CARDIFF WWTW AERATION OPTIMISATION THROUGH SCIENTIFIC CONTROL

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ABSTRACT

Aeration optimisation of a 16 basin SBR plant running in ICEAS (Intermittent Cycle Extended Aeration System) mode was under taken by changing the operating parameters from the traditional design of dissolved oxygen (DO) control to a scientific approach using respirometry. Measuring the critical oxygen point for carbonaceous and nitrification bacteria and combining this with in-situ Oxygen Uptake Rate measurements forms the basis of supplying only the correct levels of oxygen for the required amount of time to break down the influent BOD and Ammonia levels. These measures can be used to calculate when treatment is complete and therefore tailor the energy requirements of the site to suit the aeration supply needs. The resultant changes have led to sustainable operational savings of over 20% of aeration energy consumption and reducing carbon emissions whilst maintaining compliance.

KEY WORDS

Aeration, AS Bioscope, energy, oxygen, respirometric, Strathkelvin, sustainable, uptake

INTRODUCTION

This paper will discuss an overall product model that combines a number of pieces of equipment, the expertise of scientists and consultancy support to optimise the aeration process of the activated sludge treatment plants of Cardiff & Afan WwTW, and initial investigations of other top energy sites. This was achieved using an innovative, cutting edge technology saving Giga Watt hours of energy and assisting Dwr Cymru Welsh Water (DCWW) & Kelda Water Services (Wales) (KWS(W)) in reducing their Carbon footprint. The scientific equipment used by the project was obtained from Strathkelvin Instruments along with their consultancy support working together with the KWS(W) Operations and scientific project teams to deliver savings.

Balancing supply and demand and ensuring sustainable methods is vital to the future of our environment. Water companies use many different methods to treat sewage. One method that is used is Activated Sludge treatment; this has a massive energy demand as air is pumped from large blowers into the treatment process. All sewage has an oxygen demand and it is this demand that we want to supply. The treatment process uses bacteria which biodegrade the incoming sewage as food and removes the organic carbons and ammonia from the sewage. It is essential that they receive a supply of oxygen, else they cannot respire resulting in them dying and resultant discharge of untreated sewage to the environment. Therefore to ensure treatment is complete an excess amount of air is pumped into the process, which can be very inefficient and costly under existing methods of dissolved oxygen control. With the prospect of increasing power prices, and the importance of reducing carbon emissions a sustainable solution to this problem must be found.

PRODUCT MODEL

The product model involved a scientific approach to measuring the baseline results, boundaries and the scope for change for optimisation by understanding the normal operating conditions of the plant. Once these parameters were identified, a step by step optimisation programme with built in safety margins could commence through the changing of these operational conditions. The model enables us to make changes in real time and provide a quick feedback response with immediate management of risk to compliance.

