviour.

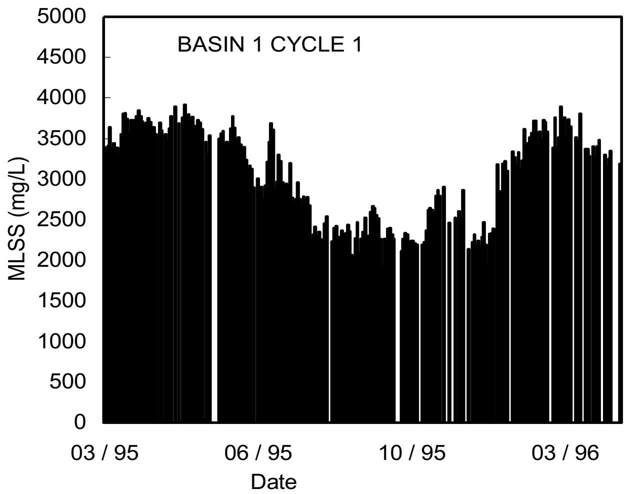

FIGURE 1. SUMMARY OF OPERATING MLSS

Analysis of the end of sequence SOUR provides a basis for the selection of an operating protocol during short and expanded periods of low organic loading in order to optimize the metabolic activity of the biomass. Under these circumstances it is only necessary to provide short sequences of high intensity aeration to maintain adequate viability of the biomass. A source of particulate substrate in such regularly starved facilities would be helpful to biomass maintenance, if it is available. Weekend operational adjustment at this facility simply requires a selection of an aeration maintenance program which is reset some two hours before the start of factory production on the following Monday morning. While some biomass viability is lost, it is minimal by comparison with that which is otherwise destroyed by the practice of over aeration. Sensing of the trend change that takes place in SOUR with successive cycles provides a simple tool by which to modify the rate and duration of aeration in a sequence. This parameter also assists with the settling of the solids wasting program.

CONCLUSIONS

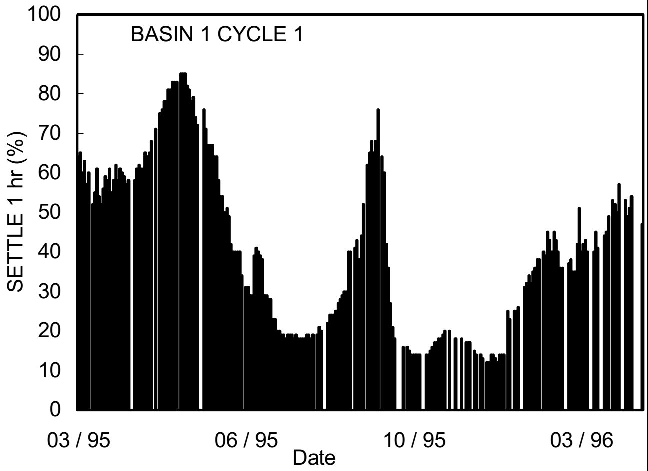

FIGURE 2. SUMMARY OF 1 HOUR SETTLING

Optimal kinetic biological selectivity pressures can be assessed by the POUR/SOUR ratio as defined and used in this paper.

For this wastewater it was determined that the set-point POUR/SOUR ratio should be equal to or greater than 2.5 to maintain good and efficient solids-liquid separation.

Adaptation of the process operating conditions to yield this ratio results in an optimal input of process oxygen through sequence time and rate of input..

Operation for appropriate POUR/SOUR reaction conditions requires manipulation of air on time, aeration intensity and biosolids inventory.

Measurement of SOUR (in-basin) provides the basis for the control of the aeration sequence time.

Operation on the basis of SOUR maintains optimal biomass viability during low load periods.

