CYCLIC ACTIVATED SLUDGE TECHNOLOGY - RECENT OPERATING EXPERIENCE WITH A 90.000 PE PLANT IN GERMANY

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ABSTRACT

Cyclic activated sludge technology was selected for the Potsdam Wastewater Treatment Plant (90,000 p.e.). The cyclic activated sludge facility comprises four modules integrated into two circular basins. Construction was commenced in February 1998 with seeding of the plant for start up taking place in October 1998. Process performance has been met since Spring 1999 at 80-90 percent of design load. In order to optimize start-up procedures, respiration rates were used as a guidance for process stabilization and online process optimization during normal operation. Operation for co-current nitrification denitirification provided an ammonia removal of 1.1 mg NH4-N/gMLSS.h (15^0C) and a corresponding nitrate respiration rate of 0.85 mg NO_3-N/gMLSS.h under aerated conditions. Enhanced biological phosphorus removal generated an effluent mean total phosphorus concentration of 0.38 mg/L without precipitant addition.

KEYWORDS

Cyclic activated sludge technology, CYCLAZUR™, SBR, operation experience, co-current nitrification and denitrification, phosphorus removal.

BACKGROUND

Over recent years two different groups of cyclic activated sludge processes have gained increasing importance in wastewater treatment. One group encompasses the process family of Cyclic Activated Sludge Technologies which represents a certain technical development of a process philosophy (Goronszy 1979, 1985, Demoulin *et al* 1997, 1999). This process family is applied in large scale treatment throughout Germany, England, North America, parts of Asia and Australia. In different countries different trade names are used such as e.g. CYCLAZUR™ for Potsdam WWTP.

The second group of processes has been made popular through the work of Irvine (Irvine *et.al.,* 1983) and Wilderer (Wilderer *et.al.,* 1986) and are known by the acronym of SBR (sequencing batch reactor). SBR methodology is very commonly used for scientific studies, bench scale testing, and full scale applications of mainly small and medium size plants worldwide.

DEVELOPMENT OF “CYCLIC ACTIVATED SLUDGE TECHNOLOGY“

The development of this technology started in Australia as early as 1965 (Goronszy, 1979). In view of the designated application for large scale plants and the usage of the process advantages offered by the co-current nitrification/denitrification (co-N/DN) the following process features were developed:

- Short cycle times (4 hours and less), introduction of biological selector zones using transverse partial baffle walls, fill sequence regulation for filamentous sludge bulking control and co-current nitrification/denitrification, means of regulating the kinetics of oxidation reduction potential depletion for enhanced biological phosphorus removal (EBPR) (Goronszy *et al* 1991). Through process operation for co-current nitrification/denitrification formalized mixing sequences and equipment were omitted. The biological selector addressed process needs for filamentous sludge bulking control and EBPR.

- Process control using in-basin respiration rates, which allowed permanent control of the metabolic activity of the biomass and consequently changed the principles of process operation from a time based control to a demand oriented process control.

- A clear water withdrawal system for high rate decanting of up to 2.5 m of solids free effluent within a short time from basins having surface areas of up to 8000 m^2 (i.e. multiple basins and multiple decanters).

- Establishment of adjustable normal and high flow operating protocols.

The above mentioned developments were commenced in Australia and later adapted and developed for North America climates and extended to meet local climate and discharge requirements of Central Europe. Cold climate co-current nitrification/denitrification and redox controlled EBPR were demonstrated in the Austrian Grossarl plant, (Demoulin *et al,* 1997), in 1994 for the first time in Europe. The first such plants to use this technology in Germany are the Potsdam (FRG, 90,000 pe) and Neubrandenburg (FRG, 140,000 pe) facilities (Demoulin *et al,* 1999) which came online in early 1999.

HISTORY OF SBR TECHNOLOGIES

Pioneers of wastewater treatment processing using activated sludge were Arden and Lockett (1914). Because automatic operational tasks were yet to be mastered, activated sludge processing soon became a continuously aerated process. Through the development of time controlled automation systems, together with submerged aeration devices that were essentially non-fouling led to the SBR process (Irvine et al; 1983), (Wilderer *et al,* 1986). This methodology typically comprises the following features.

