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On-Line Monitoring and Process Control of SBR Cycles for Nutrient Control from Wastewater

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Abstract: Nitrogen (N) and phosphorus (P) are nutrients for the growth of living cells. Their presence is essential for biological treatment of domestic wastewater. However, uncontrolled discharge of nutrients with treated effluent from wastewater treatment plants leads to eutrophication– a condition that promotes growth of undesirable aquatic plants and adversely impacts the quality and aesthetic of the receiving bodies water. To address the increasing regulatory requirements for nutrient control from treatment plant discharges utilities around the globe implement advanced wastewater treatment processes for N and P removal. Among various configurations of biological wastewater treatment reactors Sequencing Batch Reactors (SBR) have been demonstrated as an effective technology for nutrient control. SBR conducts all functions of treatment process including BOD oxidation, nitrification, denitrification, enhanced biological phosphorus removal (EBPR) and clarification of the mixed liquor in the same reactor tank. SBR operates in repeating cycles, each consisting of the above steps in series. Each step carries out a specific biochemical reaction to fulfill the overall treatment goal. The cyclic and stepwise operation of an SBR is precisely controlled by a Programmable Logic Controller (PLC). This paper presents a case study of successful nutrient control by SBR with the help of automatic real time process control by a PLC. It discusses the working principle of SBR and the function of each process step. The test program consisted of continuous monitoring of multiple process parameters to monitor the removal of BOD, TSS and nutrients, in each cycle of the sequencing batch reactor (SBR) at the wastewater treatment plant. On-line, real time, monitoring of pH, oxidation reduction potential (ORP), dissolved oxygen (DO), ammonia-N, nitrite-N, nitrate-N and orthophosphate-P demonstrated excellent correspondence between these parameters and the individual biochemical reactions in each step. Subsequently, the SBR cycle control logic was changed from time and DO based, to ORP based. This demonstrated the potential for a higher energy efficiency in plant operation while maintaining the effluent quality in compliance with the state regulation for BOD, TSS, TN, TP of 5, 5, 3 and 1 mg/L, respectively.

Keywords: SBR, ORP, DO, Biological Treatment, Nutrients Control

1. Introduction

Uncontrolled release of nutrients (nitrogen and phosphorus) causes eutrophication of the water environment leading to the impairment of the aesthetics and health of the receiving body of water. Regulators around the globe are enforcing increasingly stringent N and P limits in wastewater treatment plant discharges requiring adoption of advanced nutrient control technologies. Implementation of nutrient control in treatment plants following conventional activated sludge process requires addition of reactor volumes for biological removal of N and P as detailed in literature [1]. Sequencing Batch Reactors (SBR) achieve effective nutrient control in addition to the control of BOD by operating the treatment system in repeating steps of time. This mode of operation enables real time monitoring and control of SBR reactors with the help of on-line instrumentation and control systems. This paper presents a case study of a 4.5 million liters per day (MLD) wastewater treatment plant based on SBR process serving the City of Carrabelle, FL. The design influent conditions are – flow = 4.5 MLD (peak = 13.6 MLD), BOD = 255 mg/L, TSS = 225 mg/L, ammonia-N = 23 mg/L, TKN = 35 mg/L and total phosphorus = 6.3 mg/L; and the discharge permit requires the effluent BOD, TSS, TN and TP of 5, 5, 3 and 1 mg/L, respectively on a monthly average basis. Before its final discharge, the treated effluent is first treated by a set of disc filters to achieve the TSS limit consistently and is disinfected by application of sodium hypochlorite solution in a chlorine contact structure.

The wastewater treatment process by SBR operates in repeating cycles. Each cycle treats a new batch of influent in multiple sequential steps that are separated by time. A fresh batch of influent is introduced into the SBR tank in the Fill step. It mixes up with the treated liquid remaining in the tank from the previous cycle, such that the feed constitutes a part of a given batch. Primarily the fill step is anoxic, during which the nitrate formed in the earlier cycle and remaining in SBR tank after Decant step, is removed by denitrification. The next part of the feed step is an Anaerobic React step, during which fermentation of the organic matter in the raw sewage takes place in the absence of air. Simultaneously, the polymeric phosphorus bound with the bacterial cells releases as inorganic orthophosphate ions. This is followed by Aerobic React step. During this step all the BOD removal and nitrification takes place by aeration. Phosphorus is taken up by the biomass by the enhanced biological phosphorus removal (EBPR) mechanism. At the conclusion of the aerobic react step, the aeration and mixing of the liquid is stopped and sludge is allowed to Settle under quiescent condition. After settling, the clear liquid on the top of the sludge blanket is decanted out in the Decant step as treated effluent. This completes one full cycle of an SBR. These cycles are repeated in sequence and the steps in each cycle are presented in Figure 1. Typically, the duration of each cycles is 6 to 8 hours. The ability to separate individual nutrient control reactions into separate steps in a given cycle is a distinct advantage of an SBR over its continuous flow counterpart.

