



Ramon BUÑOL i TORDERA

IMPROVE THE ENERGY EFFICIENCY OF A FULL
SCALE INTEGRATED FIXED FILM ACTIVATED
SLUDGE (IFAS) PROCESS AT THAMES WATER
OXFORD WWTW

SCHOOL OF WATER SCIENCE
MSc THESIS
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Supervisor: Bruce Jefferson, Kieran Healey, Angela Barugh

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Dedicated to the late Ramon, Joan and Consol. When I was flagging, whenever I doubted my way, I always felt you close to me.

Dedicat als meus absents, Ramon, Joan i Consol. Sempre que m'he sentit flaquejar, sempre que he dubtat en el meu camí, sempre us he sentit recolzant-me al meu costat.

Abstract

The primary objective of integrated fixed film activated sludge (IFAS) is to remove dissolved pollutants from wastewater. This process allows an increased treatment capacity in comparison with conventional activated sludge. Thames Water has been operating a full scale IFAS biological process demonstration lane of 870 m³ at the Oxford wastewater treatment works for over two years.

The aim of this study was to evaluate the benefits of using an ammonia feed back control system as an alternative to a conventional set point dissolved oxygen control in order to improve energy efficiency in the aeration system. The main finding was that the adjustment of dissolved oxygen (DO) set points regulated by the feedback control system resulted in periods of excess or deficiency of DO in the wastewater with an total over aeration of 14.7 % and under aeration of 9.8 %. Investigation into the causes of the deviations found that the speed of the control equipment was unable to match the responsiveness of the control set point leading to periods where the air control valve was either too open or too closed.

A linear equation was established to relate the influent wastewater flow with the time taken by the ammonia to be detected in the settled sewage stream in the IFAS process lane. Thus a feed forward control philosophy was suggested to control the aeration system, as opposed to the feed-back control system in order, to improve the target DO set point.

Alongside this study, a comparison of the energy costs between IFAS with the ammonia feed-back control philosophy and a conventional activated sludge set point DO control system was completed. The analysis found negligible difference between the two processes. In addition when compared to the calculated design aeration requirements for set point DO control for the observed actual oxygen required (AOR) loadings, it was found that operating the IFAS system in NH₄-N feed back control requires significantly less air. It can therefore be concluded that, with further research, the IFAS process can still be optimised to reduce aeration energy costs.

Executive summary

Introduction

Modern demands on the design and construction of new wastewater treatment works (WWTW) are becoming ever more rigorous due to increasingly stringent discharge consents (European Parliament, 2000) (European Communities Directive, 1991) (European Communities Directive, 1978) and increasing urban populations (National statistics, 2009).

The challenge to find space for the construction of these new treatment works has demanded research into new techniques to reduce the footprint for wastewater treatment processes.

One solution is to use existing assets and to improve their performance by upgrading with new technologies. The integrated fixed film activated sludge (IFAS) process offers the possibility of increasing treatment capacity for existing wastewater treatment plants by placing the support media into the aeration zone or reducing tank volumes for any new construction (Ødegaard et al., 1999).

There are several types of support media used for the biomass to adsorb in the activated sludge process. They include dispersed media and fixed media, such as structured or knitted fabric media placed in the aeration basin (Weerapperuma et al., 2005).

Dissolved oxygen is required for the respiration of aerobic microorganisms. There are two main systems of dissolved oxygen (DO) control in wastewater systems: the conventional dissolved oxygen set point control system and the ammonia feed back control system.

The dissolved oxygen set point normally operates in an activated sludge (AS) process with DO set point of 2.0 mg/l. In the ammonia feed back control system utilises online monitoring of both ammonia and nitrate for the feedback loop and DO for determining set point band, this zone normally operates in IFAS process with DO set point of 2 mg/l to 4.5 mg/l.

Objectives

This project will focus on the follow objectives:

- Characterise influent and effluent flow and load of wastewater and final effluent.
- Monitor energy consumption in kWh of IFAS system in comparison with activated sludge system and recommend improvements for energy efficiency as much as possible.
- Test nitrification rates of biomass on plastic media and in the MLSS (mixed liquor suspended solid) of IFAS system and compare with MLSS of conventional activated sludge system.

Experimental methods

For the purpose of this study a full scale IFAS process and conventional activated sludge plant at Oxford wastewater treatment works were used to compare the two systems in terms of process performance and energy efficiency.

NH₄-N feed back control was used in the IFAS process as opposed to a DO set point control used in the activated sludge process.

Conclusions

Over a two month study, the principle conclusions are as follow:

- Compared to the calculated design aeration requirements for set point DO control for the observed AOR loadings, the IFAS system in NH₄-N feed back control requires 24 % less air.
- The power consumption per m³ of influent treated and kg AOR loading are comparable for the IFAS under feed back control and the AS process under DO set point control.

- An analysis of the feed back control operation indicates that there is an excess and deficit of DO in the tank due to a different demand of air flow to the target set point. As a consequence the feed back control system is not operating as efficiently as it could.
- Data analysis indicates that the reason for the this extra/deficit air flow consumption is because the air delivery supply system does not operate quickly enough to respond to system demands. In particular the valve positioning is frequently in the wrong position.
- Prediction of ammonia load to the works will allow feed forward control of aeration system as opposed to feed back control. The efficiency of the $\text{NH}_4\text{-N}$ feed back control system would benefit from future research in development of feed forward control.
- By optimising the $\text{NH}_4\text{-N}$ control system further improvements in aeration efficiency could be obtained to those already indicated by the comparison with DO set point operation. Further investigation into this area is recommended.

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Acronyms and nomenclature

AC:	Advanced control strategy
AS:	Activated sludge
BAF:	Biological aerated filters
BOD:	Biochemical oxygen demand
COD:	Chemical oxygen demand
DO:	Dissolved oxygen
F/M:	Food: microorganism ratio
H-IFAS:	Hybrid Integrated Fixed Film Activated Sludge
HRT:	Hydraulic retention time
IFAS:	Integrate fixed film activate sludge
IR:	Internal recycling flow
MBBR:	Moving Bed Biofilm Reactor
MBR:	Membrane bioreactors
MCRT:	Media cells residence time
MLSS:	Mixed liquor suspended solids
NPV:	Net present value
O&M:	Operation and maintenance
RAS:	Returned activated sludge
SRT:	Solids retention time
SS:	Settle sewage
TKN:	Total Kjehldahl nitrogen
TN:	Total nitrogen
WWTW:	Wastewater treatment works

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1. INTRODUCTION

In both municipal and industrial wastewaters significant quantities of BOD₅ and total nitrogen can be found, with typical concentrations of 190 mg/l and 20-70 mg/l respectively. One of the important aims in the last thirty years in waste water technology has been to remove these contaminants. In order to remove ammonia in the waste water treatment plants, biological or physic-chemic processes are used. The advantage of the biological processes are: there is a lower production of sludge, the sludge can be reused in agricultural applications and there is a better public perception as an environmental friendly system in comparison with chemical procedures. Biological processes for BOD and nitrogen removal are generally referred as biological nutrient removal (BNR) (Oldham et al., 2002).

Activated sludge is accepted as the more common process for the removal of dissolved organic matter and nitrogen in industrial and municipal wastewater. The removal of nitrogen in the activated sludge tank is achieved through two continuous reactions; nitrification and denitrification (Oldham et al., 2002). Nitrification is the biological oxidation of ammonia to nitrate/nitrite by two genera commonly noted autotrophic bacteria, *Nitrosomonas* and *Nitrobacter*, which oxidize ammonia to nitrite and then to nitrate, both taking place under aerobic conditions. Denitrification is the biological reduction of nitrate/nitrite to nitrogen gas that takes place in anoxic conditions. Bacteria capable of denitrification are commonly genera *Achromobacter*; *Aerobacter*; *Alcaligenes*; *Bacillus*; *Brevibacterium*; *Flavobacterium*; *Lactibacillus*; *Micrococcus*; *Pasteurella*; *Proteus*; *Pseudomonas*; *Spirillus*. *Pseudomonas* species are the most common and widely distributed of all the denitrified (Metcalf & Eddy et al., 2003)

Integrate fixed film activate sludge (IFAS) is a wastewater treatment process that takes a conventional activate sludge wastewater treatment system adding some form of support media to promote the development of slow growing bacteria, such as nitrifiers (Rutt1 K. et al., 2006).

