Real time control for reduced aeration and chemical consumption: a full scale study

A. Thornton, N. Sunner and M. Haeck

ABSTRACT

The use of the activated sludge process (ASP) for the nitrification/denitrification of wastewaters is commonplace throughout the UK and many other parts of the industrial world. Associated with this process are significant costs arising from aeration requirements and for selected sites, the need to provide an external carbon source. These costs can constitute up to of 50% of the total running cost of the whole plant and as such, any effort to reduce them could realise significant benefits. This paper investigates the use of real time control (RTC) using online sensors and control algorithms to optimise the operation of the ASP, leading to greater efficiency and sustainability. Trials were undertaken at full scale to assess the benefit of such a system at a 250,000 population equivalent (PE) works on the south coast of the UK, using Activated sludge model No.1 (ASM 1) as a basis for the control system. Initial results indicate that it is possible to significantly reduce both aeration and chemical consumption costs whilst still delivering the required effluent quality. Over the trial period the aeration requirements were consistently reduced by 20% whereas, a reduction in methanol consumption of in excess of 50% was observed.

Key words | activated sludge process, aeration control, methanol, nutrient removal, real time control, sustainable

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INTRODUCTION

With the soaring cost of energy and ever increasing pressure to find sustainable solutions, the water industry finds itself in the same dilemma as many other large power hungry entities within the UK and further a field. The operation of existing infrastructure is associated with significant increases in operating costs, which are only going to rise further in the foreseeable future. Coupled with this is the ever increasing pressure to operate in a sustainable fashion and in the modern industrial world, this has become a significant driver. However, unlike many other industries, the scope to find low cost, sustainable solutions is significantly reduced by the fact that running alongside ever increasing costs are even more stringent consent levels.

Many modern wastewater treatment works use the activated sludge process (ASP) for removal of nutrients, namely, ammonium and nitrate, to meet the increasingly stringent effluent consent concentrations imposed by the relevant regulatory bodies. The use of this process for ammonium removal requires the input of large amounts of air to provide the required levels of dissolved oxygen (DO) to facilitate the microbial conversion of ammonium to nitrate. Commonly, although not exclusively, the aeration of such processes is provided by a series of blowers, which run continually to meet the demands of the plant. The use of blower systems is a relatively power intensive process and in many cases can contribute in the region of 50% of the total power consumption of the works in question (Ferrer 1998). The use of the ASP for nitrate removal often requires the addition of an external carbon source, such as methanol, to facilitate the microbial conversion of nitrate to nitrogen gas

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which is then dispersed to the atmosphere. The addition of methanol can contribute significantly to the operating costs and for a moderate sized works can run into hundreds of thousands of pounds.

An opportunity now exists to significantly reduce the energy demands of the activated sludge process by the use of online instrumentation for the real time control of both aeration and methanol dosing systems. This concept is by no means a new one but until recently, the lack of confidence in the accuracy and reliability of the associated instrumentation has proved prohibitive. Recent technological advancement has led to an increased level of confidence in such instrumentation and this can only result in an increase in their use.

Conventional control methods for blower systems focus on maintaining a fixed DO concentration (setpoint) within the reactor to ensure that there is enough DO present to facilitate the nitrification process (Lindberg & Carlsson 1996) under all conditions. This is commonly achieved by the positioning of DO sensors in the reactor (Ingildsen *et al.* 2002). The output from these is used to control the amount of air delivered by the blowers (Olsson & Newell 1999). These conventional methods for blower control do offer some opportunity to optimise the air delivery systems for ASP's. The fixed DO setpoint in the lanes can be set as low as possible, without compromising compliance, in attempt to minimise the airflow and thus reduce the power consumed by the blower systems. However, if the DO concentration could be modulated according to load (i.e. the setpoint for DO could be in line with demand), then further significant power savings could be realised by lowering DO setpoints over lengthy periods of the day. In recent years many authors (Ferrer *et al.* 1998; Suescun *et al.* 2001; Wette & Ingerle 2001; Ingildsen *et al.* 2002; Krause *et al.* 2002; Meyer & Popel 2003; Vrecko *et al.* 2003; Vrecko *et al.* 2006) have investigated the merits of RTC for aeration control using instrumentation as a way of more accurately controlling the air requirements for nitrification within ASPs and other processes. The research was undertaken using, simulation, pilot studies and full scale studies and results return varying degrees of success, with reported aeration reductions ranging from 5–45%. This paper outlines full scale studies to assess the impact of RTC on the optimisation of the activated sludge process with a view to leaving a permanent control system in place at the end of the trials.