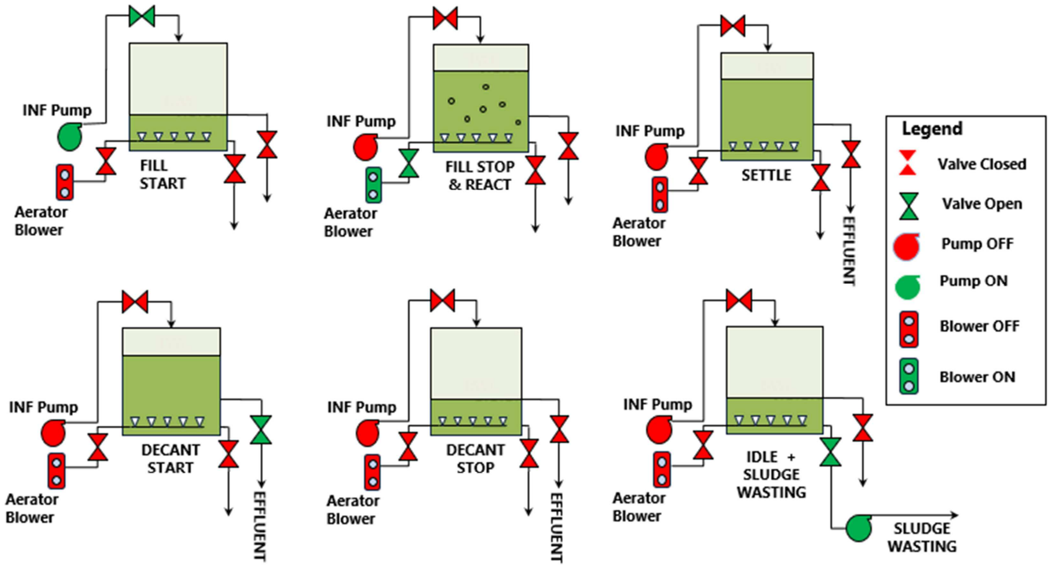

Figure 1. *Process setps in an SBR operating cycle.*

In the past, the steps in an SBR cycle have been controlled automatically by programmable logic controllers (PLC) through set durations of time for each step. However, this type of control is not optimal because such times may be too short or too long for the intended biochemical reactions in a given step. Too short time may result in incomplete treatment. Too long step times may lead to inefficient operation due to excessive consumption of aeration energy. One of the current control strategies involves adjustment of cycle times automatically based on influent flow rate to reduce energy consumption and enhance operation. Dissolved oxygen (DO) control in the SBR tank has also been introduced as an alternate parameter to control the durations of the biochemical reaction steps. After completion of the nitrification step, the DO in the basin starts rising sharply. This prompts the PLC to move to the next step. However, the transitions between various reaction steps are not very sharp on a DO trace. The study reported here involves use of another parameter – oxidation reduction potential (ORP) in lieu of DO to precisely control the steps of an SBR. Much work based upon this principle has been reported in laboratory scale. The present study demonstrates the concept of effective and robust process control of a full-scale operating plant utilizing ORP as the control parameter.

1.1. Theoretical Background

Wastewater treatment for organic pollutants (BOD) and nutrients is comprised of several biochemical reactions in series and mediated by enzymes originated from living cells. A reaction is driven forward by the thermodynamic function, Gibbs Free Energy (G). It proceeds spontaneously from higher total free energy of the reactants to the lower total free energy of the products such that the free energy change in a chemical reaction is expressed mathematically as:

$\Delta G = \Sigma G_p - \Sigma G_f$, where p and f denote product and feed species respectively, and for a spontaneous reaction, ΔG is negative (-ve). As a reaction progresses spontaneously the value of ΔG gradually increases from negative numbers and approaches zero. Ultimately, the reaction comes to an equilibrium when $\Delta G = 0$. This means that spontaneous reactions release free energy. The reactions for which ΔG = positive (+ve), do not proceed spontaneously and free energy from outside must be supplied to make them happen.

The value of G under 'standard conditions' of a temperature of 25°C and 1 atm pressure is denoted as G^o, and the free energy change for a chemical reaction under those conditions are denoted by ΔG^o. A redox reaction is composed of a pair of half cell reactions, one of which contains an electron donor and the other contains an electron acceptor, each involving a change of free energy, ΔG. For a given redox reaction, the free energy change (ΔG), ORP (E) and reaction equilibrium constant (K_{eq}) are mathematically related as follows:

$$\Delta G = -nFE = \Delta G^o + RT \ln K_{eq}$$

Therefore, $-nFE = -nFE^o + RT \ln K_{eq}$
and, $E = E^o - (RT/nF) \ln K_{eq}$
Where, n = no. of electrons involved in the redox reaction
F = Faraday's Constant = 96,485 Coulombs = 96.485 kJ/volt
R = Universal Gas Constant = 8.314 J/(mole).(°K), and
T = Absolute Temperature, °K
K_{eq} = Half cell reaction equilibrium constant
E = Half-cell ORP under reaction conditions, and
E^o = Half-cell ORP under standard conditions

The ORP of a chemical or biochemical reaction is measured by an electrochemical cell consisting of a reference electrode, e.g. calomel, or silver/silver chloride, etc., and an anode made up of a noble metal, e.g. platinum, that is not sensitive to oxidation or reduction. The Tables of Standard Free Energy Changes (ΔG^o) and Standard Half Cell Potential (E^o) values are available from standard references [4]. Since the biochemical reactions in wastewater treatment are electrochemical in nature, the ORP can be utilized to monitor the progress and completion of specific reactions. The nitrification and denitrification half cell reactions may be represented as:

Nitrification reaction:

$$\tfrac{1}{8} NH_4^+ + \tfrac{3}{8} H_2O = \tfrac{1}{8} NO_3^- + \tfrac{5}{4} H^+ + e, \text{ and}$$

Denitrification reaction:

$$\tfrac{1}{5} NO_3^- + \tfrac{6}{5} H^+ + e^- = \tfrac{1}{10} N_2 + \tfrac{3}{5} H_2O$$