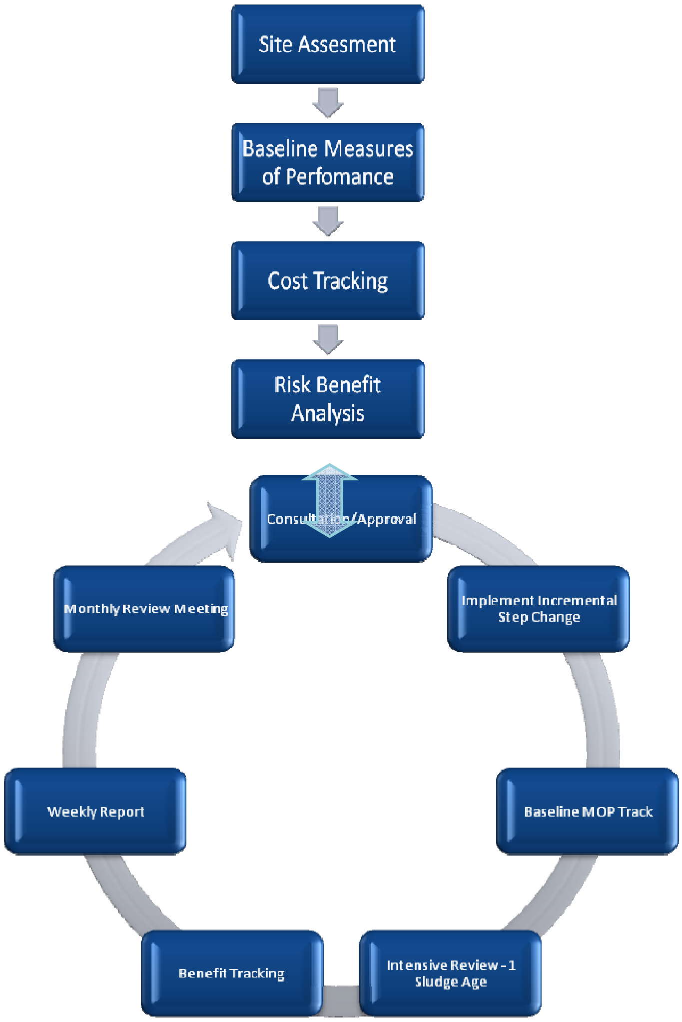

Figure 1: The product model showing the process that was followed in developing the optimisation process at Cardiff WwTW

The two main pieces of equipment used during the trial and implementation of the product model were the Strathtox and AS Bioscope. The Strathtox is laboratory based and is used to conduct a range of temperature controlled tests on activated sludge samples, so it can mimic the conditions of the treatment process. It is portable so that it can be used on other sites to determine the individual treatment process characteristics. The AS Bioscope is used in-situ in the activated sludge plant and can be used to measure the Oxygen Uptake Rate (OUR) and dissolved oxygen (DO) over a range of varying site conditions such as loading and temperature.

Figure 2: Picture of an AS Bioscope

Figure 3: Picture of a Strathtox

The AS Bioscope and Strathtox testing used in conjunction with each other, provide the following vital information before starting the optimisation process:

- Critical Oxygen Points tests – minimum level of dissolved oxygen required
- Respiration rates - rate of oxygen consumption for biodegradation
- Oxygen uptake rates – actual oxygen consumed
- Biochemical oxygen demand (short term) – level of treatment
- Carbonaceous / Nitrification inhibition – measurement of toxicity
- % Nitrification rates – amount of Ammonia which can be degraded
- Bacterial Health monitoring tests – quality of population

These features provide us with the information on the level of oxygen required for maintaining the process and measuring the amount of oxygen that is wasted. The Strathtox & AS Bioscopes have the facility to measure the actual design parameters of the plant such as percentage oxygen used separately by carbonaceous and nitrifying bacteria.

The project was started with the potential of saving 30% of aeration costs, which for Cardiff WwTW was around £300K. The savings would reflect in reduced operating costs, and CO_2 emissions giving better value for all DCWW customers.

A key feature of the product model was the transfer of knowledge between the consultancy staff from Strathkelvin Instruments and KWS(W).

Trial and Optimisation Process

This started with an initial assessment followed by a three month trial project from July 2008 on two of the 16 SBR treatment basins at Cardiff WwTW and consequently the start of the implementation process with full roll out by March 2009. We achieved this by implementing a team to join both Strathkelvin's knowledge of their equipment and its application, with KWS(W) operational knowledge of the treatment plant to deliver a specific optimisation process.

The initial testing carried out before the trial in July showed that optimisation was possible on the site at Cardiff and therefore during the trial period on two of the sixteen basins, the product model was followed introducing a step change program. The key to the step change program was calculating the critical oxygen points for both carbonaceous (BOD consent) and nitrification (ammonia consent) bacteria to provide us with our optimisation boundaries for the implementation process.

Figure 4 shows all the factors that were considered before optimisation can be implementated, but it is important to note that optimisation is only possible within the design constraints of the existing treatment plant. Each one of the points are important in maintaining compliance of the site and understanding the optimisation process.

Figure 4: Optimisation Factors, Cardiff WwTW Operation

The plant was designed by ITT for a population equivalent of 880,000, the EA consent conditions are 50 mg/l BOD, and 20 mg/l Ammonia, with a Upper Tier of 250 mg/l Total Suspended Solids. Urban Waste Water Conditions also apply at Cardiff WwTW with consent limits of 25mg/l BOD and 125 mg/l COD. The site treats a maximum flow of 523,584m^3/day.

