PROCESS AND AERATION OPTIMISATION USING ONLINE OFFGAS ANALYSIS

Ian Trillo [1], Mike Smith [2]
1. ATC, Barcelona, Spain
2. INVENT PACIFIC, New South Wales, Australia

ABSTRACT

OffGas analysis has been extensively used over the last 40 years for aeration system performance evaluation and aeration system design/retrofit purposes. In recent years, with the development of online OffGas measuring equipment, benefits of real time OffGas analysis data can be integrated into process and aeration optimization strategies. This paper describes examples of real cases where online OffGas data has been used to improve accuracy and stability of aeration control and reduce overall system aeration requirements through optimization of process configuration and operating conditions.

INTRODUCTION

In an activated sludge process where oxygen is supplied to the biomass using subsurface aeration equipment, OffGas analysis is a technology that allows measurement of the aeration systems oxygen transfer efficiency under actual process conditions. The OffGass analysis, combined with additional system and operating condition information (including DO levels, air flux rate and aeration system clean water transfer performance, etc) can be used to develop online data of the process oxygen uptake rates (OUR) and wastewater oxygen transfer characteristics (α value).

Real time availability of this data provides, at any point in time, the actual oxygen requirement of the process and in addition, the parameters that allow quantifying the exact amount of air required to supply the process with the oxygen necessary for biological activity. Implications of the ability to quantify airflow as compared to identifying the need for “more air or less air” eliminates iterative algorithms in the determination of control actions (blower output, valve positions, etc.). Furthermore, knowledge of the effect of changing wastewater oxygen transfer characteristics, such as α values reduces the need for control system tunning and the need for a tuning compromise between control response times for high load-low transfer and low load-high transfer conditions that occur throughout a day, week or on a seasonal basis.

Knowledge of the OUR and α data opens the door to implementing strategies that provide a more precise dissolved oxygen profile. This avoids the common situation where higher oxygen demand in portions of the aeration of the basin with lower α values is managed with increased air supply, resulting in a higher airflow requirement, but less than ideal DO profile. In other terms strategy’s than eliminate under aeration or over aeration saving energy consumption and maximising process performance.

This paper describes the implementation of online OffGas analysis at two BNR wastewater treatment plants in Europe and the results obtained in the application of process and aeration optimisation strategies based on online OffGas data.

METHODS AND APPARATUS

In both the case studies presented below the key apparatus involved has been availability of an online OffGas analyser as described in *Jenkins et al (2004)*.

Although the characteristics of the two types of units used is somewhat different, both the A2C online analyser used at the Terrassa WWTP and the INVENT ALPHAMETER used at the Erlangen WWTP share the same principle of operation.

The units are based on analysis of the oxygen content in the exhaust air leaving the aeration basin surface (OffGas) and the oxygen content in the ambient air entering the compressors. This information, in combination with site ambient conditions, wastewater temperature, aeration system clean water performance data and airflow to the selected measuring location is used to develop OTE (Oxygen Transfer Efficiency) of the aeration system, mixed liquor α values and process OUR (Oxygen Uptake Rate).

OffGas sampling is performed locating on the tank surface a suitable gas capture device (hood) and conveying the collected gas to an analytical circuit where gas composition is measured.

The online OffGas analysers used in the studies presented include an internal PLC (Programmable Logic Controller) to process the gas composition data and perform parameter calculations.

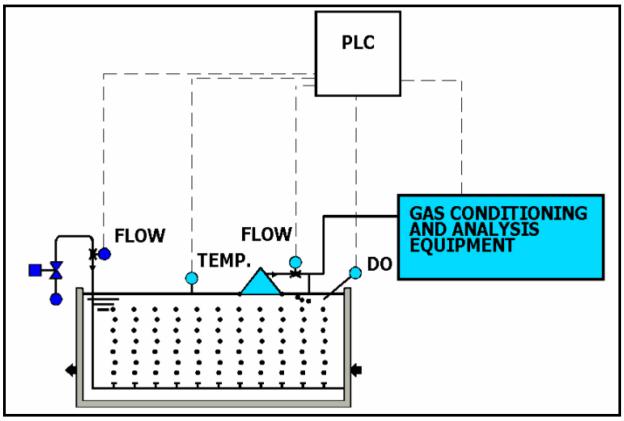

Figure 1: Online OffGas Apparatus Schematic

Availability of calculated data in the instrument PLC is communicated to the plant control system (or Aeration Master Control Panel) in order to allow parameter monitoring and incorporation of generated data into the control strategies tested.