Since hydrogen ions are involved in both reactions, the equilibrium constants K_{eq} of these half cell reactions contain hydrogen ion concentration terms, and hence the standard ORP values of these reactions are also functions of pH. Charpentier, et al. [3] developed an EH –pH diagram extending the concept of Porbaix's diagram for water to the redox reactions relevant to wastewater treatment. They reported an ORP value of + 400 mV at pH 7 for nitrification of ammonium ions. Conversely, denitrification will be favored as the ORP drops below + 400 mV. The pE-pH diagram presented by Sawyer, et al [4] also confirms nitrate as the predominant nitrogen form at equilibrium in aqueous systems above an ORP value of +400 mV. Interestingly, this value corresponds quite closely to the standard ORP of the complete redox reaction for nitrification obtained by theoretical calculations, as given below:

$$\tfrac{1}{8} NH_4^+ + \tfrac{3}{8} H_2O = \tfrac{1}{8} NO_3^- + \tfrac{5}{4} H^+ + e^- \ \Delta G^o = 34.50 \text{ kJ/mole } e^-$$

$$H^+ + \tfrac{1}{4} O_2 + e^- = \tfrac{1}{2} H_2O \ \Delta G^o = -78.14 \text{ kJ/mole } e^-$$

Adding up, $\tfrac{1}{8} NH_4^+ + \tfrac{1}{4} O_2 = \tfrac{1}{8} H_2O + \tfrac{1}{8} NO_3^- + \tfrac{1}{4} H^+$

Or, multiplying throughout by 8, $NH_4^+ + 2 O_2 = H_2O + NO_3^- + 2 H^+$

$$\Delta G^o \text{ for the overall reaction} = 34.50 - 78.14, \text{ i.e. } - 43.64 \text{ kJ/mole e}$$

$$\text{Standard ORP, } E^o = -\Delta G^o/F = 43.64/96.485, \text{ i.e. } 0.452 \text{ Volts, or } 452 \text{ mV}$$

Since a part of the energy released due to the biochemical reactions in wastewater is utilized for new cell synthesis, a smaller part of the total energy can be utilized by the biomass to support their activities, e.g. movement, metabolism, reproduction, etc. and the rest dissipates as heat. The rise of temperature due to this heat dissipation is generally insignificant because of the large mass of water and relatively low concentrations of biomass and substrate in wastewater under treatment. However, in special cases of treatment of high strength industrial wastes in covered tanks the temperature rise may be appreciable.

The presence of various components other than strictly the nutrients in question gives rise to multiple competing redox reactions simultaneously. Moreover, rarely the reactions attain equilibria because it takes a very long time and it is not practical to design reactors providing such large retention times. These limitations complicate the prediction of a precise ORP value for a particular set of half cell reactions of interest in an actual wastewater environment. Some investigators reported ranges of ORP values for various half cell biochemical reactions occurring in wastewater environment. The recommendations of Goronszy, et al [6] are depicted as Figure 2.

In absence of a unique set of ORP values associated with specific nutrient control reactions e.g., nitrification, denitrification, fermentative phosphorus release and phosphorus uptake, various researchers have used other parameters in conjunction with ORP as tools for SBR control, especially for nutrient removal applications. Kim and Hao [9] utilized pH and ORP data acquired from continuous on-line measurements from a laboratory scale SBR to develop a control strategy. Because of the potential uncertainty of absolute ORP values associated with individual nutrient control half cell reactions they utilized the specific trends of the ORP and pH traces to indicate the completion of specific treatment reaction (s) such that a programmable logic controller (PLC) can advance the SBR to the next step of treatment. A conceptual set of pH, ORP and dissolved oxygen (DO) trends in an SBR cycles is presented as Figure 3.