MATERIALS AND METHODS

The site where the trials were conducted was 250,000 PE plant on the south coast of the UK and consisted of two identical ASPs (each with four lanes) configured as a 4-stage Bardenpho plant with methanol addition in the secondary anoxic zone (Figure 1). The settled sewage and the RAS were combined before being distributed to the 8 identical ASP lanes. Shortly after the installation of the plant, the fixed DO setpoints in the aeration zones for all lanes were optimised as follows; Zone 1–2.0 mg l^{-1}; Zone 2–2.1 mg l^{-1}; Zone 3–1.6 mg l^{-1} and Zone 4–0.5 mg l^{-1}. The existing methanol control was on a feed forward basis using a nitrate probe in the outlet of zone 4 on each lane to calculate the required amount of methanol to be dosed at any instant.

To facilitate the real time control trials, the plant was divided into 4 sections, with each section comprising two lanes, one a master and one a slave. Instrumentation (supplied by Hach-Lange, Dusseldorf, Germany) was installed on each master lane (Figure 1), to transmit the required data back to the RTC controller. The controller then calculated the required setpoints for DO and methanol dosing, which were then transmitted to the existing site plc. The slave lanes only had DO sensors in zones 1 and 4, with the DO concentration in zones 2 and 3 being a calculated value in

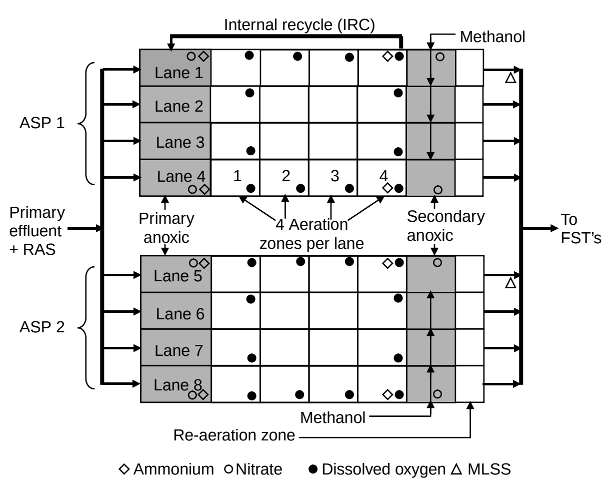

Figure 1 | Instrumentation configuration for the real time control trials.

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the existing site plc. The data for the MLSS was collected at the outlet of ASP1 and ASP 2 and the average value calculated by the RTC plc. In addition to the sensors shown in Figure 1, there was also a suspended solids sensor on the outlet of the primary settlement tanks (PST's). It is important to note that the existing site plc was the unit that controlled the site, whilst the RTC plc was the unit which generated the setpoints for the on site plc to operate with.

The initial trials were operated by controlling lanes 1 and 2 in real time control and the remaining sections in fixed DO setpoint control as a reference. Prior to the commencement of the trials, an extensive analysis of the flows entering the ASPs was undertaken to ensure that the RTC lanes and the reference lanes were receiving the same load, so as to provide an accurate comparison.

For the nitrification control, the DO setpoints for the RTC, were calculated on a feed forward basis for each individual aeration zone, using input data from the ammonium sensor in the primary anoxic zone ($mg\,l^{-1}$); the total flow entering aeration zone 1 ($l\,s^{-1}$); the temperature of the activated sludge (°C); the settled sewage suspended solids concentration ($mg\,l^{-1}$); the settled sewage COD concentration ($mg\,l^{-1}$) and the required NH_4^+-N concentration (ammonium setpoint) in the ASP effluent ($mg\,l^{-1}$). The control algorithm was based on ASM 1 (Henze *et al.* 1987) with the following input parameters being available as setpoints in the controller:

- The yield for autotrophic biomass
- Decay coefficient for the autotrophic biomass
- The ammonia half saturation value for the autotrophic biomass
- The oxygen half saturation value for the autotrophic biomass
- The maximum specific growth rate for the autotrophic biomass
- The temperature coefficient for autotrophic growth
- The temperature coefficient for the ammonia half saturation value, and
- A coefficient for the embedding of nitrogen into the biomass.