- Time cycles for separate aerobic, anoxic and anaerobic sequencing within the so called „reaction phase“ for strictly separated nitrification, denitrification and EBPR. To obtain these reaction conditions influent equalization and mechanical mixing became a process characteristic

- Process control using cycle times with separate programs for different operating conditions

- Different types, shapes and brands of clear water withdrawal systems are used such as rope guided floating decanters, simple submerged valving equipment or baffle arrangements.

IMPLEMENTATION OF THE CYCLIC ACTIVATED SLUDGE TECHNOLOGY AT THE POTSDAM WWTP

The Potsdam facility was designed to treat primary settled sewage in a four basin configuration, with anaerobic digestion of the waste sludge mixture. The four basins are configured as two 52.5 m diameter circular structures, each divided diametrically to form two half circle reactor basins. The selector in each basin is contained in a peripheral quarter circle section in which settled sewage and a flow of sludge from the main reactor are admixed. Each basin is equipped with two decanters designed to remove 1.8 m of supernatant clear water at specific weir loads of up to 170 L/s.m. in less than one hour.

Each basin is integrally connected to allow operation on a four hour dry weather cycle and a three hour wet weather cycle plus an “emergency” cycle to allow one basin to be taken out of service. Each cycle includes time sequences for fill, aeration, settle (no inflow) and effluent withdrawal (decanting) with all sequences contributing to the reaction time for EBPR and co-current nitrification/denitrification.

The selector is designed to allow maintenance or variation to oxic, anoxic, anaerobic retention time components. The mixed conditions at the inlet of each selector associate with a very high potential (maximum) oxygen utilization rate (POUR) Goronszy *et. al.,* (1986) which is typically in excess of four times the specific oxygen utilization rate (SOUR) in the main reactor volume. The sludge flow to the selector is typically less than 30 percent of design average dry weather flow (in comparison to 300 – 400 percent of total return flows in conventional systems.
A selective growth pressure against filamentous microorganisms, such as Microthrix p, is maintained in favor of floc forming microorganisms. This feature provides considerable enhancement to the settling

properties of the biomass as demonstrated during the start up of the Neubrandenburg plant in which a bulking seed sludge was used (Demoulin *et al,* 1999). No mechanical mixing devices are used as baffled walls are properly placed to provide the necessary mixing, solids entrainment and floc-formation velocities in the selector. The primary process mechanism taking place in the selector relates to enzymatic transfer of readily degradable soluble organic substrates into the biomass (viz. biosorption). By design phosphorus release occurs in the selector with only minimal denitrification taking place.

The combination of the selector and cyclic sequencing of aerated and non aerated phases leads to typical DO and ORP-profiles throughout the overall cycle as shown in Figure 1.

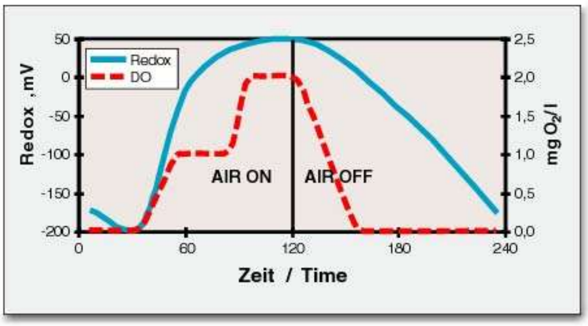

Figure 1. Typical DO and ORP-profile (Ag/AgCl) for co-N/DN and EBPR

A balanced process is achieved and regulated by online-measuring of the specific oxygen uptake rate in the basin in such a way that the floc reaction profile allows for nitrification at the peripheral sections and denitrification at the inner parts of the floc (Figure 2). Nitrate penetration is governed by its rate of diffusion which is of the order of ten times that of dissolved oxygen. Under aerated conditions there is typically no nitrate limitation in the interior zone of the floc. Sufficient carbon provision for denitrification is achieved through the carbon storage (biosorption) mechanism and the proportional DO demand regulation which minimizes the use of substrate carbon by oxic metabolization.

Under extreme conditions, e.g. long-lasting low temperatures with high total nitrogen concentration in the influent, the process can be regulated such that during the aeration phase there is mainly nitrification also within the flocs with denitrification taking place mainly during settling. Rising of activated sludge due to nitrogen gas bubbling does not occur as during the relatively short time cycles only low concentrations of nitrate nitrogen have to be denitrified in each cycle.