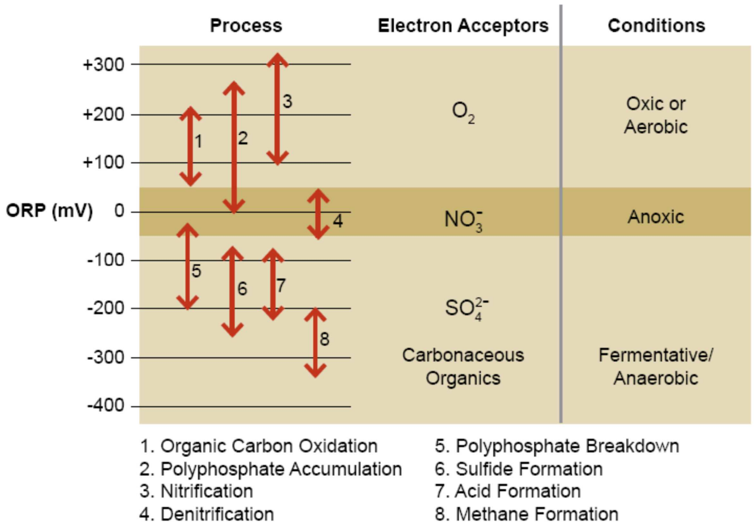

Figure 2. *RANGES OF ORP FOR VARIOUS METABOLIC REACTIONS [6].*

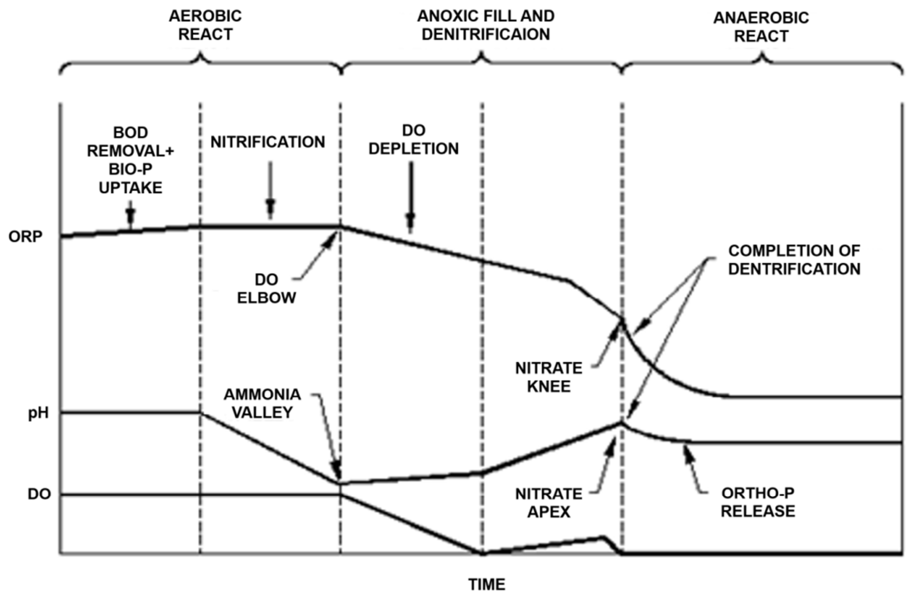

Figure 3. *Conceptual ORP, pH and DO profiles during the cyclic operation of an SBR (settle and decant steps are not shown).*

As aeration progresses in the 'React' step, nitrification follows BOD removal. The ORP trace will initially rise during aeration but the slope will become flat during the nitrification process. This point on the ORP trace is identified in the literature as 'DO Elbow' (DE). Towards the end of the aerobic react cycle, the trace of the pH is expected to clearly indicate completion of nitrification as it gradually drops to a minimum value, called 'Ammonia Valley' (AV). On time scale, the AV and DE points of the pH and ORP traces respectively are expected to occur at the same time. If aeration is still continued beyond this time the ORP will still keep rising until air is shut off. Therefore, the pH and ORP traces confirm conclusion of nitrification and prompt the PLC to move the SBR operation to the next step, which is 'Settle'. Air will be stopped at this point. After completion of the 'Settle' and 'Decant' steps the 'Fill' step starts. At this time ORP will start dipping indicating onset of denitrification. Simultaneously, the pH also will start rising due to the release of alkalinity by denitrification reaction. Even after stopping the aeration blowers a small amount of dissolved oxygen may still remain in the initial stage of the 'Anoxic Step'. After some time of starting the anoxic fill period, the ORP trace drops at a steeper slope. At this point all the remaining DO disappears. Finally, at the conclusion of denitrification, the ORP trace starts dropping at a sharper slope indicating the onset of anaerobic reaction. This transition point on the ORP plot is called the 'Nitrate Knee'. This corresponds to a high point on the pH trace as a result of alkalinity recovery, which is called the 'Nitrate Apex'. All these points mentioned above are very well identifiable transition points with slope changes on the respective traces of ORP and pH. Therefore, if a control logic is programmed to calculate the slopes of these lines, $\frac{d(ORP)}{dt}$ and $\frac{d(pH)}{dt}$, then those points of change of the slopes can be utilized as signals to change the operating steps of an SBR. This forms the basis of a pH and ORP based strategy for SBR control.

1.2. Literature Review

Numerous studies involving ORP as the tool for monitoring and control of wastewater treatment processes have been reported in the literature. Koch and Oldham [5] conducted an extensive study at the University of British Columbia involving biological nutrient removal experiments on bench and pilot scale activated sludge reactors in both batch and continuous flow mode. From these studies they determined that ORP is a very valuable tool for monitoring the nature of biological activity within a reactor. From the collected data they could easily identify the transition points (knees) as the biochemical process transitioned from one type to another.

Goronszy, et al [6] conducted bench scale studies on the site of the Catawaba Island Biological Nutrient Removal Facility, OH. This is a plant serving a holiday resort which causes large variations in flows and loads, and equipped with gradually increasing aeration intensities in the three aeration zones in series in the continuously operated activated sludge system. The bench scale prototype was simulated to operate in batch sequence. Among other parameters they also collected ORP data with time in a batch and showed that the ORP depletes in the anaerobic selector following a first order kinetics. The average first order rate constants were determined as -0.27 and -1.44 hr^{-1} respectively for the cases when 100% sludge and 80% sludge + 20% raw sewage combination were used in the selector.

Demoulin, et al [7] observed that 35% higher nitrification and 28% higher phosphorus removal could be achieved by SBR over conventional activated sludge process in a full-scale domestic wastewater treatment plant (serving a ski resort area). This was possible by optimizing the SBR performance with the help of on-line monitoring and control of SBR steps by ORP. Based on these results they determined that in the design of a full-scale treatment system it would be possible to achieve a volume reduction of 30% for the SBR over the conventional activated sludge reactor under identical influent flows and loads.

Zipper et al [8] developed an ORP based control strategy for nitrification, denitrification and phosphorus removal on both continuous and batch operated activated sludge pilot reactors. The results demonstrated substantial energy saving with high effluent quality using on-line ORP signal for automatic control of the reactor operations.

Geraney, et al [10] reviewed a few on-line sensors for full scale activated sludge plants to continuously monitor nitrification/denitrification. They reported the various commercial instruments available in the market that operated on the principle of respirometry to monitor both BOD and nitrification. An on-line sensor, Biological Residual Ammonia Monitor (BRAM) that works on titrimetric principle, based upon changes in pH, is available in the market to continuously monitor nitrification and denitrification in activated sludge systems. Another commercially available total nitrogen (TN) control system is Denitrification Carbon Dosage System (DECADOS), that operates with the help of a combination of a pH and an ORP sensor, following the principle described in the earlier section.