Ultimately, the purpose of the studies presented was to assess the possible advantages for process and aeration control of having live data on three important parameters that before the existence of online OffGas instrumentation were not available for plant operators or control programmers.

Front this standpoint, live OTE and α values could be important because they allow establishing a relationship between the air introduced into the system and the actual amount of oxygen transferred to the process.

One of the biggest problems in aeration control is the fact that due to variations in parameters affecting oxygen transfer (α values, DO levels, etc..) a certain amount of air will transfer different quantities of oxygen to the wastewater, in such a way that identical aeration system operating conditions or control changes will result in different net oxygen inputs to the process. As a consequence of this, and in order to achieve control stability, control systems incorporate time constants and tuning factors that need to represent a compromise between the response time required at fast changing conditions, but that are not too aggressive to create oscillations or hunting during the less demanding periods of operation.

This means that even control systems that achieve 'stable' control have the potential of being improved if the relationship between air feed and net oxygen transfer is incorporated into the control logic. Incorporating such information would allow the control system to automatically change the magnitude of the control actions as a function of the net impact of such control actions on the process.

By way of example, let´s consider a system that requires an increase in oxygen of 100 kg/hr and that the aeration system is performing with an OTE of 15%. The amount of air required to produce this net increase in oxygen to the process would be 33% lower than if the system was performing with an OTE of 10%.

However, without information on the actual OTE values the control system cannot notice the difference between the two cases and would react in exactly the same way. If tuning parameters are adequate for the system performing with a 15% OTE then all control actions will prove to be slow when the system is performing at 10% OTE.

On the other hand, the availability of live OUR data could also be of great relevance for control purposes because it represents knowledge of real process requirements.

Almost all control systems in operation today are directly or indirectly based on the use of Dissolved Oxygen (DO) as process control variable. Target DO levels are established (setpoints) and air is increased or decreased as a function of the difference between the DO levels in the basin and the DO setpoints (DO error). However, no consideration is given to how much oxygen is being transferred to the mixed liquor nor to how much oxygen the process needs. If our DO levels are below setpoint we understand that more oxygen is required, and if our DO levels are above setpoint we consider we need less air. In essence, the instrumentation commonly used for control allows us to qualitatively determine when we need to supply more oxygen or when we need to reduce the amount of oxygen, but it does not allow us to quantitatively determine how much increase in oxygen is needed or by how much we need to reduce the oxygen input. This results in control strategies based on trial & error or iterative control action calculation loops simply because they lack both a real process target value "meeting the oxygen requirements of the process", moreover the effect of the control actions calculated or performed.

This is the point where knowledge of live OUR data represents an improvement over conventional process and aeration control systems. Live OUR data allows quantitative determination of process requirements and this information, combined with OTE data allows determination of the exact airflow required by the system at any given point in time. This avoids the need for trial & error and iterative procedures therefore reducing control action response times and increasing control system accuracy.

Accuracy in control can play a significant role in aeration system energy optimisation. In the vast majority of systems, DO setpoints used for control are higher than the DO values really required from a process point of view. This is due to the fact that a comfortable safety margin in DO levels is adopted to allow for the deviations and DO excursions that occur under normal plant operation. It is not strange to see system operating at 2,0 mg/l or above just make sure that the minimum DO values are never too low to jeopardize process stability. However, if control accuracy reduces the magnitude of these excursions or deviations, setpoint may be lowered while providing the same DO level safety.

Importantly, the ability to transfer oxygen is proportional to the difference between DO saturation concentration and the DO levels in the basin (oxygen transfer driving force), reducing DO setpoints and actual DO values increases oxygen transfer thus reducing overall air requirements, providing the opportunity for energy savings.

When conducting the studies described below it became apparent that, beyond issues strictly related to aeration control, availability of live OUR, OTE and α value data opened the door to an additional approach on process/aeration optimisation.

Comparison of OUR and oxygen transfer parameters between different zones of the aeration tank allowed the assessment of where in the tank the oxygen demands are taking place in relationship to the 'cost' of supplying oxygen to the process in each zone.