Prior to the trials commencing, extensive wastewater characterisation was performed to determine the most suitable values for the input parameters. Where these could not be assessed to satisfactory levels, well established default values were adopted. In addition to the feedforward control element, there was also a closed loop control, which used data collected by the ammonium sensor situated in the outlet of the final aerobic zone. This was used to compensate for medium term (over a few hours) deviation from the required NH_4^+-N setpoint possibly arising from model simplification or imprecise measurement.

The methanol dose was calculated by using a closed loop control based on the data collected from the nitrate probe situated in the secondary anoxic zone ($mg\,l^{-1}$); the total flow entering the secondary anoxic zone ($l\,s^{-1}$) and the required NO_3^--N concentration (the nitrate setpoint) in the ASP effluent ($mg\,l^{-1}$). The methanol dose was then calculated to deliver the stoichiometric requirement for denitrification process. The methanol dosing control assumed that there was complete mixing of the MLSS in the secondary anoxic zone.

The inclusion of a nitrate probe in the primary anoxic zone was to facilitate the control of the internal recirculation flowrate. However, at the time of writing, trials for this module of control were not complete and for the trials outlined in this paper, the internal recirculation flowrate was fixed at $350\,l\,s^{-1}$ for each lane.

RESULTS AND DISCUSSION

Installation and commissioning of the RTC system commenced in June 2008, with the trials starting in earnest in week 3 of September of the same year. The trials were implemented so that a direct comparison could be made between real time and fixed DO control by operating lanes 1 and 2 with RTC and lanes 7 and 8 with the fixed DO setpoints outlined previously. Throughout the trial period, maximum and minimum DO setpoints of $2.5\,mg\,l^{-1}$ and $0.75\,mg\,l^{-1}$ were selected for each zone of the lanes under real time control and the effluent ammonium setpoint was fixed at $1.0\,mg\,NH_4^+\text{-}N\,l^{-1}$. A comparative assessment of performance was made by observing the impact of the controller on a number of parameters including; the outlet ammonium concentration; the dissolved oxygen concentration in each zone; the dissolved oxygen setpoint in each zone; the aeration flow to each zone and the total daily air

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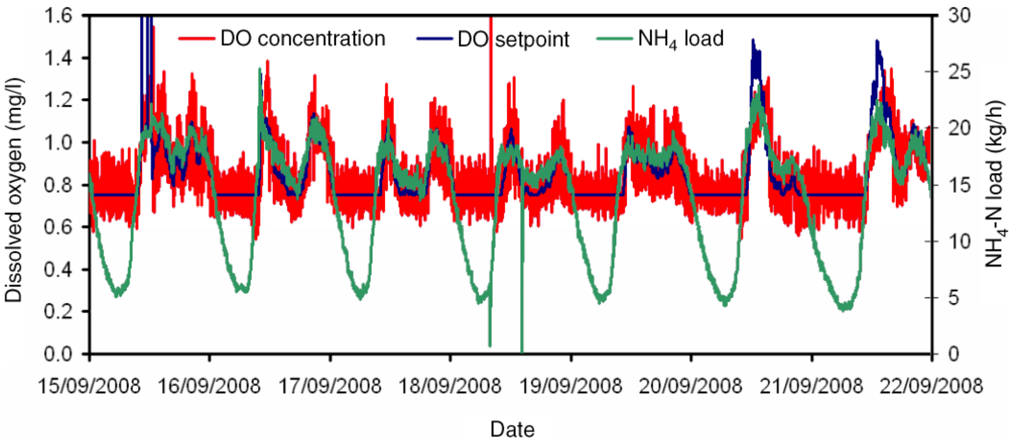

Figure 2 | Lane 1 load and lane 1, zone 1 DO/DO setpoint characteristics.

requirements for each pair of lanes. The diurnal flow profile at the site shows that the peak flow arrived at the inlet at between 10:30 and 11:00 am. The resulting load is flow proportional but there is a time lag of approximately 2 hours, with the load reaching the inlet to the lanes at between 12:30 and 13:00 pm.