IFAS technology has been used both in municipal as industrial waste water treatment plants. The primary objective of IFAS process is to increase treatment capacity or reduce tank volumes when included in new plant design (Rutt1 K. et al., 2006).

There are several types of support media used to fix the biomass in the activated sludge basin. They include dispersed plastic media submerged in the aeration basin, and fixed media, that is placed in the aeration basin.

Plastic media submerged in the aeration basin is now available from several manufacturers. The two types where media is used are the Moving Bed Biofilm Reactor (MBBR), and IFAS. The same media can be used in both processes the difference being that IFAS process has a return activated sludge recycle and MBBR process does not (Phillips et al., 2005).

MBBR and IFAS processes began using sheets of asbestos in the 1930s and 1940s, from this point systems developed to using plastic media in the 1960s, and rope media in the 1970s (WEF, draft under publication). The technology of submerged plastic media was developed in Norway in the mid-1980s (Phillips et al., 2005). The “moving bed biofilm process” was developed between university (Norwegian University of Science and Technology-NTNU) and industry (the Norwegian company Kaldnes Miljøteknologi AS-KTM). Kaldnes Miljøteknologi AS was bought by Anglian Water in UK in 1995, later was bought by Anox AB in 2002 forming AnoxKaldnes AS in 2004 and finally was acquired by Veolia Water Solutions & Technologies in 2007 (Ødegaard H. et al., 1999).

The implantation of the IFAS process is now in several full scale plants (Rutt1 K. et al., 2006), the improvement of the treatment capacity is widely demonstrated. The question is –when is IFAS the better choice (Johnson et al., 2006).

The selection of appropriate treatment schemes for wastewater treatment plants is controlled by several factors and perhaps the most important are economic.

2. LITERATURE REVIEW

2.1 MBBR design systems

The moving bed bioreactor (MBBR) technology uses one reactor for aerobic and one reactor for anoxic processes. In the aerobic processes the carriers are kept in suspension by the introduction of air from aeration diffusers, while in anoxic processes a mixer provides the energy to keep the carriers in movement (Veolia Water Solutions & Technologies, 2008a).

The AnoxKaldnes MBBR technology is flexible and can be used in many different configurations. In addition to being used for secondary treatment, the MBBR can also be used as pre-treatment, post-treatment or when the support media is added in the mixed liquor of activated sludge process also named integrated fixed film activated sludge (IFAS) (Veolia Water Solutions & Technologies, 2008a).

MBBR as sole biological treatment

A schematic of this treatment process is showed in the figure below. It has the follow features:

- No returned activated sludge (RAS) required
- Not backwash cycles required
- Can be coupled with most types of solids separation

The application areas are:

- Used for organic removal
- Used for nitrification and denitrification

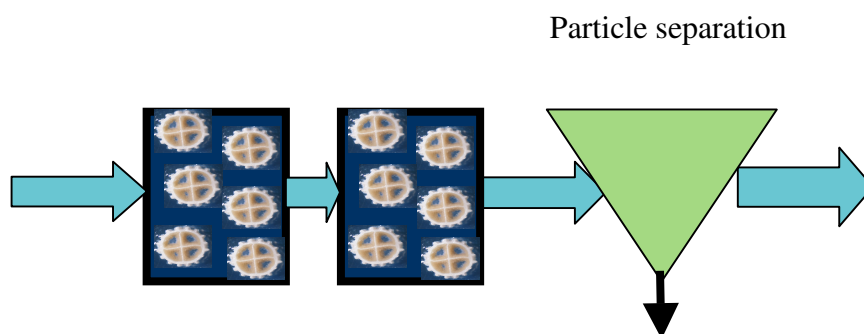


Figure 2-1: MBBR as sole biological treatment

The MBBR process can also be coupled with an activated sludge plant to give an MBBR/AS process (Veolia Water Solutions & Technologies, 2008a).

MBBR as pre-treatment

This configuration consists of one or more MBBRs, followed by an activated sludge system. The high-rate biofilm stage is designed to pre-treat the wastewater to remove the readily biodegradable organic matter prior to the activated sludge plant.

MBBR pre-treatment has the follow features:

- 2-3 times higher capacity than conventional activated sludge
- Removes 50-70% of biochemical oxygen demand (BOD)
- Improved activated sludge operability and dewater ability
- Decrease of 30-50 % bio sludge production
- Improved tolerance to variations and disturbances

The application areas are:

- Used for organic removal
- Used for nitrification and denitrification

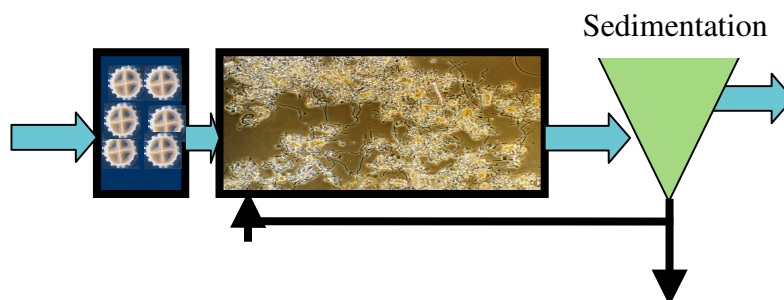


Figure 2-2: MBBR as pre-treatment

MBBR as post-treatment

It entails a supplementary MBBR biofilm stage after the aerated lagoon. In the aerated lagoon organic content is removed and nitrification may also take place.

The application areas are:

- Used for organic removal
- Used for nitrification and denitrification

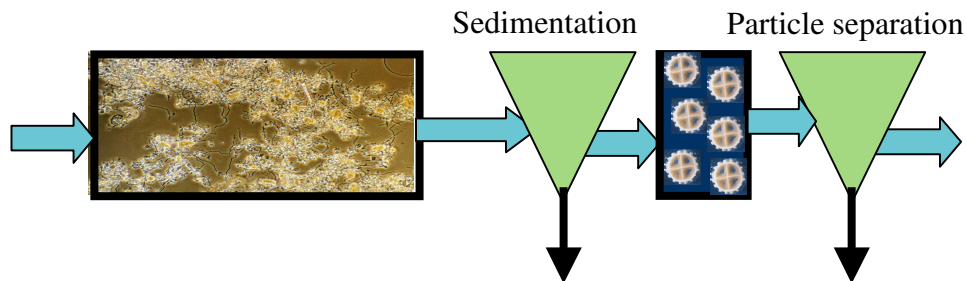


Figure 2-3: MBBR as post-treatment

MBBR in activated sludge (IFAS/Hybas™)

The schematic of this treatment process is showed in the figure 2-4. It has the follow features:

- IFAS process utilises both suspended and attached growth within the same reactor
- Nitrification takes place mainly in the biofilm whereas BOD_5 removal and denitrification takes place in the suspended sludge
- Can be coupled with most types of solids separation
- The sludge age of the activated sludge can be kept short. A short sludge age has the benefit of higher specific carbonaceous activity and excludes growth of filamentous bacteria

The application areas are:

- Used for organic removal
- Used for nitrification and denitrification
- It is also possible to include enhanced biological phosphorus removal
- Nitrogen removal in much smaller volumes than for a conventional activated sludge plant

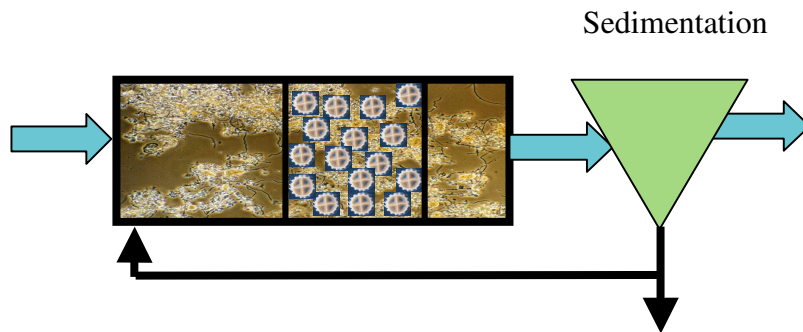


Figure 2-4: MBBR in activated sludge

MBBR Disadvantages:

- Requires an efficient screening pre-treatment
- Low retention time in the reactor therefore little hydrolysis of suspended solids
- The outer biofilm is continuously being renewed due to abrasion; hence the sludge age of this part of the biofilm is low. The sludge leaving the reactor with the effluent is not stabilized
- Risk of the outlet screen being clogged by the carriers
- Cost of the carrier and outlet screens
- Energy consumption can be higher than with conventional AS plants due to higher operating dissolved oxygen (DO) level and higher energy input to anoxic reactors for mechanical mixing.