From a process point of view, one may accept that a certain overall oxygen demand needs to be fulfilled in order to achieve treatment goals. However, spatial distribution of this oxygen demand may not necessarily be unique.

All operative conditions along a basin being equal (including DO levels), special distribution of oxygen demands depends primarily on process configuration, wastewater composition and flow. However, one may act on the system by changing operative conditions in different sections of the basin to modify the oxygen demand profile along the tank.

Although this topic is not the subject of the present paper, this affirmation is based on the principle that activity of the biomass in the process is related to DO levels in the mixed liquor. Whereas the total amount of biomass may remain constant, the activity of the biomass will depend on the availability of oxygen. If focus is placed on the biological floc, low DO values may result in oxygen only penetrating the floc partially in such a way that the biomass closest to the centre of the floc does not get any oxygen and is basically passive. Above certain DO levels, oxygen penetrates the entire floc and all the biomass contributes to oxygen uptake.

This explains why OUR of a mixed liquor sample increases as DO rises and reaches an asymptote for DO values above a certain level.

This principle has been used to optimize air requirements of the systems tested, modifying DO setpoints at the different control zones in the basin to redistribute OUR values and air requirements along the tanks in such way that more air is diverted to zones with better oxygen transfer performance resulting in lower air requirements without affecting the overall amount of oxygen supplied to the process.

As will be presented below, the impact of OUR profile managing based on OUR and oxygen transfer performance data is significant.

Case Study 1: Terrassa WWTP (Spain)

The Terrassa WWTP (Spain) is a biological BNR treatment plant with a design capacity of 75MLD m Before a major upgrade finalized in 2011, the plant was a conventional activated sludge plant with four parallel basins. After the upgrade, the plant consists of five biological treatment lanes: four IFAS lanes equipped with textile media cages and one conventional activated sludge lane. Of the total of five lanes, only the four IFAS lanes are currently in operation.

Each treatment lane consists of an anoxic zone, a two-pass aeration zone and a post-denitrification zone. Aeration zones are equipped with fine pore membrane disc diffusers installed below the fixed media support cages.

Three HV-Turbo compressors were installed during the upgrade while the pre-existing six positive displacement blowers have been kept operative as standby units. The original control system included a fixed main header pressure setpoint control loop for compressor operation and PID based control loops for each of the four operating aeration basins.

The system was run at a constant main header pressure of 0.60 bar and fixed DO setpoints of 2.0 mg/l across the basin to ensure suitable conditions for nitrification. With this setup and control strategy, average DO values around 2.0 mg/l were achieved with typical DO variations between 0.5 and 3.2 mg/l.

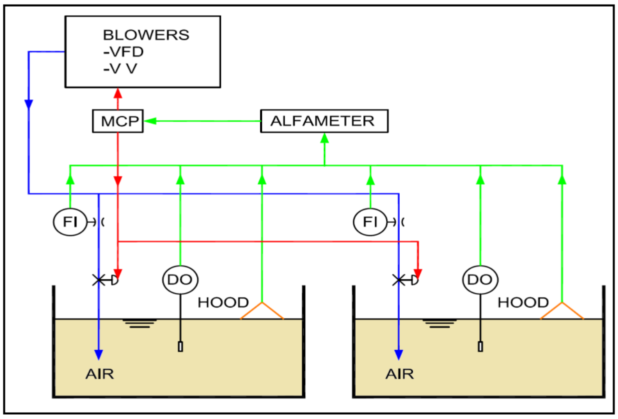

Figure 2: Implemented Control System Simplified PI

As part of the plant upgrade, the system was equipped with a total of ten OffGas collection hoods (two per basin) and a new flow based Master Control Panel that receives airflow requirements to each zone from the five online OffGas analysers and manages air production and distribution to each control zone (operating the ten existing control valves). Master Control Panel logic includes flow based control of air production and Most Open Valve (MOV) control logic for valve operation.