The incoming sewage enters the Sequenced Batch Reactor (SBR) plant via four inlet screens, and then fed via the distribution system to the treatment process. The plant has 16 basins split equally into two phases which then aerates the incoming sewage for a set amount of time prior to the next stage in the process of settlement before finally the clean liquors are decanted off to be discharged into the Bristol Channel 4.5km off-shore. In each flow mode aeration lasts for 50% of available cycle time, settlement for 25% and decant for 25%.

DISCUSSION

The graph below (figure 5) shows the difference between the carbonaceous and nitrification critical oxygen point. Under traditional parameters of Activated Sludge the plant would normally be set up to control to 1mg/l and 2mg/l of oxygen respectively. The critical oxygen point at Cardiff WwTW for carbonaceous bacteria was calculated to be 0.8mg/l and the critical oxygen point for the nitrifying bacteria was 3.5mg/l (see figure 5). When the air being supplied to the treatment process increases the dissolved oxygen well above the critical oxygen point for either carbonaceous or nitrification excess energy is being used to deliver air that is not required for treatment, (shown in the below graph as energy waste). Figure 5 also shows that if the amount of air being supplied to the treatment process falls below a certain level it can cause bacteria stress resulting in the treatment process being affected and risking compliance. Therefore by calculating the critical oxygen points linked with the optimisation features outlined in figure 4 gives us our product model boundaries creating a sustainable method of aeration optimisation by controlling air flow into the treatment basin.

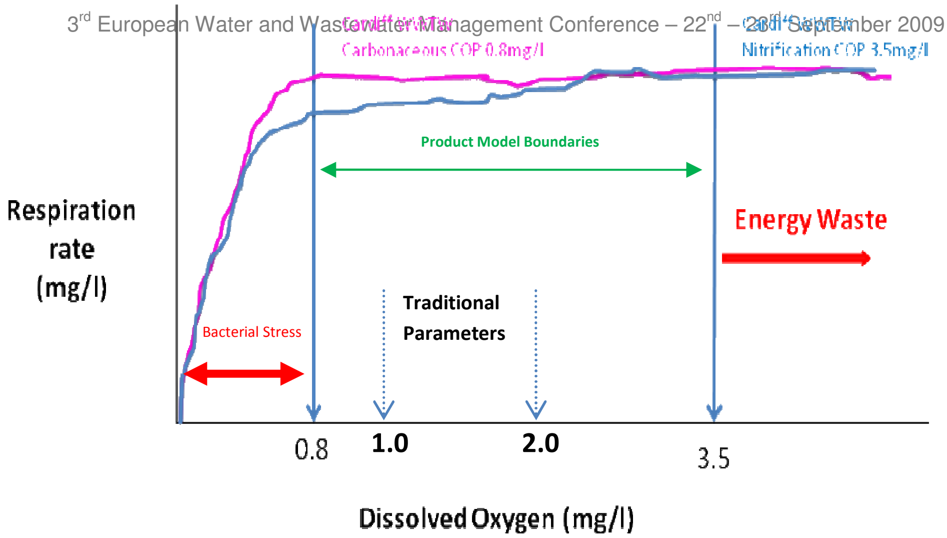

Figure 5: Cardiff WwTW Respiration Rate vs. Dissolved Oxygen depicting Critical Oxygen Points

The critical oxygen point shows the minimum level of dissolved oxygen required by the bacteria for ingestion, respiration, growth and division and therefore it is vital that the correct amount of air is delivered to the treatment basins. If the amount of oxygen is below the critical oxygen point the bacteria will become inhibited and will not be able to grow, therefore treatment and compliance will be affected or lost completely. During the project the critical oxygen point was calculated for both the carbonaceous and the nitrifying bacteria, this is important as carbonaceous bacteria break down the Biological Oxygen Demand (BOD) first as these molecules are smaller and therefore are much easier and quicker to break down and require a lower amount of oxygen to complete this task. The nitrifying bacteria absorb up the ammonia that is within the incoming sewage and oxidise the ammonia to provide energy required for growth, this process is known as nitrification. This process is carried out by two different species of bacteria *Nitrosomonas* which oxidise ammonia to nitrite and the second species *Nitrobacter*, which oxidises nitrite to nitrate. This process of ammonia oxidisation requires an increased amount of oxygen as this process is relativity inefficient chemical oxidation and therefore requires a greater amount of oxygen giving a higher critical oxygen point.