If the control model was correct, the expectation was that that the DO setpoint and hence, DO concentration in the RTC lanes should follow a similar profile. That is to say that the DO concentration in each zone should be proportional to the incoming load. Figure 2 illustrates the correlation between the DO setpoint in lane 1, zone 1; the DO concentration in lane 1, zone 1 and the incoming load to the lane for the first seven days of the trial. Results show that, at loads of 14 kg NH_4^+-N h^{-1} and above, there is a strong correlation between all three, with both the DO setpoint and the DO concentration tracking the load as it increases and decreases. Below this value there is a distinct discrepancy between the DO characteristics and the incoming load. This can be attributed to 2 factors. Firstly, for each aerated zone of the ASP, there was a stipulated minimum airflow required for continual mixing and secondly there was also a minimum DO setpoint of 0.75 mg O_2 l^{-1} imposed on the control. Therefore at times of low load, the minimum airflow and the minimum DO setpoint were the overriding factors.

Results for the fixed control are markedly different, with a continual setpoint (and concentration) of 2.0 mg O_2 l^{-1} being observed in the same zone for lane 8, the master reference lane. This resulted in a significant difference

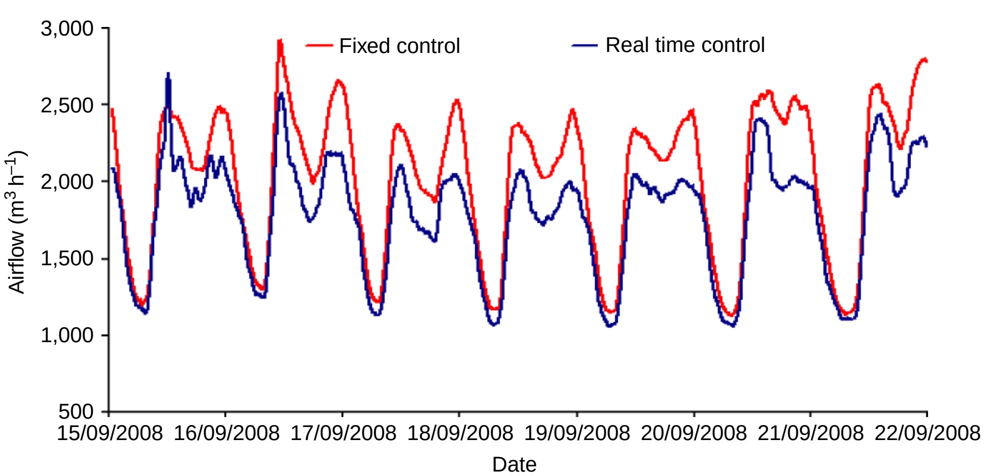

Figure 3 | Airflows for aeration zone 1 of master lanes 1 and 8.

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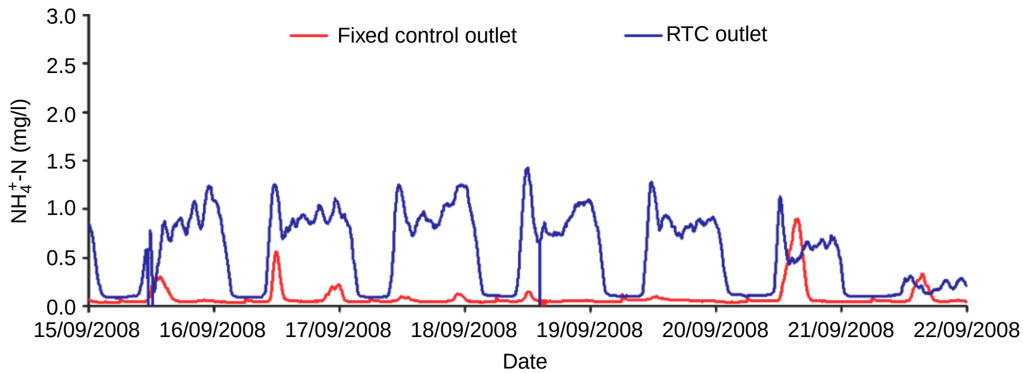