After a few months of operation of the new control system, the following observations were made:

- Control allowed achieving average DO values of 2.0 mg/l reducing deviations from setpoint to below ±0.2 mg/l for over 95% of the time and observing no bigger deviations from setpoint for periods over 10 minutes.
- OUR distribution between the two control zones of the basins showed over 70% of the total oxygen demand took place in the first half of the basin.
- α values in the first half of the basin ranged between 0.38-0.45. Corresponding values in the second half of the basin were considerably higher ranging between 0.55 and 0.65.

These observations lead to the general idea that with improved control accuracy one could freely modify setpoint values down to values around 0.8 mg/l (if necessary) without the system experiencing DO deviations greater that those observed prior to the upgrade.

In addition, most of the weight of the process was shifted towards the first half of the basin, where transferring oxygen required approximately 33% more air than the second half of the basin.

Under these circumstances, the first step undertaken was to lower setpoints in the first half of the basin to shift the oxygen demand towards the second half of the tank. In this process, an upper limit of 40% of the oxygen demand to be satisfied in the second part of the basin was agreed with the plant operator to allow for a process safety margin avoiding overloading of the second part of the basin that could potentially result in compromising achievement of water quality criteria.

Setpoints in Zone 1 of the basins were slowly reduced down to 1.3 mg/l were the target OUR distribution was met and process performance under these operating conditions was verified.

Once this target was achieved, setpoints for both control areas were simultaneously reduced searching for the minimum setpoint values possible that ensured process performance.

It was observed that process started showing instability and/or oxygen demands above 40% of total demand in Zone 2 at DO levels in Zone 1 around 0.5 mg/l, but that above these values the process showed robust performance as long as DO levels in Zone 2 were kept above 0.9 mg/l.

As a result of these observations, the plant currently operates the system with target DO setpoints of 0.8 mg/l in Zone 1 and 1.00 mg/l in Zone 2 with no negative effects on process. Both carbon and nutrient removal goals are achieved consistently.

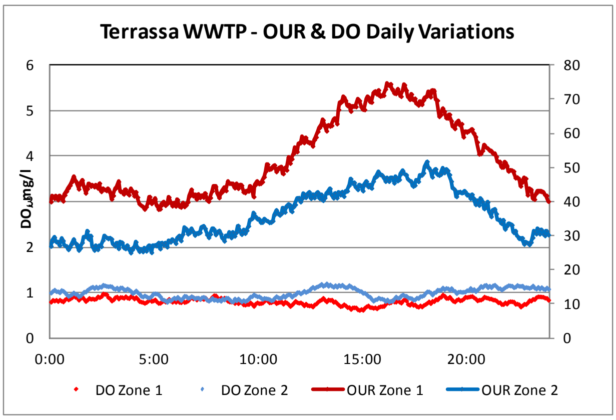

Figure 3: DO&OUR Data at Terrassa WWTP

In addition, the change from the old pressure control of blowers to the flow based control logic (including MOV logic) has allowed reducing system operating pressure down to 0.52 bar.

Incorporation of real time OTE, α value and OUR data obtained through online OffGas analysis into aeration control and process management strategies at the Terrassa WWTP has allowed achieving the following results:

- Improved stability and control limiting DO excursions to ±0.2mg/l from target setpoints during normal plant operation
- Reducing DO setpoints by between 1.00 and 1.20 mg/l with no effect on process performance resulting in a reduction of airflow requirements between 10-12% with respect to requirements associated to operating the system at the previous DO setpoints.
- Optimization of OUR profile to balance biological activity along the process lane to avoid stress on the initial section of the basin and lower activity in the second half of the basin and to redirect airflow requirements to the zone of the basin that is more effective from an oxygen transfer point of view.
- Lower system overall operating pressure due to more balanced air distribution, more compensated and open valve positions and flow+MOV control logic.
- Reduction of overall airflow requirements through combined optimization of OUR, α and aeration system performance distribution resulting in reduced energy consumption.

- Overall combined airflow requirement reduction between 15-25% and energy savings between 15-20%.

Case Study 2: Erlangen WWTP (Germany)

The Erlangen WWTP (Germany) is an activated sludge BNR plant with a design capacity of ~20MLD. The biological treatment of the incoming waste is performed in four parallel biological treatment lanes consisting in one anoxic chamber and three aeration zones per lane. Zones are physically divided by concrete walls that rise from the tank bottom to about 30 cm from the basin surface. All three aerated zones in each basin are equipped with identical number of tubular fine pore diffusers in such a way that diffuser density is uniform across the whole aeration lane. Compressed air for oxygen supply is produced in a blower building common to all four lanes equipped with four Siemens Turbocompressors.