Once this stage was completed ammonia and short term BOD profiles were conducted on the two trial basins to understand the flow distribution of untreated sewage across the basin, due to us running in ICEAS (Intermittent Cycle Extended Aeration System) continuous feed mode. Biodegradation rate profiling is normally carried out on plants that operate with a continuous flow footprint or on a time basis for SBR's. However an SBR operating in ICEAS mode requires assessment against both a continuous flow footprint and time basis. In addition the basins need to be assessed during settlement and decant to determine the extent to which untreated influent infiltrates the basin.

It was decided that measurements should be sampled across what the site operators determined to be the best case (Basin 6a) and the worst case (Basin 2a) scenarios. During the settlement and decant phases of the cycle samples were gathered on a time and footprint basis. These samples were returned to the laboratory and tested for Ammonia expressed as N levels and the level of BOD determined using the BOD (short term) protocol provided by Strathtox system using basin Endogenous settled activated sludge. These would give a measure of how far the untreated load progressed across the lagoon during non-aerating cycles.

The data gathered during aeration, settlement and decant cycle, identified little change in BOD load during the non-aerating phase of the cycle. This data would support a theory that the influent flow is laminar along the bottom of the basin during this part of the cycle giving increased opportunity to extend this part of the cycle time.

Figure 6 shows an example of the biodegradation profile of basin 5a at Cardiff WwTW on 23rd October 2008 in winter normal flow with an aeration time of 108 minutes. It can be seen that treatment is complete when the OUR (red line) flattens out. This is indicated on the graph by the vertical black dotted line (also seen in figures 7 & 8). The biodegradation profile was repeated over many different aeration cycles covering different flows to assess all conditions.