Figure 4 | Lane effluent ammonium concentrations for master lanes 1 and 8.

between the respective airflows, with considerably more air being delivered to the lane operated with fixed DO setpoints. Similar results were observed for zones 2 and 3, where there were significant reductions in the airflow being delivered to the RTC lanes when compared to the reference lanes. Results for zone 4 are somewhat different, with the DO setpoint and concentration proving to be greater in the RTC lane than in the fixed control lane. This results in significant increase in airflow under RTC control when compared to fixed DO setpoint control. The major contributing factor is the fact that in the reference lane (lane 8), the inflated setpoints in the preceding zones (1–3) resulted in a greater proportion of the load being removed than in the RTC lane (lane1). As a result, it is possible to operate at a lower setpoint in zone 4 of the reference lanes, as there is simply less load to be removed.

Even with this in mind, the resulting aggregate of all four zones shows a significant reduction in air requirements for the real time control lanes than the fixed control reference lanes. The chart below (Figure 3) shows the total daily airflow for the 2 pairs of lanes involved in the trial as outlined above, with the total reduction in airflow being consistently in the region of 20%.

As outlined previously, the ammonium setpoint under RTC was 1 mg NH_4^+-N l^{-1}, whereas, under fixed control, full nitrification was usually observed. Results show that it was difficult to consistently achieve an effluent from RTC of 1 mg NH_4^+-N l^{-1} (Figure 4). More detailed observations show that the effluent concentration from the RTC lanes was significantly affected by the periods of low load, whereby the ammonium is reduced to almost zero in the outlet. This again is a result of both the minimum DO setpoint and minimum airflow being the overriding parameters in the controller. Therefore, at times of low load, a degree of excess aeration was observed, resulting in an increased removal of ammonium. At times of peak load, the controller is much more equipped to control to the setpoint. Nevertheless, there is small number of oscillations

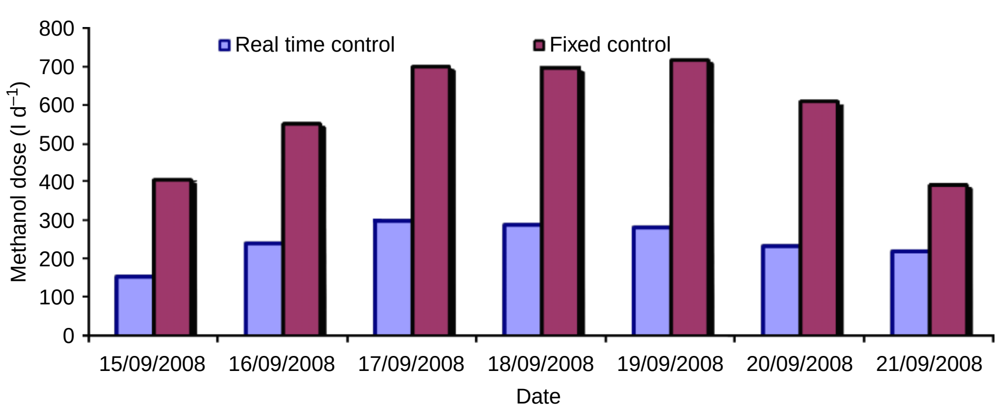

Figure 5 | Daily methanol consumption for master lanes 1 and 8.