Peng, et al [11] studied the effectiveness of pH and ORP based fuzzy logic to control the carbon addition rate in the denitrification process in an SBR. They used brewery wastewater, sodium acetate, methanol and endogenous biomass as the sources of carbon for denitrification and found that sodium acetate resulted in the highest denitrification rate, with brewery waste, methanol and endogenous carbon in decreasing order. The results demonstrated that, although instantaneous addition or addition in large batches of the substrate produced the largest denitrification rates, it is best to add the necessary amount continuously at small rates for the sake of optimizing the consumption of substrate and also to minimize the reaeration time upon completion of nitrification.

Gupta, et al [12] developed a new method of ORP monitoring in anaerobic flow through reactors. The measured ORP values by this method are lower, and claimed to be more accurate, than those by conventional methods as it avoids the effects of oxygen contamination, hydrodynamics and temperature changes encountered in traditional ex situ measurement. In situ measurements are prone to frequent fouling of probe leading to erroneous results. The new method consisted of circulating a small stream of the reactor liquid by a pump through a specially constructed housing containing the ORP probe. The housing is equipped to overcome the problems associated with conventional in situ and ex situ measurement of ORP.

In conjunction with the studies and investigations conducted in the open domain for utilizing ORP as a tool for nutrient control in wastewater treatment several proprietary processes were also developed and patented in the past. Stensel et al [13] developed a DO and ORP based automatic control strategy for nitrogen removal by controlling the aeration and mixing of an oxidation ditch in order to achieve low levels of total inorganic nitrogen (TIN) concentration.

Applegate and Dubey [14] patented an ORP based control logic to maintain steady anoxic and anaerobic conditions in the respective zones of an activated sludge reactor in order to facilitate biological nutrient removal.

None of the work reported above correlated the fates of the nutrient species, e.g. ammonia, nitrate, nitrite and orthophosphate by any direct measurement of those parameters with the continuous variation of ORP in the wastewater as the biological treatment process gradually progresses in an aeration tank. While several investigators reported such results from laboratory analyses of grab samples collected in a finite frequency it is well known that a large amount of valuable information is lost by following such a procedure. The study reported here was primarily aimed at capturing the important information on variations of the nutrient species and ORP, DO and pH simultaneously in order to clearly establish the changes in the chemical characteristics of the wastewater caused as a result of various biochemical reactions in nutrient removal processes. To overcome the problem of loss of information the data was collected on a continuous basis by real time with the help of on-line probes. Additionally, to remove any concerns on the repeatability of bench or pilot scale results to full scale operation this study was conducted on a full-scale operating SBR reactor. A secondary purpose of this study was to investigate if any, or a combination, of the physicochemical parameters, e.g. pH, ORP, DO, etc., could be utilized for continuous, real time, on line monitoring and automatic control of a biological nutrient removal (BNR) process in a full scale activated sludge process. The author believes this study is unique considering these points of view.

2. Materials and Methods

2.1. Test Set-Up

It is necessary to know the wastewater treatment process flow train to understand the test set up since the tests were conducted in full scale plant. The wastewater collected in a network of sewer lines enters the plant through a headwork structure. The influent, free from grit and screenings, then enters two parallel SBR reactors of 3.8 million liters (ML) each, designed to operate in a phase difference of 180^o. The decant streams from the two SBRs collect in a downstream equalization tank, which feeds a disc filter unit to remove particulate matter carried over by the SBR decant streams in order to fulfill the effluent requirements. During the time of the test program reported here the monthly average flow was below 0.76 MLD and the wastewater characteristics were – BOD = 200 mg/L, TSS = 150 mg/L, ammonia = 30 mg/L, TKN = 35 mg/L, TP = 4 – 5 mg/L and wastewater temperature in the range of 20 to 25°C. Because of the low flow the plant used only one SBR (SBR 2) instead of two. The SBR 1 was used as a pre-equalization tank.

2.2. Sampling and Analysis

The SBRs at Carrabelle are equipped with continuous on-line monitoring of DO (Cerlic Model No. O2X) with the ability to measure ORP also. The pH data were obtained by using a Hach pH meter. All the analyzer outputs were directly transmitted real time to the process control computer. The probes were suspended from the top of the SBR tank and held in place by an internal support so that they were always immersed in water. The plant monitors daily influent and effluent BOD and TSS and effluent total nitrogen (TN), nitrate-N, and total phosphorus (TP) from composite sampling and reports their weekly average values. Effluent coliform count analyses are done from grab samples. All these analyses are conducted by off-site, state certified laboratories following Standard Methods [2] procedures. To aid in process control, the disinfected final effluent quality is continuously monitored by an on-line Chem Scan Process Analyzer marketed by Applied Spectrometry Associates, Inc. of Waukesha, WI. This instrument continuously withdraws samples from the treated final effluent line, and measures and displays the effluent ammonia-N, nitrite-N, nitrate-N and orthophosphate-P.

The test program consisted of continuous monitoring of pH, ORP, DO, ammonia-N, nitrite-N, nitrate-N and orthophosphate-P of the SBR 2 mixed liquor for four weeks with the help of on-line probes and meters. A second Chem Scan analyzer (identical and in addition to one existing on the final effluent line) was installed outside the SBR basin to withdraw samples of mixed liquor by a pump at preprogrammed intervals to monitor the ammonia-N, nitrite-N, nitrate-N and orthophosphate-P of the mixed liquor. The pump suction line was attached to a float that was floating on the SBR water surface all the time. All the analytical data were acquired by the PLC and displayed in real time on the control computer. These results are discussed in detail in the next section.