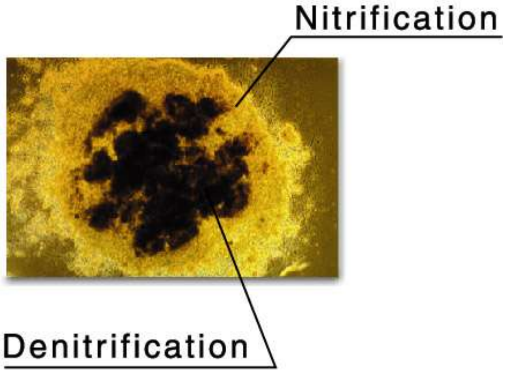

Figure 2: Representative view of a sludge floc under a light microscope with suggested zones for co-N/DN

Process control using in-basin respiration enables a direct control over biological phosphorus removal. Operating data shows much less than stoichiometric precipitant addition is required to arrive at concentrations of less than 0.5 mgTP/l without tertiary filtration.

DESIGN DATA AND PRESENT LOADING CONDITIONS

Design flows and loadings are summarized in Table 1; present loading conditions are summarized in Table 2 as 85 percentile values. Effluent requirements are less than 2 mg/L total phosphorus, less than 18 mg/L inorganic nitrogen and less than 75 mg/L COD as two hour representative samples under all flow conditions (to 60000 m^3/d).

Qd	m^3/d	21.100
DWF	m^3/h	1.300
Storm flows	m^3/h	2.500
BOD	kg/d / mg/l	4.500 / 210
COD	kg/d / mg/l	9.000 / 420
TN	kg/d / mg/l	990 / 47
TP	kg/d / mg/l	180 / 9

Table 1. Flows and loadings after primary settling

START UP EXPERIENCE AT POTSDAM WWTP

Data presented herein cover the start up period commencing in October 1998 with in-basin temperatures of about 8 °C. The average daily flows arriving at the head works were considerably lower than predicted so that the resulting concentrations are about a factor of 2 higher than predicted (Table 2). Hydraulic peak flows nevertheless occur especially in early spring with peak flows
matching the design numbers of Table 1, but spilling the sewer system and therefore delivering peak 2 hr nitrogen and carbon loads at the same time with peaking factors of 4:1 (Figure 3).

BOD	kg/d / mg/l	3600 / 434
COD	kg/d / mg/l	7200 / 868
TN	kg/d / mg/l	720 / 93
TP	kg/d / mg/l	123 / 13

Table 2. Loading conditions for start up

Respirometric techniques were used to monitor process stabilization and online optimization during normal operation. Figure 4 summarizes the development of the ratio of the Potential (maximum) Oxygen Utilization Rate (POUR) of the biomass under aerated substrate saturated conditions and the Specific Oxygen Utilization Rate (SOUR) at the end of the aeration cycle. There is a significant increase from a low ratio value of 2 to 4 to values in excess of 6.