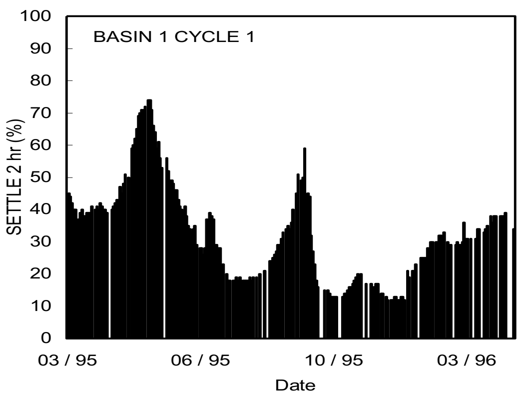

FIGURE 3. SUMMARY OF 2 HOUR SETTLING

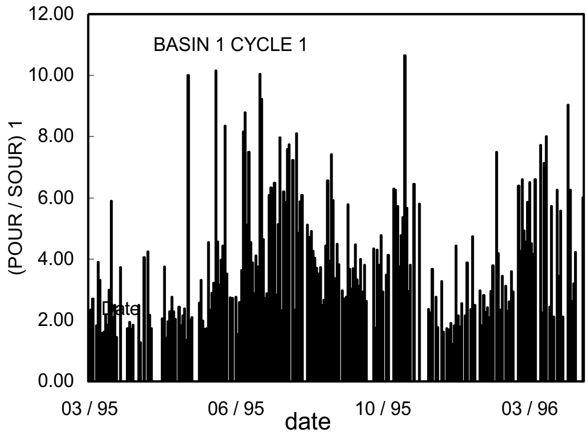

FIGURE 4. SUMMARY OF POUR/SOUR RATIO, END OF CYCLE

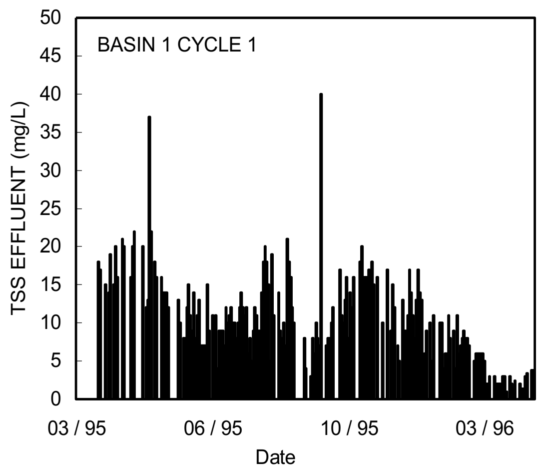

FIGURE 5. SUMMARY OF EFFLUENT TSS

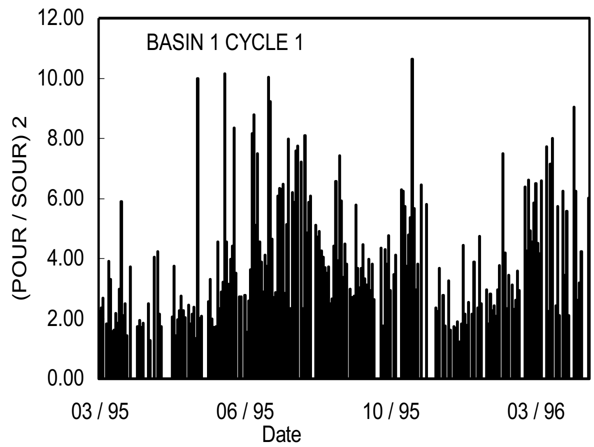

FIGURE 6. SUMMARY OF POUR/SOUR RATIO, DURING CYCLE

REFERENCES

Klapwjk, A., Spanjers, H., and Temmink, H. “Control of Activated Sludge Plants Based on Measurements of Respiration Rates.” Wat. Science Tech. 28, 11/12, 369-376.

Goronszy, M.C. and Eckenfelder, W.W. (1986) "Floc Loading Biosorption Criteria for the Treatment of Carbohydrate Wastewaters." Proc. 41st Purdue Industrial Waste Conference, 37-47.