3. Results and Discussions

Figure 4 shows the profiles of the seven process parameters through two typical cycles of a day. It appears to closely correspond with the conceptual profiles in Figure 3. The traces of the process parameters obtained from the experimental program are not as precise as those in the conceptual Figure 2 due to the matrix effect of wastewater environment. However, all the important biochemical reactions as the SBR operations transitioned from one step to the next can be very clearly identified. The ORP maximum, as defined by the DO elbow point, quite closely corresponded with nitrate maximum, ammonia minimum and ortho-P minimum points indicating completion of phosphorus uptake also in addition to nitrification. Therefore, this point may very well be considered to be the time of completion of 'Aerobic React" step. Subsequently, the air blowers shut off automatically based on the high DO set point. The DO then started dropping during the 'Settle' and 'Decant' steps. The residual DO continues depleting after start of the 'Fill' step. The nitrate knee point could be clearly identified during the 'Fill' step on this ORP profile, as shown on Figure 5, indicating termination of denitrification. It may be observed that past the nitrate knee the remaining part of the 'Fill' step was anaerobic, when the ORP dropped further to a minimum value. Even though the orthophosphate release started from the anoxic part of the 'Fill' step it maximized during the anaerobic part. The ORP trace was observed to contain several spikes. This is due to the fact that the ORP probe is cleaned automatically with fresh water on a timer basis. The cleaning water contains DO which causes the ORP to rise instantaneously at the times of cleaning of the ORP probe. Similarly, the DO probe also has a few spikes during the aeration cycle which are caused by the automatic OFF and ON conditions of the blowers based upon the high and low residual DO concentration settings in the SBR basin. The minimum ORP point also corresponded very well with the minimum nitrate, maximum ammonia and maximum ortho-P concentrations. Therefore, this point may very well be considered to represent the completion of the 'Fill' step. The pH profile was observed to be flat throughout the cycles. This could be because of the fact that the source of water in Carabelle, like in many other places in Florida, is groundwater, containing relatively high alkalinity in the range of 170 to 200 mg/L as $CaCO_3$. Therefore, pH remained unchanged during the SBR cycles and could not be utilized as a tool for process control in conjunction with ORP, as was originally planned for. Interestingly, the nitrite-N concentration profile also was flat and at zero throughout the cycles indicating immediate conversion of nitrite to nitrate as soon as it was formed.

As a result of the above observations, it was decided to use ORP alone as the primary control parameter. Accordingly, the SBR cycle settings were converted from DO based to ORP based. The flexibility to switch back to DO or time-based operation was still retained in the program in case of failure to meet nutrient control goals with the new control philosophy. According to this new logic, the Fill step starts at the conclusion of Decant or Idle step and terminates at -150 mV. React step starts at the conclusion of Fill step and terminates at +250 mV. Settle step starts at the conclusion of React step and terminates at +50 mV in order to prevent the possibility of ortho-P release as a result of drop in ORP during this step. Decant step starts at the conclusion of Settle step and terminates at a predetermined bottom water level. The ORP set points above can be changed and selected by operator based upon the plant data and the wastewater characteristics in the plant.