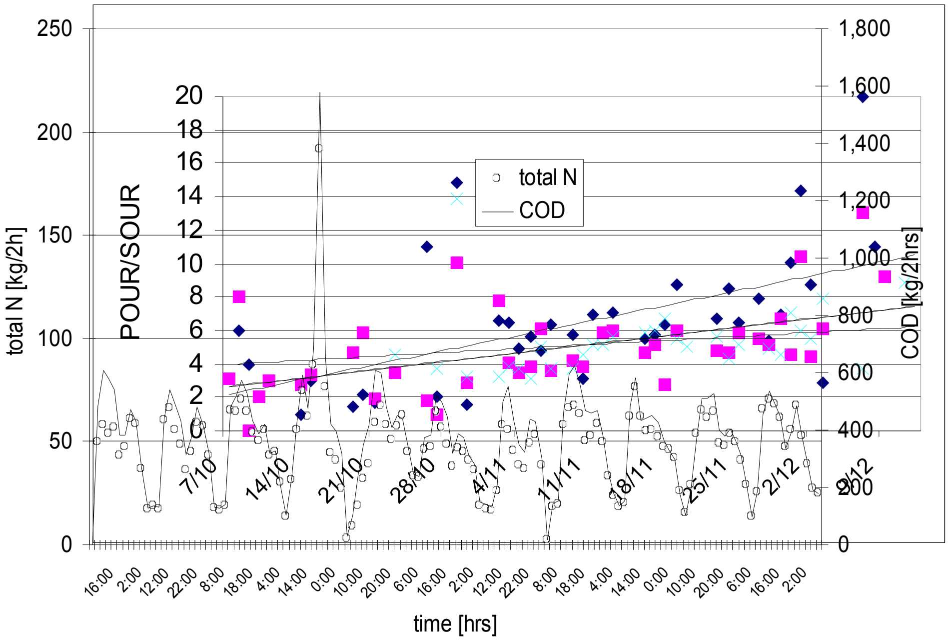

Figure 3. Peak loadings arriving at WWTP POTSDAM during start up in spring 1999

Figure 4. Development of the ratio of POUR under saturated conditions to SOUR under in-basin conditions in winter 1998 for basins 1 to 3. Lines show linear regression.

In parallel, a significant drop in ammonia effluent concentration was obtained without any significant nitrite concentration, from up to 40 mg NH_4-N/l down to less than 5 mg/l within the time period form October to January.

A maximum nitrification rate at 15°C ($r_{N\text{-max},15}$) of 1.1 mgNH_4-N/kg MLSS-h was obtained by simulation of effluent concentrations . The equation for ammonia oxidation was calibrated as

$$r_N = r_{N\text{-max},15} * NH_4\text{-}N_{\text{in basin}} / (NH_4\text{-}N_{\text{in basin}} + 1) * 1{,}103^{(T-15)}.$$

Figure 5 shows a special peak loading event with an instantaneous 2 hr peak of over 3-times the values in a preceding 2 hr-sample and a factor of 4 compared to the daily average in reference to total N and COD loads as well as hydraulic flow.

This load condition was used to assess the response of the process control system, for operation at low temperatures, to a peak load stimulus in order to maintain the stated effluent quality limits. During normal operating conditions, the predicted and actual effluent ammonia nitrogen concentrations were close; while the simulated peak value of 12 mg NH_4-N/l showed a higher response value to the actual measurement of 8.2 mg NH_4-N/l, probably as a result of incomplete simulation of retention time distribution in the process basins.

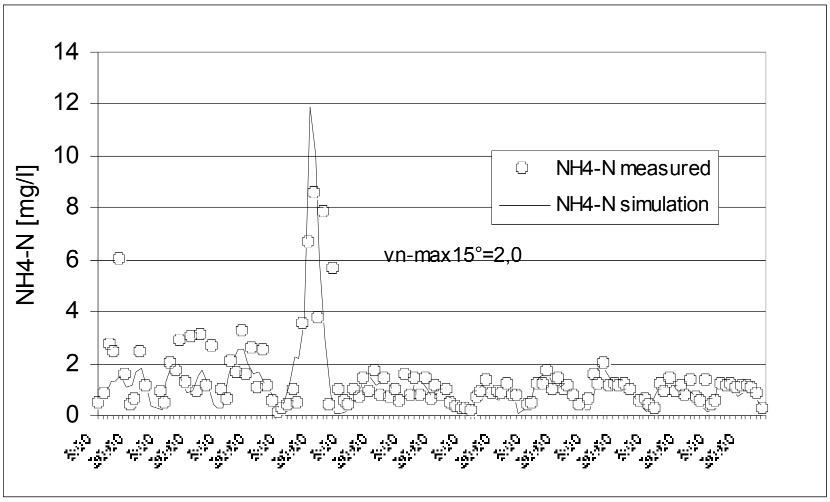

Figure 5. Comparison of predicted and actual measured 2 hr ammonia concentration during a special peak loading event in spring 1999. Total survey period was 11 days.

The rate of aerated denitrification was determined in 2 hrs nitrogen mass balances. Performance measurements showed that 85 % nitrogen removal during start up and 90-92% nitrogen removal during early summer of 1999 was obtained.

The variation of the aerated denitrification rates throughout a day is shown in Figure 6. The numbers follow the daily influent variation as per Figure 3 which clearly shows that denitrification is not limited by an upper limit in the denitrification rate but simply follows the nitrogen supply. Values of up to 0.85 mg/g MLSS.h were observed in the data at average influent COD:TN ratios of only 8:1.