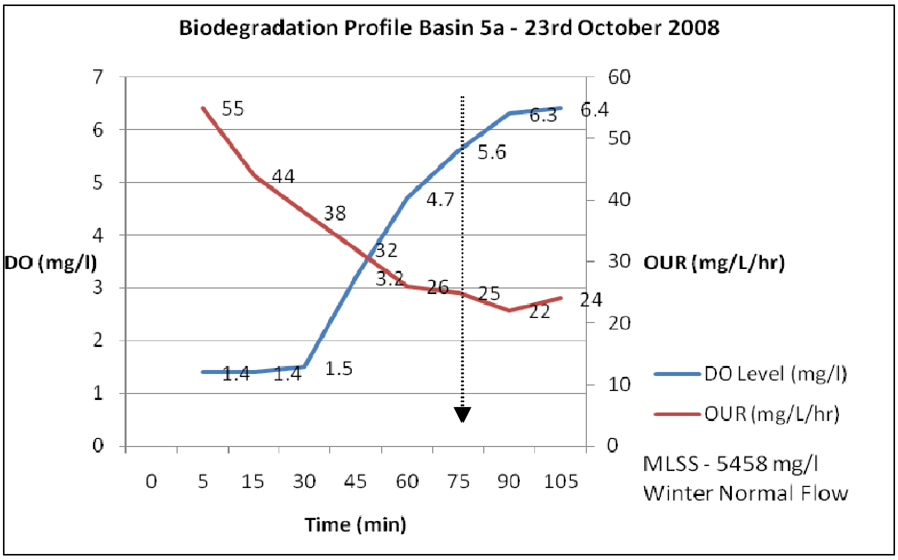

Figure 6: **An Example of a Biodegradation Profile in Winter Flow Mode**

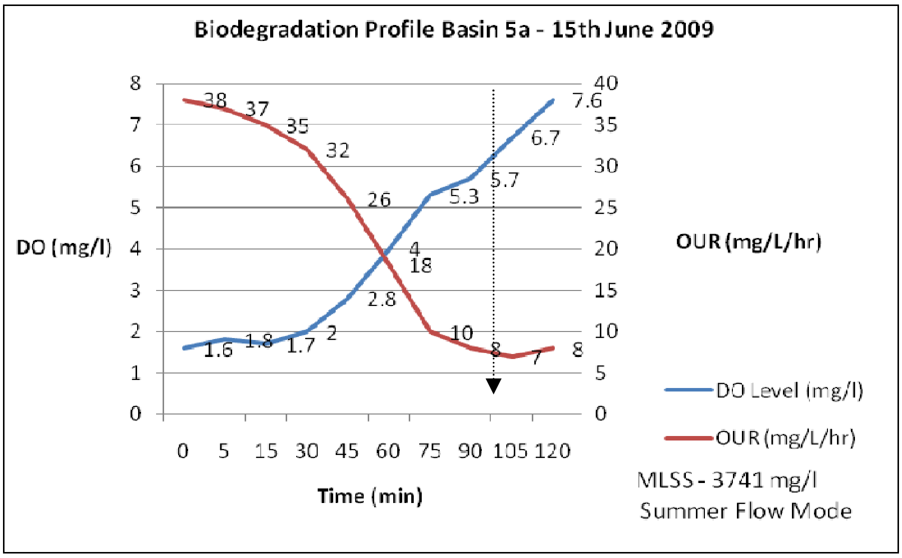

Figure 7: **An Example of a Biodegradation Profile in Summer Flow Mode**

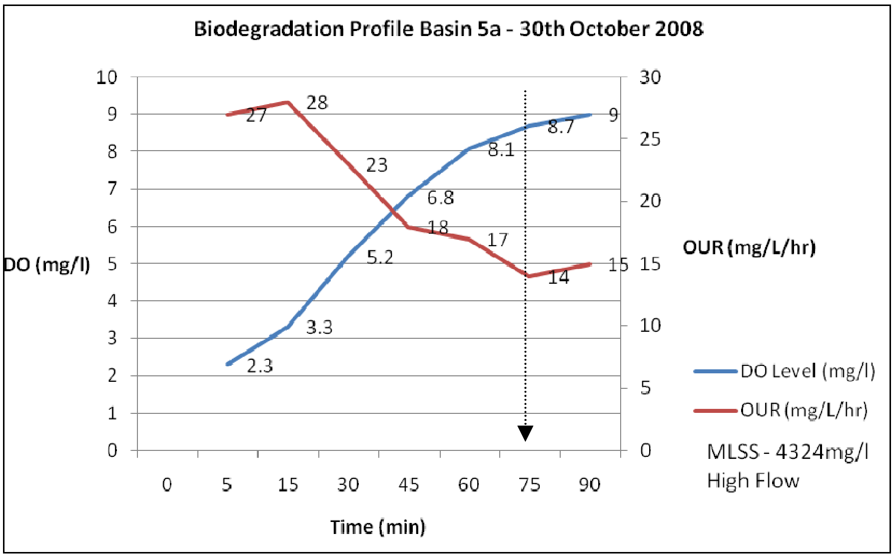

Figure 8: An Example of a Biodegradation Profile in High Flow Mode

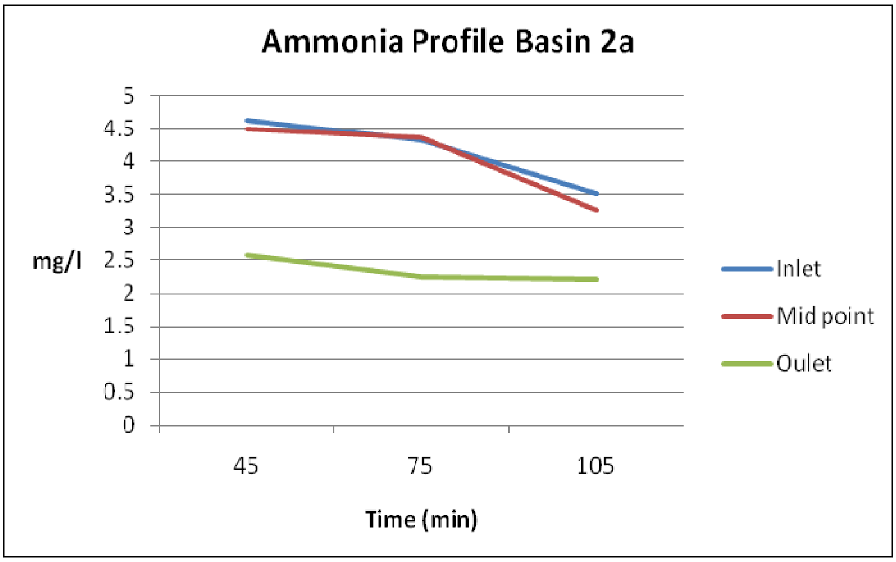

Figure 9: Ammonia profile across the basin over the aeration cycle

This graph in figure 9 shows the reduction in Ammonia concentration across the aeration cycle. Inlet Ammonia levels were 12mg/l and combined discharge sample was measured at 4mg/l.