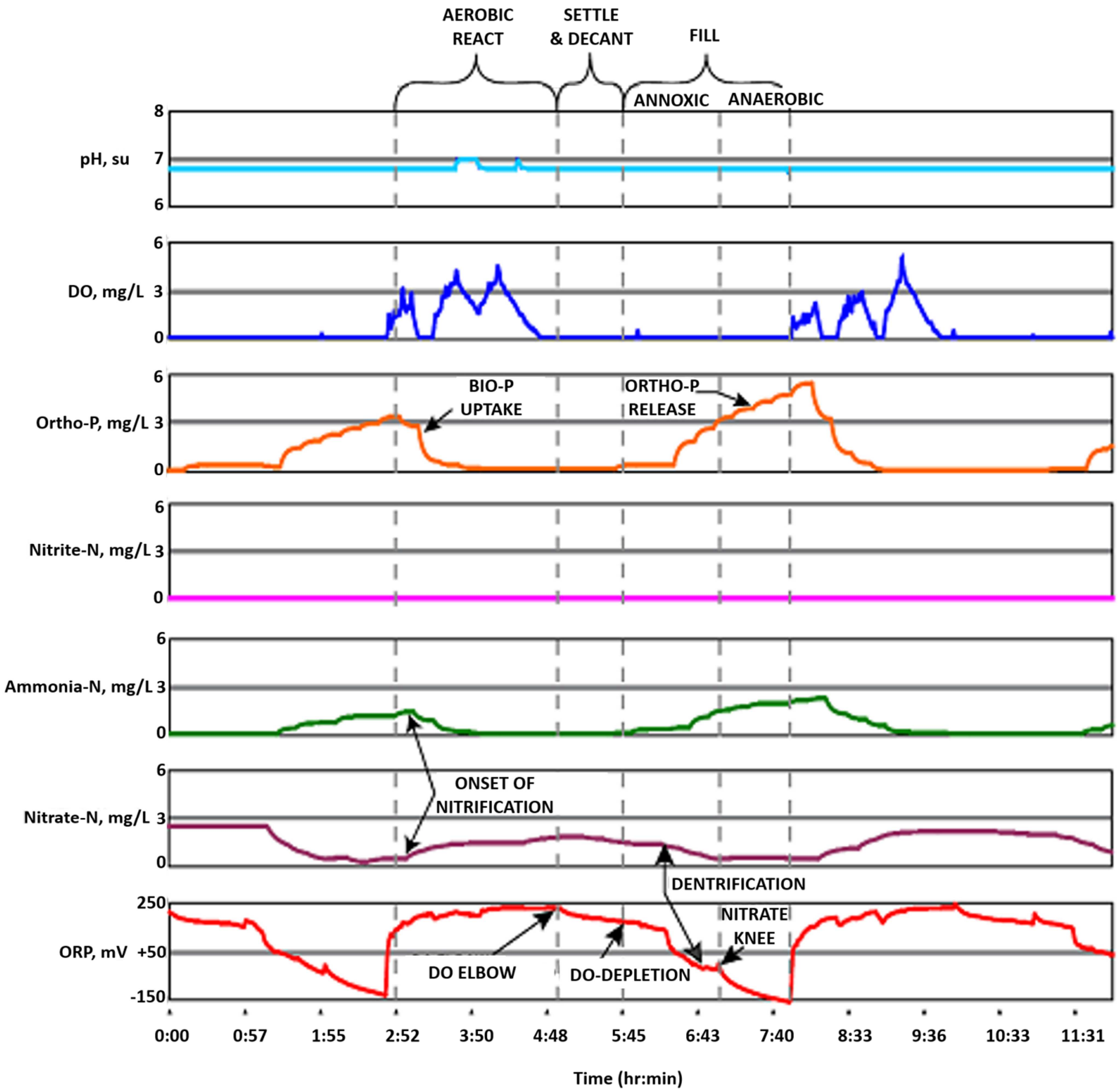

Figure 4. *pH, ORP, Do, ammonia-n, nitrite-n, nitrate-n and ortho-p profiles in two typical cycles of a day.*

All the above transitions from aerobic (nitrification) to anoxic (denitrification) steps and anoxic to anaerobic (phosphorus release) could be clearly identified from the field scale data. The final concentration of total N and total P continue to be within limits as before, as shown by the final discharge stream on-line analyzer and presented in Figure 5.

4. Summary, Conclusions and Current Advances in Nutrient Control Technologies

ORP is an effective process parameter to control the steps in an SBR cycle. ORP based control may lead to savings in operating cost over DO based control by terminating aeration as soon as nitrification is complete. However, the control points for various steps in a cycle are not unique and they may vary over a range depending upon the type of wastewater. Operator needs to select the right set points within the ranges based upon the operating experience and the wastewater characteristics. A second parameter, e.g. pH over and above ORP, is helpful in further optimizing the control action. In this study pH could not be utilized as it remained constant throughout the entire treatment cycles primarily because of the large buffering capacity associated with high alkalinity of the source water. Therefore, instead of pH, an alkalinity profile was developed as shown in Figure 6, during the course of an operating cycle by collecting six samples and conducting wet chemical analyses for alkalinity with time. The drop of alkalinity with nitrification and its recovery with denitrification can be easily visualized from Figure 6. Thus, the provision of an on-line alkalinity analyzer will be very helpful to monitor real time changes of alkalinity with nitrification and denitrification and can be utilized to better define the completion of aeration and anoxic cycles in conjunction with ORP. This study clearly demonstrates that a superior control of an SBR operation, and hence the optimization of its operating cost, can be very effectively achieved by simultaneous on-line monitoring of ORP and alkalinity.