2.1.1 IFAS design systems

2.1.1.1 IFAS System Design Considerations

Primary treatment

To avoid rag and material build up in the aeration tank, one primary operational treatment or screening is required in the IFAS treatment process. With that preliminary process ragging can be evaded on the aeration basin that induces clogging of the dispersed support media and retaining screens (Brentwood Industries, 2001).

Mixing

Mixing is required for a correct operation of suspended solids, substrate transfer, and oxygen diffusion.

Coarse bubble diffusers are applied in the aeration tank to the dispersed support media. This technology is applied in some type of media such as the biofilm chip to suspend it using the flow induced by the aeration system. To avoid that the mass is separated from the media, the air flow should not be too vigorous (Brentwood Industries, 2001).

Hydraulic profile & volume displacement

In the hydraulic profile with dispersed support media have it should be considerate that the displaced volume for the media can affect the hydraulic retention time (HRT), to avoid this some considerations are required when sizing the aeration tank (Brentwood Industries, 2001).

Another consideration is the heat loss in the aeration tank. It will be increase for the screen used to retain the support media in the tank (Brentwood Industries, 2001).

Oxygen transfer

In the IFAS process the aeration tank operates with a DO concentration of 4 mg/l to 5 mg/l . This concentration of DO is provided by the air flow injected into the tank and has to satisfy the demand of the additional biomass and the oxidized BOD. When the fixed support media is in the aeration tank, the media increases the bubble retention time therefore increasing the oxygen absorption efficiency (Brentwood Industries, 2001).

Equipment access

For the correct maintenance of IFAS installations, the design has to allow for removal of the suspended media from the tank when operations of up keeping in the diffusers,

mixers and valves are required. With that, a storage area to move the media during these operations is required. When a fixed support media is in the aeration tank, then it has to be lifted out or moved aside to allow the other maintenance operations. (Brentwood Industries, 2001).

2.1.1.2 IFAS Process Design Considerations

Biomass effective area

The correct operation of IFAS processes is dependent on the activity of biomass and the quantity of biomass growing on the surface of the support media. The factor that relates the amount of biomass in the support media is the effective area that is not the same as the measured surface area of the support media (Brentwood Industries, 2001).

In dispersed systems, for example, overgrowth of the biomass on the porous support media limits the diffusion of oxygen and nutrients to the bacteria. Also, abrasion from the normal tumbling action of the support media in the reactor can remove slime from the surface, which reduces the effective area (Brentwood Industries, 2001).

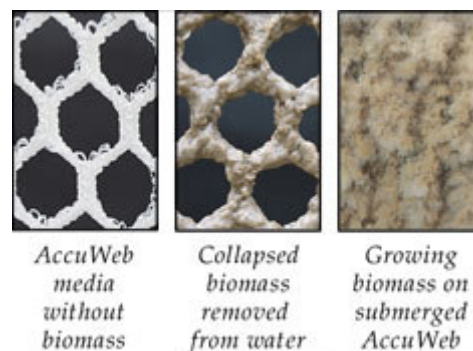


Figure 2-5: Effective area of support media

The Figure 2-5 shows a media without biomass and a media collapsed by biomass. A biofilm is a group of micro-organisms and their extracellular products, attached to a solid surface area. The biofilm structure is as follow:

- The porosity is bigger in the outer layer of the biofilm
- The pore size is bigger in the outer layer

- The density increases with the thickness of the biofilm

As well in the dispersed media (Figure 2-5) as in fixed systems, the bacteria can grow outward from the fixed surface, thus increasing the effective area. The effectiveness of PVC sheet support media in IFAS systems may be limited by mixing and the possible plugging of certain passages within the modules (Brentwood Industries, 2001).

Media location

The location of the support media within the reactor has a limited effect on the relative amount of biomass growth on the support media. Figure 2-6 show one study of an aerobic tank 40.2 m long x 5.2 m wide x 9.2 m deep, samples taken along the length of the reactor only varied by $\pm 10\%$ of the average (Brentwood Industries, 2001).

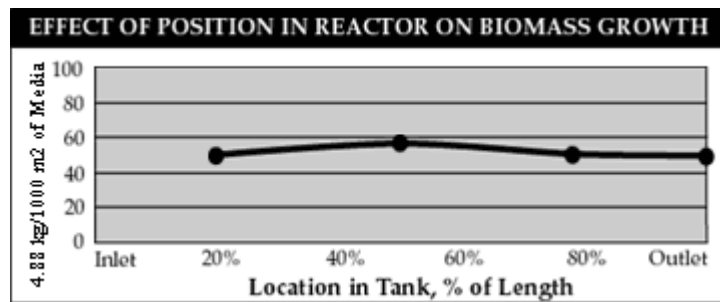


Figure 2-6: Effect of position in reactor on biomass growth

2.1.1.3 IFAS Process Design Methods

Equivalent MLVSS method:

A simple method of estimating the amount need for the support media is to consider the additional quantity of biomass required to achieve a improvement in treatment using conventional resources. The Table 2-1 determine the amount of media necessary to support the growth of that amount of biomass (Brentwood Industries, 2001).

Table 2-1: Equivalent MLVSS Method results

MEDIA TYPE	BIOMASS GROWTH	MEDIA REQUIRED
Sponges	120 mg/sponge ⁽¹⁾	25,000,000 sponges
Finned Cylinders	6-10 kg/m ³ ⁽¹⁾	300-500 m ³
Rope	6.6 gm/m ⁽¹⁾	460,000 m
Fabric (AccuWeb)	195-292 kg/1000 m ² ⁽²⁾	12,356 m ²

(1) *Investigation of Hybrid Systems for Enhanced Nutrient Control, Water Environment Research Foundation, 2000.*

(2) *Brentwood Industries Research*

The amount of additional biomass needed can be estimated using food: microorganism ratio (F/M) or solids retention time (SRT). For instance, if there is a 20 % increase in BOD loading, it needs a 20 % increase in biomass to maintain a targeted F/M. Similarly, if 33.3 % increase in SRT to support nitrification, the biomass must be increased by one-third. The resulting mass can be converted directly into media requirements (Brentwood Industries, 2001).

Kinetic method

Specific removal rates for support media for nitrification designs are published and available. For instance: for rope-type media, the ammonia oxidation rate is reported as 0.6-0.8kg/1000 m²/day. For web-type media, this converts to 22-30 kg/1000 m²/day. The table 2-2 reported values for different support media (Brentwood Industries, 2001).

Table 2-2: Kinetic methods results

MEDIA TYPE	SPECIFIC REMOVAL RATE	CONDITIONS	MEDIA REQUIRED
Sponges	.4-.8 kg/m ³ /day	10-12° C	360 m ³
Finned Cylinders	.4-.8 kg/m ³ /day	10-12° C	360 m ³
Rope	.6-.8 kg/1000 m/day	10-12° C	240,000 m
Fabric (AccuWeb)	22-30 kg/1000m ² /day	10-12° C	6,540 m ²

2.1.3 Comparing conventional activated sludge process and IFAS process

In a study research comparing design and operational criteria in an IFAS pilot plant was compared with full scale extended aeration activated sludge. The aim of this study was to determine the feasibility of improving traditional systems such as activated sludge when it is transformed into IFAS process (Mehrdadi et al., 2005).