Linking the data collected from the ammonia and BOD (short term) tests with the biodegradation profiles collected using the AS Bioscope determined that the aeration cycle time could be reduced initially by 16% with a built in safety factor.

By tailoring to the needs of the bacteria we have created a sustainable method of operational control for aeration, resulting in reduced operational expenses, energy consumption and CO_2 emissions. Since the introduction of respirometric control at Cardiff WwTW aeration cycle time under high flow mode and winter flow mode has been reduced by 15 minutes and 18 minutes respectfully, with the potential to reduce the aeration cycle time during summer flow mode by 20 minutes.

In addition further savings are predicted following the summer flow mode which is still to be assessed due to poor weather conditions during summer 2008 and the re-introduction of the RAS (Return

Activated Sludge) control option which will enable us to utilise another 10% of basin volume, enabling further aeration reductions.

Benefits & Developments

The trial started in July 2008 for three months and from the end of September 2008 the product model was rolled out to the remaining 14 treatment basins at Cardiff WwTW. By the end of December 2008, 50% of the site had the reduced cycle time implemented into the SCADA system. The roll out continued until the end of March 2009. Due to the success at Cardiff WwTW the product model was used to investigate the remaining top energy usage sites to see if there was any possibility of optimisation, and so far Afan WwTW has had 6 out of 8 basins optimised.

The unique feature of the AS Bioscope is that it uses real time monitoring and site specific and that it can measure the oxygen uptake rate of the micro-organism within the treatment process within a matter of minutes, meaning that any optimisation program is unique to that site taking into account the process loading conditions. The Strathtox has unique software that calculates the critical oxygen point which is key to developing an optimisation program as you can see what the bacteria are doing, "taking the guess work out of optimisation". Also the AS Bioscope was new to the market, Strathkelvin Instrument Ltd. had newly developed this technology/concept and KWS(W) was the first water company to use this full product model linking the data from the Strathtox, AS Bioscope and the company's experiences to develop the optimisation product model.

The unique feature is that the whole product model is a new innovative approach to activated sludge treatment process. The main reasons for this product model being such a success are;

- New Innovative Approach
- Delivering sustainable energy savings & reductions in carbon footprint.
- Process Optimisation based on scientific approach giving confidence in changes introduced.
- Managing compliance at every step in the process, by supplying the actual oxygen demand to meet final effluent Compliance
- Better performance measurements of Activated Sludge plants.

The key non-financial benefit to the business is that by tailoring oxygen supply to the needs of the bacteria we have reduced the amount of carbon emissions of the site. Therefore by calculating the critical oxygen point and using the oxygen uptake rate, we have delivered a more sustainable method of managing the treatment process providing more for less and ensuring compliance (see figure 10).