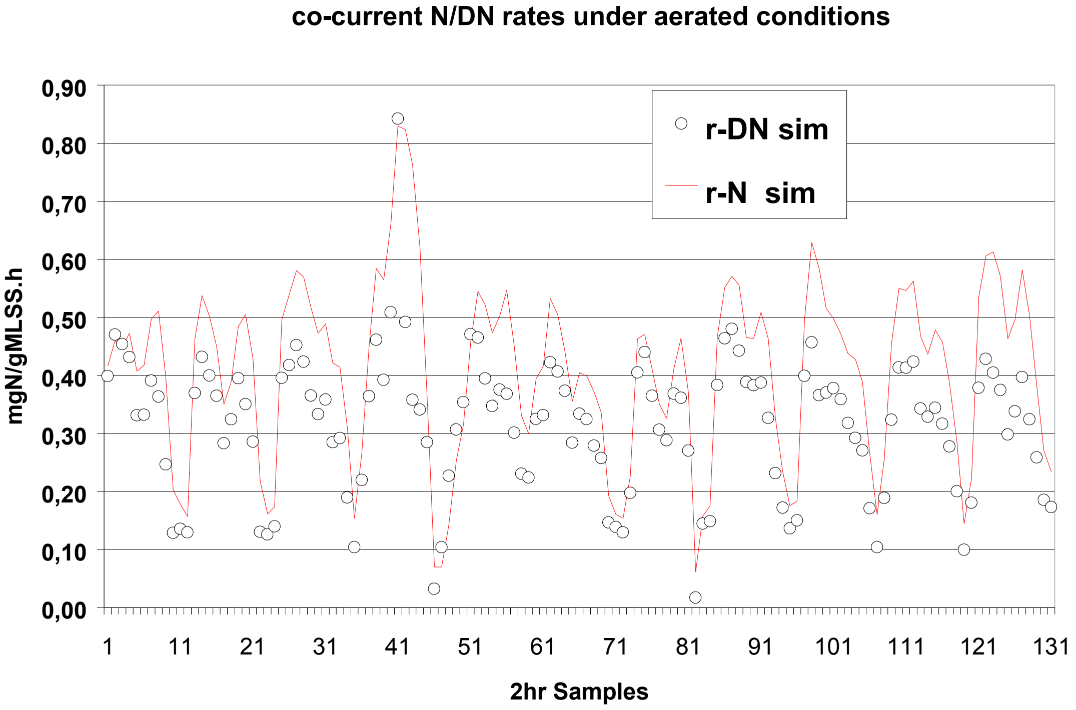

Figure 6. Comparison of daily fluctuations in nitrification rates (r_N) and denitrification rates (r_{DN}) during an 11 days survey period.

Figure 7. Effluent concentrations of total-P 3 weeks after stopping the polishing dosage

Figure 7 shows the stability of total P effluent concentrations without precipitant dosing at a COD/TP ratio of 49.7. Specific incorporation rates of 20gP/kgCOD$_{in}$ can be back calculated from the above figures. Average TP effluent concentrations of 0.38 mg/l were observed as 2 hr flow-proportional samples.

Figure 8 shows an overview of one circular process basin with a surface area of 4000 m^2.

Figure 8. CYCLAZUR^{TM} Cyclic activated sludge technology at WWTP Potsdam

CONCLUSIONS

Whilst Cyclic Activated Sludge Technology and Sequencing Batch Reactor processing have been developed in different directions they still belong to a similar grouping of the activated sludge process. Operating experience at the Potsdam WWTP demonstrates low temperature treatment performance with instantaneous peaks of up to 4 : 1. Stable co-current nitrification denitrification is evidenced with total nitrogen removal of up to 92% using online measurement of biomass respiration without using any formal non-aerated mixing sequences. A rate of nitrification, at 15^{0}C, at saturated conditions, of 1.1 mg N/g

MLSS.h was determined for this wastewater and subsequently used to predict performance under shock loading conditions resulting from initial wet weather flows. Aerated denitrification rates of up to 0.85 mg N/g MLSS.h, over two hour cycles of aeration, were determined. Rates of denitrification did not show any limitations to environmental conditions other than nitrogen supply.

An average phosphorus incorporation of 20 mg P/g COD in provided average effluent concentrations of total phosphorus of 0.38 mg/L without the addition of precipitants. Typical values for the ratio of the potential (maximum) oxygen utilization rate and in-basin SOUR are of the order of 6 : 1 which gives an explanation to a high degree of selectivity against the growth of filamentous microorganisms through the formation of a substantial substrate gradient. This also accounts for a high resilience against peak and shock loads.

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