The results of this investigation clearly showed that IFAS can be successfully upgraded in three stages: aerobic; anaerobic; anoxic. With regard to the obtained results, the IFAS reactor's carbonaceous organic removal efficiency is at least 5-6 times higher than traditional AS process efficiency. The organic degradation rate of the anaerobic zone was equal to $3.56 \text{ kg COD/m}^3\cdot\text{day}$ and organic degradation rate of the aerobic zone was equal to $6.22 \text{ kg COD/m}^3\cdot\text{day}$ (Mehrdadi et al., 2005).

With nitrification efficiencies, in optimized conditions with a nitrogenous organic loading rate of $628.56 \text{ gTKN/m}^3\cdot\text{day}$, a nitrification rate of the media was equal to $343.28 \text{ gTKN/m}^3\cdot\text{day}$. at Ekbatan wastewater treatment works (WWTW) a nitrification rate of extended aeration activated sludge process with the same conditions was obtained of $75 \text{ gN/m}^3\cdot\text{day}$ (Mehrdadi et al., 2005).

A denitrification rate of media with a nitrogenous organic loading rate of $347 \text{ gN-NO}_3/\text{m}^3\cdot\text{day}$ was equal to $338.17 \text{ gN-NO}_3/\text{m}^3\cdot\text{day}$ (Mehrdadi et al., 2005).

A biological phosphorus removal rate of the reactor at optimized operational conditions with a phosphorous loading rate of $243.57 \text{ g P-PO}_4/\text{m}^3\cdot\text{day}$, was equal to $204.78 \text{ gP-PO}_4/\text{m}^3\cdot\text{day}$. At Ekbatan WWTP, a phosphorus removal rate was obtained of $7 \text{ gPO}_4\text{-P/m}^3\cdot\text{day}$ (Mehrdadi et al., 2005).

In another study which conducted to evaluate the capacity of COD and nitrogen removal AS process was comparing to the IFAS process under different HRT and SRT. With that aim two pilot-scale activated sludge systems were operated in parallel. The Bioweb support media were installed in the aeration tank of one system and the other one was without support media (Sriwiriyarat et al., 2008a).

In this study, there was no significant difference in COD removal performance between the AS and IFAS processes because for COD removal at most of the experimental HRT and SRT there was enough suspended biomass in both systems. However, the AS system is more sensible to do not achieve the COD perform removal as a result of the sludge wash out from the system (Sriwiriyarat et al., 2008a).

Both systems had an excess of filamentous microorganisms. This excess is because both AS and IFAS processes were fed in mixed conditions with readily biodegradable organics, as these conditions in wastewater induce filamentous bulking in the systems (Sriwiriyarat et al., 2008a).

This study proved that by decreasing HRT and SRT and increasing the loading, the IFAS system demonstrated to be higher in capacity and stability as compared with the AS process. The amount of filamentous bacteria decreased in the IFAS process as a consequence of the attached biomass in the media, reducing the amount of substrates in contact with the filamentous microorganisms (Sriwiriyarat et al., 2008a).

The process of nitrification was higher in the IFAS system. The amount of removal was 96.6 % during all of the research period. This study proved that the nitrification was independent of the suspended SRT, but dependent on the amount of attached biomass growth on the support media (Sriwiriyarat et al., 2008a).

2.2- Control systems in conventional activated sludge process

2.2.1- Dissolved oxygen control system

In biological treatments, the soluble nitrogen components are removed from wastewater through two different processes: nitrification and denitrification. During nitrification ammonia is converted to nitrite and then nitrate through the biological process of oxidation, hence aerobic conditions are required (Murphy et al., 2009).

Oxygen is largely insoluble in water. The actual quantity of oxygen and other gases that can be present the solution is governed by (1) the solubility of the gas, (2) the partial pressure of the gas in the atmosphere, (3) the temperature, and (4) the concentration of the impurities in the water (Metcalf & Eddy et al., 2003).

The two basic methods of aerating wastewater are:

- to introduce air or pure oxygen into the wastewater with submerged diffusers or other aeration device

- to agitate the wastewater mechanically to promote solubilisation of air from the atmosphere.

Diffuser-air systems are extensively apply in wastewater treatment plants, this technology consists of diffusers that are immersed in the aeration basin, header pipes, air mains, blowers, and appurtenances through which the air passes (Metcalf & Eddy et al., 2003).

This air flow transfer oxygen that is dissolved in the wastewater. The total DO in the aeration tank can be measured as concentration of dissolved oxygen in mg/l.

Suspended growth processes (activated sludge) typically operate at lower DO concentrations than in the IFAS process. In AS process the operational DO is 1-2 mg/l, in IFAS process it is 2-4.5 mg/l (Pearce et al., 2008), higher DO concentrations are used to attain high nitrification rates in the IFAS process resulting in lower process volumes. (no web). That is because higher DO concentrations are used to attain high nitrification rates in the IFAS process resulting in lower process volumes

It is important to optimise DO in the media, to achieve an improved process performance. The correct concentration of DO in the media depends on the air supply in the mixed liquid, hence applying the necessary air represent an economic incentive. The principal difficulties in achieving the correct concentration of DO in the aeration basin are the variability of the kinetic parameters and the limited availability of on-line information (Yoo et al., 2004).

To overcome the problems of excess and deficit of DO in the system, several control strategies have been suggested recently (Yoo et al., 2004).

(Yoo et al., 2004) concludes that a good control performance for all the operating conditions cannot be expected to be achieved with a conventional linear controller.

2.2.2- Ammonia feedback control system

The nitrification rate depends directly of the oxygen rate in the aeration basin, this permit to control the demand of air through the aeration tank. The control is based of both ammonia for the feedback loop and DO for determining set point band ranges. This control philosophy relates the demand of the ammonia removal through a simultaneous test of the concentration of nitrification denitrification, hence permit achieve a good performance in the final effluent at the same time that reduce energy costs generate for the air flow apply at the system. (Thauré D. et al., 2008).

The set point is the adjusted need of air flow rate to the system depending of the concentration of ammonia and DO detected into the tank. The air flow rate is directly depending at the load of ammonia arriving to the system and the biomass activity. In every wastewater treatment plant can be determined a different set point for ammonia concentration in tank, and one minimum value and one maximum value for the calculated ammonium set point (Thauré D. et al., 2008).

At Vitoria WWTP, to reduce the aeration costs as much as possible with out reducing the current performance of ammonia and nitrate in the final effluent, a real time strategy study was conducted to regulate the ammonia and nitrate concentrations in the final effluent (Suescun et al., 2001).

Two variables were constantly modified when applying an advanced control strategy (AC) to achieve a required quality in effluent, those variables are:

- The DO level for the relation with the nitrification process and the organic matter removal
- The internal recycling flow (IR), for the relation with the the amount of nitrates into the anoxic zone (Suescun et al., 2001).

This study concludes the automatic control of both variables with the advanced control strategy, permits regulation of ammonia concentrations in the effluent at its required value constantly, and also concludes that the designed leads to the achieve of a reduction in the air flow as in comparison with traditional systems, due to the improvement in the aeration efficiency at low DO concentrations (Suescun et al., 2001).

2.3- Control system in IFAS process

2.3.1- Dissolved oxygen control system

IFAS process are characterised by the operational design for high DO concentrations. The original aeration control system consists of dissolved oxygen feedback to a modulating air valve on the air supply to the IFAS zone. This zone has been operated with DO set points of 4 mg/l in summer conditions and 5 mg/l at lower wastewater temperatures typified in winter conditions.

Because the solubility of oxygen is greater in cold water than in warm water hence the DO is higher in winter than in summer. The dissolution is exothermic, hence when apply cold temperature to the system the equilibrium goes to the dissolved form. The solubility of a gas in a liquid depends on temperature and obeys Henry's law hence is dependent of the partial pressure of the gas over the liquid (Sense, 2007).