At the time of implementation of online OffGas equipment, aeration system was controlled using a pressure control loop for compressor operation (with a fixed pressure setpoint established by the operator), and individual DO control loops for each of the three aeration zones in each lane (total of twelve individual PID control loops operating each of the twelve existing control valves). DO setpoints for each individual control zone were established by the operator and modified if required by means of a third supervisory control loop based on ammonia removal performance of the process.

Control system performance prior to initiating the online OffGas system implementation was satisfactory (DO values consistently 0.5 mg/l of target setpoints) with the exception of the first zone in each lane where DO setpoint levels could not be met at high load conditions due to limitations in the air distribution pipework configuration at the pressure setpoint used. Although this situation was known to the plant operator and could be solved by increasing the overall operating pressure of the system, it was accepted that it´s limited impact on process performance did not justify the increase in energy consumption associated to increasing the operating pressure of the system.

During the initial phase of implementation, online OffGas measuring equipment was installed in the first two aerated zones of Lane 1 of the Erlangen WWTP. Three new thermal mass flow meters were installed to measure airflow to each of the three aeration zones of Lane 1. The initial purpose of the trial was to measure process and aeration parameters in the selected control zones and replace PID control of air feed to Lane 1 with flow control loops based on process oxygen requirements and aeration system performance values obtained through online OffGas analysis.

Figure 4: Collection Hoods at Erlangen WWTP

Profibus communications were established between the online OffGas measuring unit and the existing control system (Siemens S7 PLC Platform) so that individual zone flow requirements and valve position commands determined by the OffGas system could be executed by the existing control system. During this stage, original DO setpoints were used and the supervisory ammonia control loops were kept in operation.

Following setup of equipment and testing of control capabilities, focus was placed on analysis of DO control performance, airflow distribution and control valve behaviour, OUR data and aeration system performance data.

The following observations were made:

- Control accuracy and stability in the two zones controlled using online OffGas data was satisfactory, but comparable to the performance of the existing system.
- Airflow distribution between the three aerated zones presented an approximated ratio of 3:2:1, the first zone receiving approximately 50% more air than the second zone and 300% more air than the third zone.
- OUR values ranged between 50-70 mg/l/hr in the first zone compared to between 15-25 mg/ in the second zone. No OUR data was available for the third zone. However, it is reasonable to assume that OUR values in the third zone should be lower than in the second zone and therefore quite close to values typical of endogenous respiration levels (10-15 mg/l/hr).
- α values in both zones were quite high (0,6-0,8) with values in the second zone between 15-20% higher on average than the first zone.

The initial interpretation of the data collected suggests a strong unbalance of the system towards activity in the first zone of the tank. OUR levels in Zone 2 and assumed oxygen uptake rates for Zone 3 would indicate very low activity in these zones compared to Zone 1 and would explain the difference in airflow requirements observed.

In itself, airflow distribution observed is already a matter of concern in terms of system efficiency due to aeration system and distribution pipework configuration. Due to the fact that all zones have identical diffuser density, and that Zone 1 is the zone furthest away from the blower building, valves in Zones 2 and 3 would need to be very closed in order to compensate for the difference in pressure required to allow distributing three times more air to Zone 1 than to Zone 3. This results in the need to run the system at higher pressure and that is probably the cause of the control problems and limitations observed for Zone 1 at high load conditions.

In terms of control improvement, one could be deceived by the fact that the control strategy implemented for Lane 1 did not exceed performance of the existing system. However, it must be understood that the partial implementation of the system (flow based control of Lane 1 in a pressure based control system) results in Lane 1 control being affected by the pressure based control of the remaining nine valves in the system. Improved control accuracy with respect to the existing system is anticipated whenever either the whole plant or the air production and valve operation to the sections with online OffGas based control are switched to flow control.

Although this upgrade will allow additional optimisation and energy savings strategies, the data collected with partial implementation of online OffGas equipment already provided the basis for aeration and process optimisation.