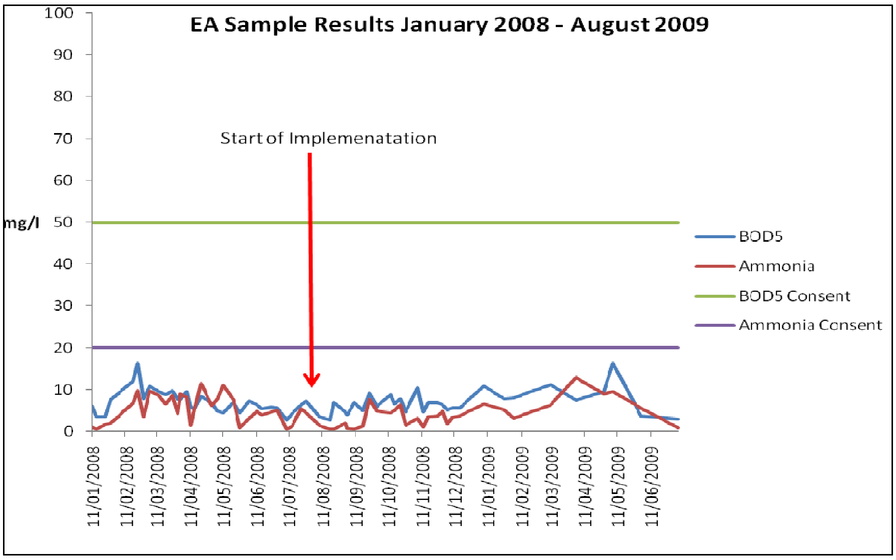

Figure 10: Cardiff WwTW EA Sample Results

Through respirometeric control, the team has delivered an annual 5.7 GWh reduction in aeration energy costs equating to 26% energy saving on Cardiff WwTW and Afan combined, Cardiff alone saves 3.9 GWh. The total Carbon dioxide emissions have been reduced by 2994 tonnes per year, equivalent to driving around the world 1300 times. This saving plus the potential further roll out to other KWS(W) sites around South Wales has a demonstrable saving to the customer Dwr Cymru Welsh Water (DCWW). In addition the DCWW initial investment has a six month pay back. Figure 11 shows each area of the optimisation program that has contributed to the 3.9GWh saved at Cardiff WwTW and the annual carbon emissions saved and remaining carbon emissions.

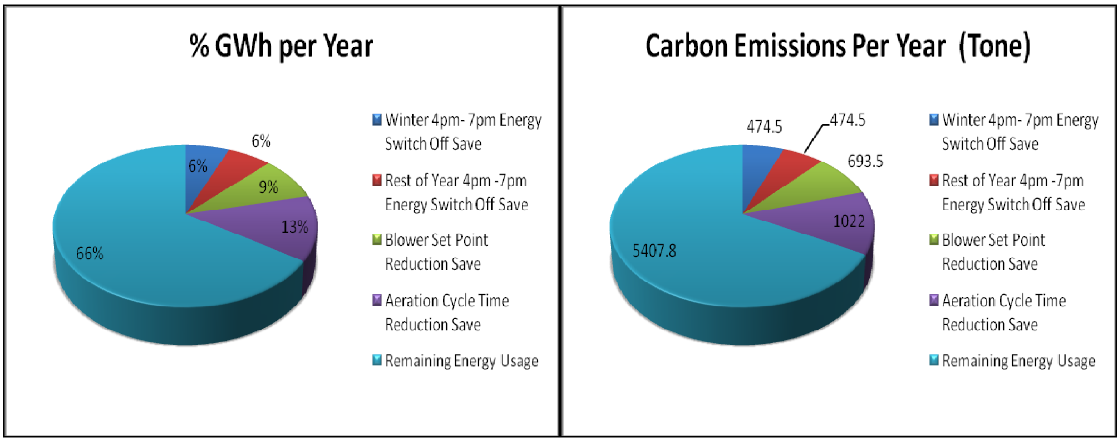

Figure 11: Annual Percentage Energy and Carbon emissions

Also another benefit is that the transfer knowledge has been retained within the company for future development of the product model, as well as KWS(W) staff development. The transfer of knowledge has also been shared in the wider KWS business, UUOS and the other AMA partners for use with other project development and process, and the Strathtox is being used to assess the impact of the centrate from our Advanced digestion projects on our activated treatment process, and helped assess impact of toxicity threatened by third party intervention.

CONCLUSION

The respirometric method of controlling the aeration at Cardiff WwTW is leading the way in developing a new operating control philosophy for KWS(W) by implementing a new more for less way of working by saving energy, reducing operational costs and CO_2 emissions, whilst also ensuring compliance. Delivering a project with a six month payback also goes beyond company requirements and achieving benefits in three areas of the business; by reducing the energy usage for the site this drives down the operational expenditure for KWS(W) which reduces the cost for their client Dwr Cymru Welsh Water (DCWW) and in turn DCWW can demonstrate that they are using their customer's money more wisely and that they are striving to operate a greener business by reducing energy usage and carbon emissions. Therefore this project also helps Dwr Cymru Welsh Water achieve their company policy by reducing the amount of energy that is required for the aeration treatment of any incoming sewage. This method of optimising the bacterial treatment process not only saves energy and money at Cardiff WwTW but the project can be adapted and changed to suit any style of Activated Sludge treatment, limited only by the existing design parameters.

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