The system is in common for the aeration control for the media free zones upstream and downstream of the media zones though these operate with conventional DO set points. The blowers respond to air main pressure which is governed by the opening and closing of the air control valves (Pearce et al., 2008).

Normally the nitrification rate in IFAS system has been found to be lineally dependent on the oxygen rate.

Two factors, the ammonia concentration, and the oxygen concentration primarily determine the nitrification rate. The influence of the parameters is schematically shown in figure 2-7 (Veolia Water Solutions & Technologies, 2009).

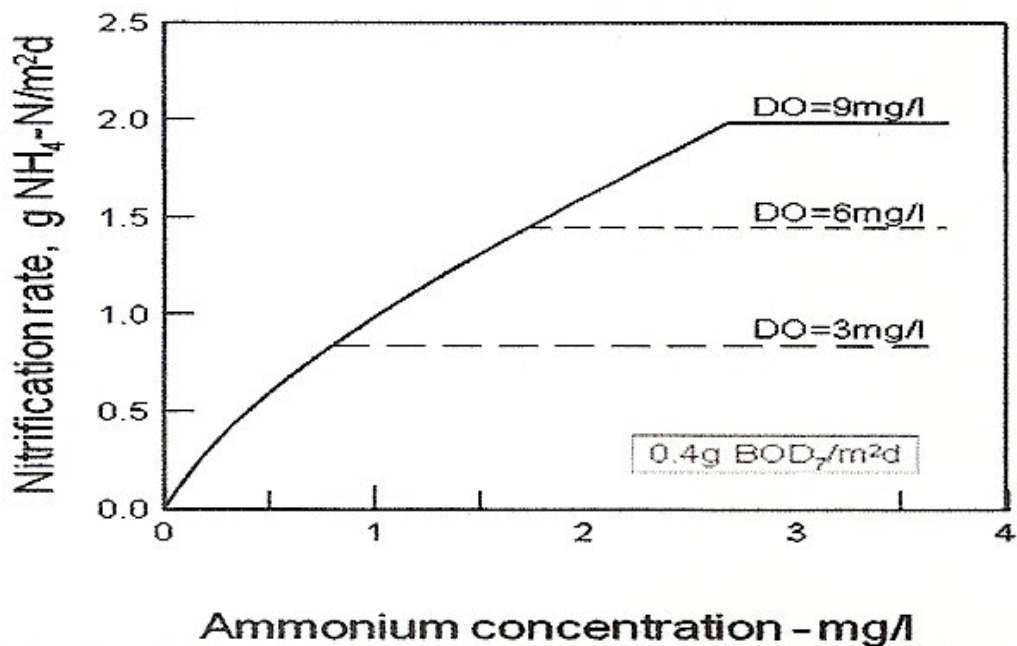


Figure 2-7: Nitrification rate with DO concentration

Alternatively, plants could be designed to operate at lower DO set points for periods of loading below the design maximum but allowing sufficient blower capacity and aeration system capacity to accommodate higher DO operation when maximum nitrification rates are required. This option is particularly attractive for IFAS design due to the relationship between media nitrification rate and DO concentration (Pearce et al., 2008).

A study with different COD/Nitrogen ratios was executed to understand the relationship between the DO and nitrogen ratio in biological nitrogen removal (Sriwiriyarat et al., 2008b).

The C/N ratios applied in this research have been 4, 6, and 10, and the dissolved oxygen concentration 2 mg/l, 4 mg/l, and 6 mg/l. (Sriwiriyarat et al., 2008b).

As a result of this study the C/N ratios 4, 6 and 10 and the DO concentrations 2 mg/l, 4 mg/l and 6 have insignificant effects on COD removal, but have significant effects in the nitrification and denitrification rates (Sriwiriyarat et al., 2008b).

Because the system operates at high solid retention time and glucose was used as the major carbon resource, the COD removal was nearly completed. (Sriwiriyarat et al., 2008b).

The study concludes that there are not advantages to placing the support media into the aeration zone of the IFAS system when the C/N ratio is 10, because the system is under loaded in nitrogen (Sriwiriyarat et al., 2008b).

When the concentration of DO descends, the process of denitrification in the anoxic zone is rises, because the electron acceptor comes from nitrite nitrogen.(Sriwiriyarat et al., 2008b).

This study concludes that the optimal DO concentrations for biological nitrogen removal in the IFAS system at the C/N ratios of 4 is 6 mg/l; at C/N 6 is 2 mg/l and at 10 is 2 mg/l, (Sriwiriyarat et al., 2008b).

2.3.2-Ammonia/nitrate feedback control

This control philosophy is in principle very similar at ammonia/nitrate feedback control in activated sludge. This system utilises online monitoring of both ammonia and nitrate for the feedback loop and DO for determining set point band ranges of operational DO (Veolia Water Solutions & Technologies, 2009). The set point is 2 mg/l DO for $\text{NH}_4\text{-N}$ concentration 0-2 mg/l; 3 mg/l DO for $\text{NH}_4\text{-N}$ concentration 2-4 mg/l; 4 mg/l DO for $\text{NH}_4\text{-N}$ concentration 4-8 mg/l; 4.5 mg/l DO for $\text{NH}_4\text{-N}$ concentration above 8 mg/l.

2.4- Evaluation at high media cells residence time (MCRT)

The slowly growing bacteria are needed for nitrification or removal of certain organic compounds which may require a longer sludge age (Veolia Water Solutions & Technologies, 2009).

In conventional Activated Sludge process the activated sludge fraction of the reactor volume is used for the oxidation of organic material, and where requires denitrification.

In this way the sludge aged at which nitrification can be attained is significantly reduced, allowing existing activated sludge plants to be upgraded for nitrification/nitrogen removal with minimal impact on the existing reactor volumes (Veolia Water Solutions & Technologies, 2009).

In the IFAS process one of the aims is to enrich a high content of slowly growing bacteria on the carrier material (Veolia Water Solutions & Technologies, 2009).

Figure 2-8 shows the threshold for biofilm surface area at different aerobic mixed liquor media cells residence time (MCRT) to achieve an effluent ammonium-N of 1.5 mg/l under diurnal average loading rates.

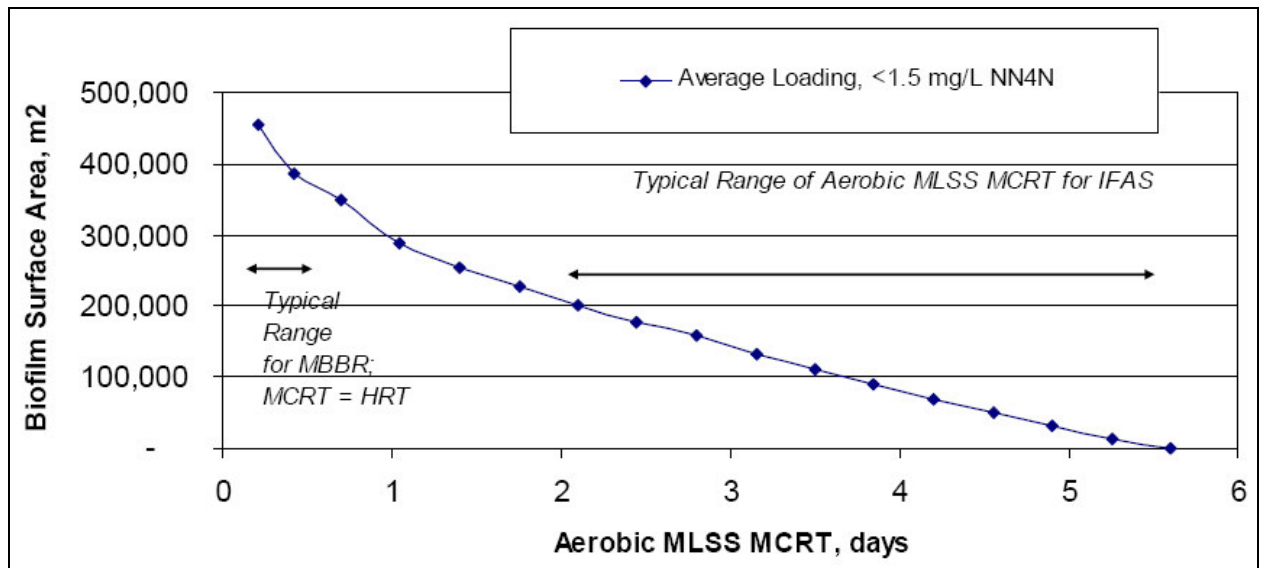


Figure 2-8: Threshold of biofilm surface Area under average loading primary effluent flow 10,000 m³/day temp 12° C, 250 mg/l CO, 25 mg/l TKN

The biomass in the IFAS system is characteristically retained in the support media, and can not be wash out hence, the effective MCRT of the biomass is higher than in the other processes. This allows a slow growing of nitrifies at low temperature that remain in the system that with out media would washout. (Weerapperuma et al., 2005).