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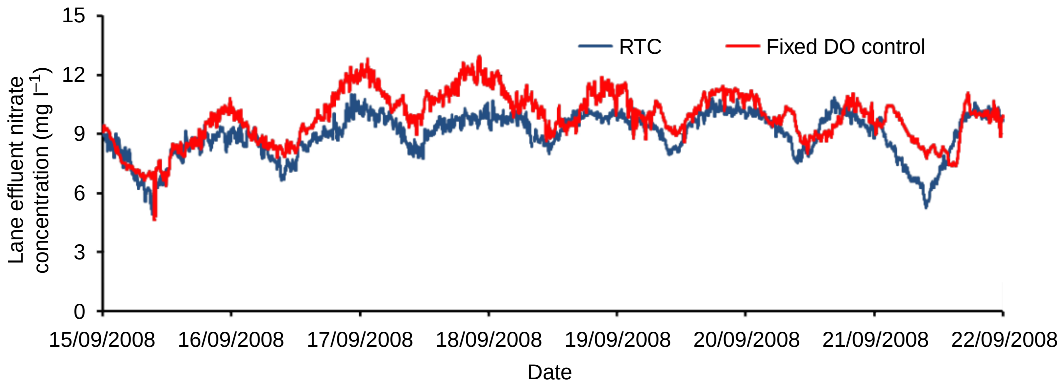

Figure 6 | Effluent nitrate concentration for master lanes 1 and 8.

in the output. There are a range of factors which could contribute to this including; a small degree of time lag between an observed increase in load and an increase in the DO concentration; small inaccuracies and approximations in the model and the attempt of the feedback controller to make correcting adjustments. In reality it is probably impossible to remove all oscillations and similar results have been observed by other authors, most notably, Vrecko *et al.* 2006. Here, the authors state that although oscillations occur, there is significantly less deviation from the setpoint using feed forward control than with any other form of control.

The effect of increased loads and the ability of the system to react to such loads can be observed in the results observed later in the trials. The ammonium concentration in the primary anoxic zone peaked at approximately 24 mg NH_4^+-N l^{-1} on 2nd November. The outputs from the RTC lane and fixed control lanes were approximately 5 and 13 mg NH_4^+-N l^{-1} respectively indicating that the RTC lane anticipated the load and increased the DO setpoint accordingly, resulting in much improved effluent quality.

Results from the methanol dosing show a significant reduction in the amount of methanol required to meet the same effluent standards observed in the effluent of the reference lanes. As with the DO control the methanol dosing followed a diurnal profile with dose rate being proportional to that of the incoming load. Results show that the methanol flow rate for the reference lane was significantly greater than that of the RTC lane for much of the day and that the relative difference increased significantly at times of peak load. Flow rates in the reference lanes commonly exceeded 20 l h^{-1}, whereas the RTC methanol dose rate rarely exceeded 10 l h^{-1}. Data collected for methanol consumption clearly demonstrates a substantial reduction in the in the daily amount of methanol consumed, resulting in an average overall reduction in excess of 50% (Figure 5), whilst maintaining a comparable effluent nitrate concentration (Figure 6).

The reduction in methanol utilisation can be attributed to 3 factors. Firstly, the lower DO concentrations in the RTC lanes facilitated the process of simultaneous nitrification/denitrification, leading to a reduction in the amount of nitrate to be removed in the secondary anoxic zone. Secondly, in aeration zone 4, much more of the available DO was utilised as the RTC system carried a greater load into the final compartment and as a result, less DO was returned to the primary anoxic zone. Finally, the establishment of an ammonium effluent setpoint resulted in less nitrate production than in the fixed control system, hence there was less methanol required for nitrate conversion.

CONCLUSIONS

During the trials a large amount of data was collected to assess the performance of the RTC for both aeration and methanol dosing control. Results clearly indicate that it is possible to operate at much lower DO concentrations for much of the time than fixed control systems whilst still maintaining the required effluent quality. Over a trial period of 10 weeks it was possible to show that consistent reductions in aeration of 20% were possible with a corresponding methanol utilisation of 50% being observed.

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In addition to this the trials also demonstrated the ability of feed forward control systems to significantly reduce the impact of abnormally high loads on the effluent quality. Indeed, were there not a maximum DO setpoint, this effect would have been more pronounced. The implementation of RTC systems for the control of the activated sludge systems offer the opportunity significantly improve the operational efficiency of a plant, providing a long term sustainable solution.

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