Focus was placed in modification of the process OUR profile so that activity and OUR requirements were reduced in Zone 1 and increased in Zones 2 and 3. To this purpose, target DO setpoints in Zone 1 were lowered and setpoints in Zone 2 increased. No major changes were made to setpoints in Zone 2.

As a result of these modifications, OUR values in Zone 1 dropped to between 40-50 mg/l/hr and OUR values in Zone 2 increased to 20-30 mg/l/hr.

Airflow distribution ratio changed to a more balanced 4:3:2 suggesting the activity (OUR) in Zone 3 also increased (no OUR data available).

This resulted in more balanced valve positions and no need to run the system with the valve in Zone 1 completely open and valves in Zones 2&3 very closed. With the new setpoint arrangement, the problems observed in Zone 1 disappeared.

One of the immediate benefits of these modifications would theoretically be a reduction in system operating pressure. However, due to the fact that changes were only made to one lane and the overall system still operated based on a fixed pressure setpoint these benefits were not immediately observed.

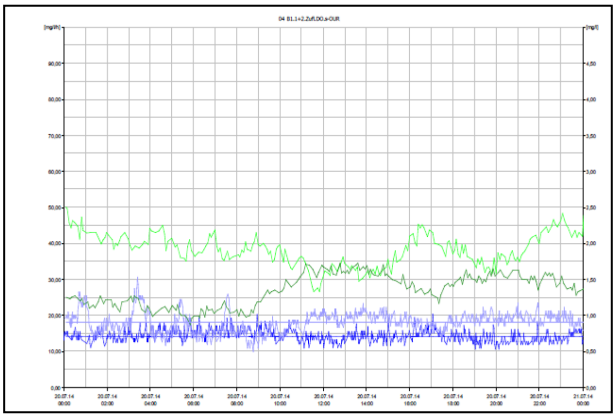

Figure 5: DO&OUR Data at Erlangen WWTP

The second benefit of the changes made was diverting air from the zone with the lowest α value to zones with higher corresponding values, requiring a smaller amount of air to achieve the same net oxygen input to the system.

The reduction in overall air requirements to Lane 1 when compared to the other lanes at the plant was quickly identified and documented. As may be seen in the Figure 6, reduction in air requirements is significant and has been evaluated around 20%.

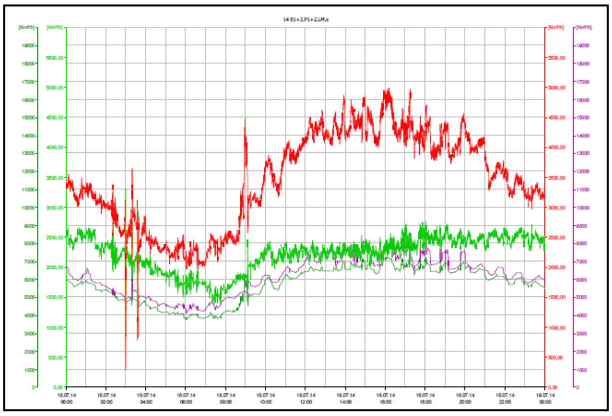

Figure 6: Comparison of Airflows Lanes 1&2

In view of the results obtained during this first stage of implementation of online OffGas analysis, the plant operator decided to mirror copy the new setpoint profile to all four basins at the plant despite the fact that the system is still operating based on pressure control.

According to data supplied by the plant operator, application of the results obtained during this first phase of implementation of online OffGas analysis process and aeration control has resulted in overall energy savings of 10% of prior energy usage.

Complete upgrade to all four lanes and modification of main control strategy from pressure control to flow control is currently under evaluation and should allow increased energy savings once the full benefits of the system (in terms of overall operating pressure and improved control stability) can be materialized.

CONCLUSIONS

Use of real time online OffGas data for process and aeration control opens the door to development of new control and process management strategies with a big potential for improvements in process stability and energy savings.

The strategies presented in the present paper have provided very successful results so far. However, the authors consider these as examples of first applications subject to improvement and/or extrapolations to other processes and applications.

AKNOWLEDGEMENTS

The Authors wish to thank the City of Erlangen and personnel at the Erlangen and Terrassa WWTP for their support and contribution during the development of the work described in this paper. Special thanks to Dr. Hallas, E. for his involvement and onsite assistance at Erlangen WWTP.

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