2.5 Life cycle cost analysis

The definition of life costs by Crites and Tchobanoglous (1998) is the total costs accrued during the project lifetime. The life costs can be itemized by amortized capital costs; annual operations and maintenance costs (Tsagarakis et al., 2003).

At the District's wastewater treatment plant in Schwyz a study has been done of concerning the construction and operating costs. In this study all new biological treatment plant were compared. The population equivalent for the new plant was 50,000 p. This do not include sludge treatment and premises (Bretscher U. et al., 2005).

Figure 2-9 show a comparison of costs for activated sludge; IFAS; and membrane biology:

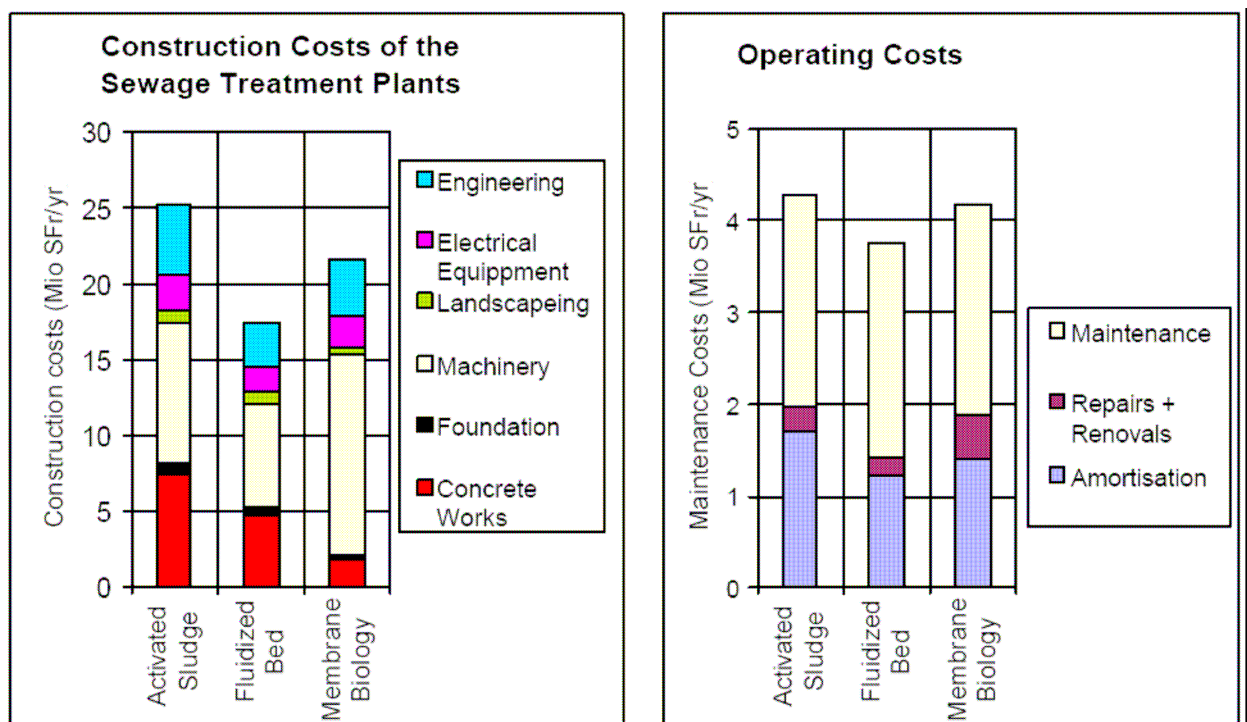


Figure 2-9: Construction Costs and Operating Costs of the Sewage Treatment Plants

The study conclude that activated sludge plant is the most expensive solution today, as well as in construction and operation costs, also the system demands the most space. Figure 2-9 shows the IFAS process as the system with the least construction and operating costs. (Bretscher U. et al., 2005).

With the IFAS the capacity of the plant can be double with out increasing the costs by adding 200 kilograms of plastic media into an existing activated sludge plant (Bretscher U. et al., 2005).

In another study, research was conducted to evaluate the economic costs of IFAS in comparison with other treatment technologies (Johnson et al., 2006).

Five treatment technologies normally considered for plant expansions and treatment upgrades were studied, such as IFAS, conventional activated sludge, step-feed activated sludge, biological aerated filters (BAF), and membrane bioreactor system (MBR). The evaluation results took into consideration each of the following six key economic factors: 1. Plant size; 2. Peak to average flow ratio; 3. Value of land; 4. Equipment costs; 5. Power; 6. Construction (Johnson et al., 2006).

The evaluation was carried out based on a 20-year project life and a discount rate of 3 percent. Capital cost opinions were developed from cost curves, unit cost factors, cost information received from equipment manufacturers, and cost information developed for projects with similar facilities. Operation and maintenance (O&M) costs were limited to power, chemicals, and special maintenance requirements for the treatment technologies. The net present value (NPV) is equipment costs (Johnson et al., 2006).

The IFAS alternative has not additional structures costs and this costs are similar for conventional activated sludge and step-feed. O&M costs are higher in MBR and in the other systems these costs are similar.

The study concludes that the IFAS process has the lowest construction costs of all the systems but the highest equipment costs in comparison with conventional activated sludge and step-feed alternatives (Johnson et al., 2006).