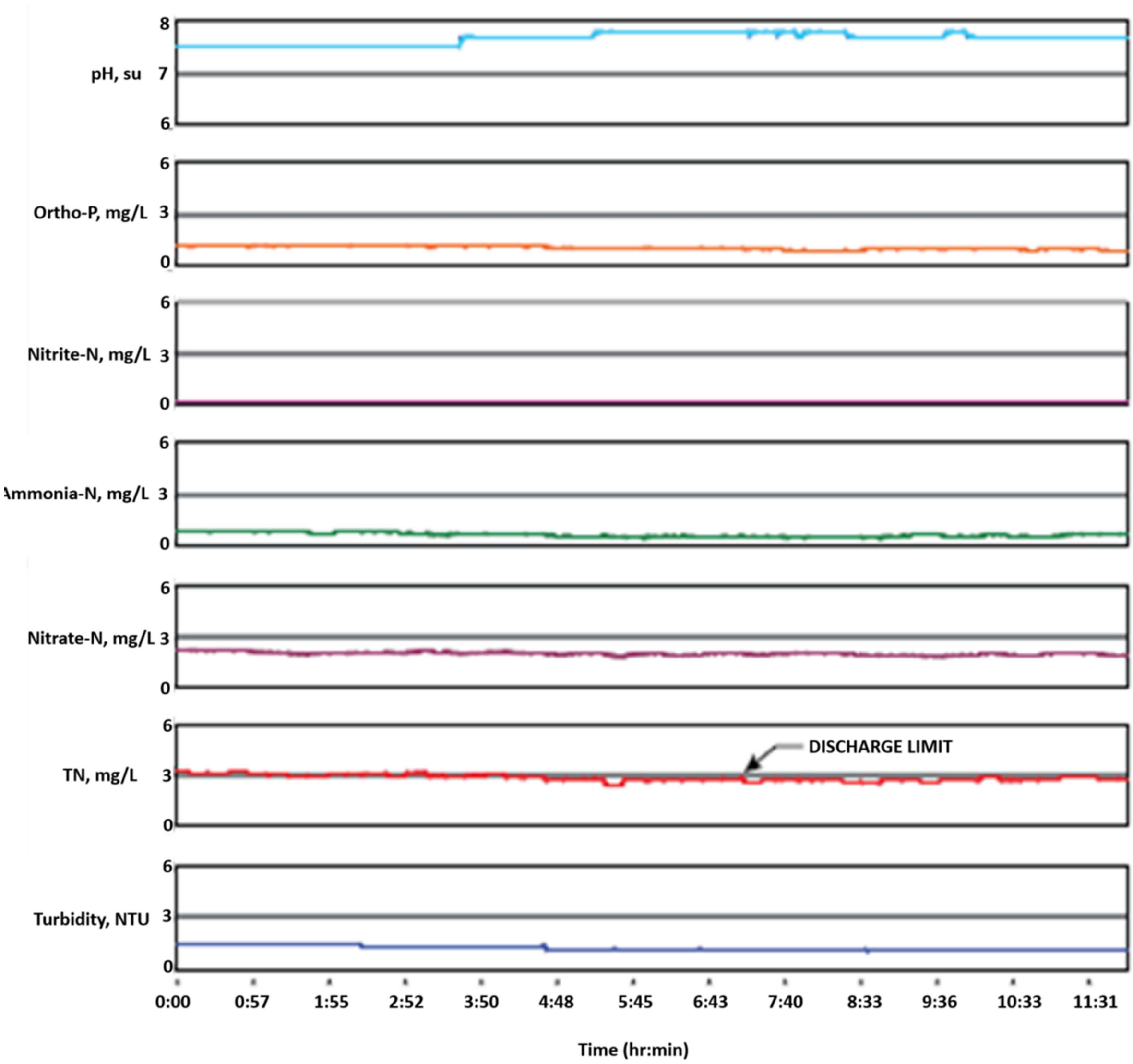

Figure 5. *Final effluent characteristics from the carrabelle after implementation of ORP based control of SBR.*

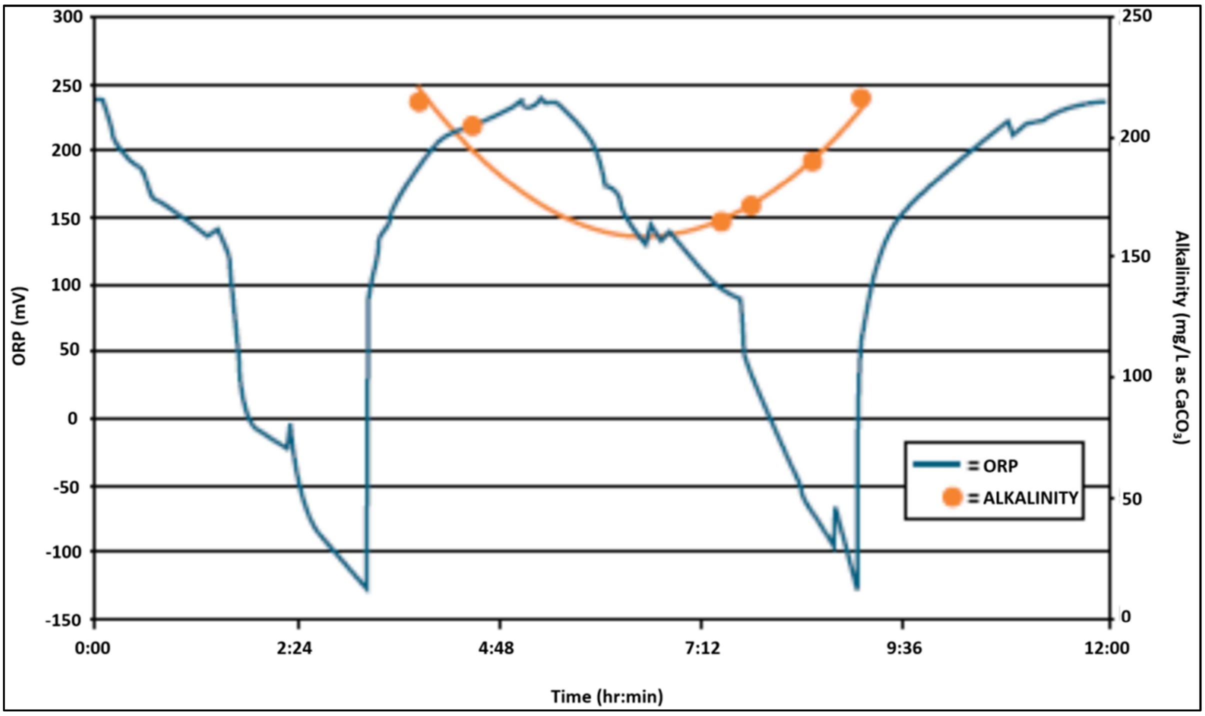

Figure 6. *Variations of alkalanity and ORP in SBR basin with time.*

The performance of an ORP based control system for an SBR depends heavily upon the ORP data continuously collected by the probe and the meter and transmitted to the PLC. Therefore, to ensure the collection of a good quality of ORP data under the aggressive wastewater environment, it is extremely important to keep up the performance of the ORP probe through a preventive maintenance program.

Current innovations in biological treatment technology helps achieve simultaneous nitrification and denitrification (NdN) by limiting DO concentration in the aeration step of SBR. The operating environment fosters the formation and growth of large flocs of sludge of 200 to 400 µm size compared to ~ 5 to 20 µm flocs in conventional suspended growth processes. These large flocs create a DO gradient from outside surface to the inside core of the flocs. High DO concentration on the surface facilitates nitrification by the autotrophic organisms but the DO limiting condition inside the floc particles promotes the growth of heterotrophic population that carry out denitrification under anoxic environment [15]. This process is marketed by various technology providers for full scale application as Granular Activated Sludge (GAS) process. The main advantages of the GAS process are significant reduction in aeration energy, reduction in SBR tank volume, achievement of effective nutrient control, and good settling characteristics of the sludge flocs. Detailed description of AGS process is available in the literature [16].

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