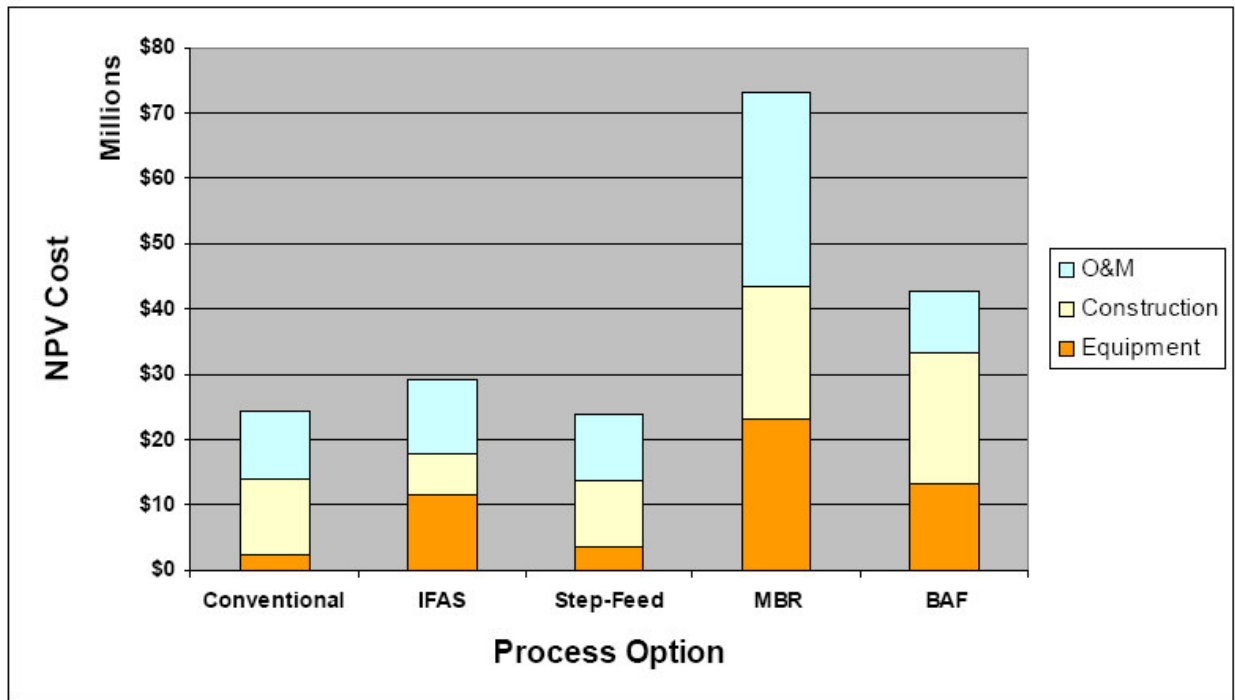


Figure 2-10: Net Present Value Cost Breakdown

2.6 Summary and Conclusion:

Owing to an increasing urban populations and the need to find space for the construction of the new treatment works, it has demanded research into new techniques to reduce the footprint for wastewater treatment processes. One solution is to use existing assets and to improve their performance by upgrading with new technologies. The integrated fixed film activated sludge (IFAS) process offers the possibility of increasing treatment capacity for existing wastewater treatment plants by placing the support media into the aeration zone or reducing tank volumes for any new construction.

Based on the extensive review of the literature carried out, the following key conclusions can be drawn:

- Moving Bed Biofilm Reactor (MBBR) technology is based on the biofilm principle with an active biofilm growing on small specially designed plastic

placed in the aeration tank. This technology can be used in many different configurations, one of these is the IFAS process.

- In biological treatments, the nitrification process need a contribution of oxygen in the aeration tank. The air flow transfer can be measured as DO, is important to optimise it in the media. Basically there are two systems to optimise the DO concentration in tank.
 - o Dissolved Oxygen control system: Consist of dissolved oxygen feedback to modulating air valve on the air supply to the aeration tank, this operated with DO set point.
 - o Amonia/nitrate feedback control: This system utilises online monitoring of both ammonia and nitrate for the feedback loop and DO for determine set point band ranges of operational DO in tank.
- Comparing IFAS process with conventional AS process, IFAS increase treatment capacity or reduce tank volumes.
- Studding construction and operating costs and comparing IFAS process with other conventional processes as AS and membrane biology, the IFAS process is the system with the less construction and operating costs.

3. OBJECTIVES

This project will focus on the follow objectives:

- Characterise influent and effluent flow and load of wastewater and final effluent.
- Monitor energy consumption in kWh of IFAS system in comparison with activated sludge system and recommend improvements for energy efficiency as much as possible.
- Test nitrification rates of biomass on plastic media and in the MLSS (mixed liquor suspended solid) of IFAS system and compare with MLSS of conventional activated sludge system.

4. RESEARCH PAPER

Improve the energy efficiency of a full scale integrated fixed film activate sludge (IFAS) process

Ramon Buñol¹, Bruce Jefferson¹, Kieran Healey², Angela Barugh³

¹Centre for Water Science, Cranfield University, Cranfield, Bedfordshire MK43 0AL,
UK

²Veolia Water Solutions & Technologies, Aqua House, 2620 Kings Court, Birmingham
Business Park, Birmingham, B37 7YE,
UK

³Thames Water Utilities Limited, R&D Innovation Centre, Reading STW Island Road,
Reading RG2 0RP,
UK

Abstract

The primary objective of integrated fixed film activated sludge (IFAS) is to remove dissolved pollutants from wastewater. This process allows an increased treatment capacity comparing with conventional activated sludge. Thames Water has been operating a full scale IFAS process demonstration lane of 870 m³ at the Oxford wastewater treatment works.

The aim of this study was to evaluate the benefits of using an ammonia feed back control as an alternative to a conventional set point dissolved oxygen control in order to improve energy efficiency in the aeration system. The main finding was that the adjustment of dissolved oxygen (DO) set points regulated by the feedback control system resulted in periods of excess or deficiency of DO in the wastewater with a total 14.7 % over aeration and 9.8 % under aeration. Investigation into the causes of the deviations found that air control valve was either too open or too closed.

An equation was established to relate the influent wastewater flow with the time taken to be detected in the IFAS process lane. Thus a feed forward control philosophy was suggested to control the aeration system, to improve the target DO set point.

Alongside this study, a comparison of the energy costs between IFAS with the ammonia feed-back control philosophy and a conventional activated sludge set point DO control system was completed. The analysis found negligible difference between the two processes. It can therefore be concluded that, with further research, the IFAS process can still be optimised to reduce aeration energy costs.

Keywords: Ammonia feed back control; set point dissolved oxygen control; energy efficiency; air control valve; full scale process; dissolved pollutants.

1. Introduction

Modern demands on the design and construction of new wastewater treatment works (WWTW) are becoming ever more rigorous due to increasingly stringent discharge consents (European Parliament, 2000) (European Communities Directive, 1991) (European Communities Directive, 1978) and increasing urban populations (National statistics, 2009).

The challenge to find space for the construction of these new treatment works has demanded research into new techniques to reduce the footprint for wastewater treatment processes.

One solution is to use existing assets and to improve their performance by upgrading with new technologies. One evaluation was conducted based on the expansion of a hypothetical plant originally designed for carbonaceous BOD removal and now being upgraded to provide nitrification and denitrification, five treatment technologies were considered such as conventional AS, step feed AS, IFAS, biological aerated filters (BAF), and membrane bioreactor (MBR). The IFAS alternative has considerably lower construction costs but higher equipment costs than the conventional and step-feed

alternatives, (Johnson et al., 2006). The integrated fixed film activated sludge (IFAS) process has been increasingly used to upgrade activated sludge (AS) plants. IFAS offers the possibility of increasing treatment capacity for existing wastewater treatment plants by placing the support media into the aeration zone or reducing tank volumes for any new construction (Ødegaard et al., 1999).

There are several types of support media used for biomass in the activated sludge process. They include dispersed media and fixed media, such as structured or knitted fabric media placed in the aeration basin (Weerapperuma et al., 2005).

(Mehrdadi et al., 2005) carried out a study to compare pilot IFAS process and full scale AS process, the results are as follow:

The carbonaceous organic removal efficiency in IFAS process, was much higher (at least 5-6 times) than extended aeration AS process efficiency.

Nitrification efficiencies, in optimized conditions with nitrogenous organic loading rate of $628.56 \text{ gTKN/m}^3 \cdot \text{day}$, nitrification rate of media in IFAS process was equal to $343.28 \text{ gTKN/m}^3 \cdot \text{day}$. In AS process was obtained as $75 \text{ gN/m}^3 \cdot \text{day}$.

Biological phosphorus removal rate with a phosphorous loading rate of $243.57 \text{ gP-PO}_4/\text{m}^3 \cdot \text{day}$, was equal to $204.78 \text{ gP-PO}_4/\text{m}^3 \cdot \text{day}$. With regarding phosphorus removal rate in AS process, was obtained $7 \text{ gPO}_4\text{-P/m}^3 \cdot \text{day}$.

The advantages of IFAS process are: 1- IFAS process utilises both suspended and attached growth within the same reactor; 2- nitrification takes place mainly in the biofilm whereas BOD removal and denitrification takes place in the suspended sludge; 3- can be coupled with most types of solids separation; 4- the sludge age of the activated sludge can be kept short. A short sludge age has the benefit of higher specific carbonaceous activity and excludes growth of filament.

The disadvantages of IFAS process are: 1- requires an efficient screening pre-treatment; low retention time in the reactor therefore little hydrolysis of suspended solids; 2- the

outer biofilm is continuously being renewed due to abrasion; 3- hence the sludge age of this part of the biofilm is low. The sludge leaving the reactor with the effluent is not stabilized; 4- risk of the outlet screen be clog by the carriers; 5- cost of the carrier and outlet screens; 6- energy consumption can be higher than with conventional AS plants due to higher operating dissolved oxygen (DO) level and higher energy input to anoxic reactors for mechanical mixing (Veolia Water Solutions & Technologies, 2008).

Dissolved oxygen is required for the respiration of aerobic microorganisms. The DO concentration in a mixed liquor is an important parameter in achieving efficient removal rates. There are two main systems of DO control in wastewater systems.

The conventional dissolved oxygen set point control system with feedback to a modulating air valve on the air supply to the air zone. In IFAS process this zone has been operated with DO set point of 4 mg/l to 5 mg/l (Pearce et al., 2008). In AS process this zone has been operated with DO set point of 2 mg/l.

The ammonia feed back control system utilises online monitoring of both ammonia and nitrate for the feedback loop and DO for determining set point band ranges of operational DO (Veolia Water Solutions & Technologies, 2009). At Oxford Thames Water IFAS plant the set point is 2 mg/l DO for $\text{NH}_4\text{-N}$ concentration 0-2 mg/l; 3 mg/l DO for $\text{NH}_4\text{-N}$ concentration 2-4 mg/l; 4 mg/l DO for $\text{NH}_4\text{-N}$ concentration 4-8 mg/l; 4.5 mg/l DO for $\text{NH}_4\text{-N}$ concentration above 8 mg/l.

2. Material and Methods

2.1 Design and dimensions of full-scale treatment plant

2.1.1 Main treatment plant

Thames Water has been operating a demonstration IFAS biological process lane at the Oxford WWTW (178,000 population equivalent) for over two years. The driver

investigating the IFAS process is to assess its potential for upgrading existing AS plants.

The Oxford treatment works was originally split into three complete separate lanes of AS of different capacities: Lane 1, lane 2 and lane 3 treat an average flow capacity of 28,000 m³/day; 13,436 m³/day and 14,571 m³/day, respectively.

The IFAS upgrade was undertaken in lane 3 (AS3) and operated as plug flow. The AS lane 2, without any media was operated in parallel, and was used as a control system to allow a performance comparison with the IFAS lane.

The IFAS has four process zones: the first being an anoxic zone, followed by an aerobic zone of 434 m³, at the end of which is the IFAS zone at 870 m³ which contains media, the final zone is an aerobic zone of 450 m³ without media, the total volume is 1,754 m³. There are baffle walls in all three aerobic zones. The anoxic zone is mixed to maintain solids in suspension, and the non-media aerobic zones utilise membrane type fine bubble aeration. AS process consist of 8 no single pass aeration lanes. There are no anoxic zones on AS process. Each line is 37.8 m * 6.9 m * 2.65 m depth giving an overall volume of 5,529 m³.

The carrier used in the IFAS reactor is Biofilm Chip™ type M media, which has a protected surface area of 1200 m²/m³. To retain biofilm media inside the determined zone, cylindrical sieves were placed on the outlet wall. For the IFAS portion of the reactor a medium bubble aeration system has been used.

2.1.2 Blowers and control systems

The compressed air flow in the IFAS aerobic zone was regulated by modulating valves. IFAS aeration system consisted of a medium bubble aeration grid. In the non media aerobic zones fine bubble membrane diffusers were used. The IFAS zone outlet sieves have coarse bubble air-knives to prevent media accumulation and sieve blockage. The compressed air was supplied to all zones from a common manifold that was maintained at a constant pressure between 490 mbar and 480 mbar by four compressors, two of

them of variable speed both in duty and two other ones at fix speed one in duty and the other in standby.

The aeration was controlled by feed-back system with online monitoring of both ammonia for the feedback loop and DO for determining set point band ranges. The set point is 2 mg/l DO for $\text{NH}_4\text{-N}$ concentration 0-2 mg/l; 3 mg/l DO for $\text{NH}_4\text{-N}$ concentration 2-4 mg/l; 4 mg/l DO for $\text{NH}_4\text{-N}$ concentration 4-8 mg/l; 4.5 mg/l DO for $\text{NH}_4\text{-N}$ concentration above 8 mg/l. The ammonia and DO sensors were placed at the end of the IFAS process.

In AS process the compressed air flow zone was regulated by modulating valves. The AS aeration system consisted of a fine bubble aeration system. The aeration was controlled by conventional set point dissolved oxygen control system with monitoring DO for determining set point. The set point in the MLSS is 1.5-2.0 mg/l DO (Veolia Water Solutions & Technologies, 2009). The blowers are controlled by Programmable Logic Controllers (PLC) that average the 4 units DO monitors which increase and decrease the blower speed according the DO set point.

Blower power consumption was controlled and recorded during 8 weeks using a portable electricity data logging meter (Southern Electric Consulting). Measurements were completed at the blower system of the IFAS process, the RAS in IFAS the AS2 process and the RAS in AS2.

2.1.3 Flow meter

The flow split to the IFAS and AS2 processes was not previously accurately determined. The flow went through a single channel and was split by two distribution weirs with different dimensions. Two portable open channel flow meters were used to measure the flow entry to the two processes jointly, and the flow entry to AS2 process. The IFAS flow was calculated by the difference of the joint and AS flows. The flow meter was a portable measuring device PCM 4 with sensor take data of flow level and flow velocity in the stream Nivus GmbH (Germany). Measurements were performed automatically every 10 min.

2.2. Site monitoring and sampling campaigns

Samples were collected three days a week over a two month period. Daily composite samples, consisting of 24 discrete subsamples of 1 l were collected from the settle sewage (SS), the outlet of the IFAS process and the outlet of the AS process, using auto samplers (Aquacell P2 –Multiform Portable wastewater sample, Aquamatic Limited, City, Country). The samples were analysed for TBOD₅,TCOD, SBOD₅,SCOD, COD, NH₄, NO₃, PO₄, TSS, TN, TON and TP.

For solids suspended and biological analysis, the samples were collected one day a week over the same period. Spot samples of 1 l and 0.5 l were collected from the outlet of the IFAS process and the outlet of the AS process to measure the solids suspended. Also one single sample for microbiological analysis was collected once a week in 500 cc bottle at the outlet of the IFAS process.

The ammonia concentration in the IFAS final effluent was measured three times a day using a ammonia Merk analyser.

2.2.1 Nitrification Test

Once every two weeks a nitrification test was performed on the Biofilm-chip media and mixed liquor from the IFAS and AS processes. Three tests were run in parallel: a cylindrical column metallic vessel (T1) was filled with 4 l sample of the mixed liquor from the AS with 6 l of settled sewage. The second vessel (T2) contained with 6 l sample of settle sewage and 4 l sample of mixed liquor from the IFAS process. The third vessel (T3) contained 8 l sample of sewage and 2 l sample of final effluent mixed with 200 units of Biofilm-chips. The vessels were placed in a water bath at 20°C and the liquid aerated to reach a DO of 4 mg/l. Nitrogen gas and oxygen were added to the reactors. The ammonia-N and nitrate were analyzed every 20 minutes and every hour, respectively.

A sample of every batch was collected to evaluate the sludge settling characteristics by calculating the sludge volumetric index (SVI)

2.3 Online Monitoring

Sensors were used to monitor the following parameters continuously:

DO (Hach Lange SC 100, HACH Company, Loveland, Colorado (US)), ammonia (both Hach Lange SC 1000, , HACH Company, Loveland, Colorado (US) and Hach Lange Evita USC 6000, , HACH Company, Loveland, Colorado (US)), temperature (Hach Lange SC 100, HACH Company, Loveland, Colorado (US)) and air flow (T-mass-AT70, Endress and Hauser Group Ltd, Manchester, UK). The data recorded by the various sensors was downloaded in SCADA.

2.4 Analysis.

The samples will be analysed for TBOD₅,TCOD, SBOD₅,SCOD, COD, NH₄, NO₃, PO₄, TSS, TN, TON . Samples were analysed using Standard Methods for the examination of water and wastewater (American Public Health Association, 1995) by the Thames Water Laboratory in Reading which is accredited by the United Kingdom Accreditation Service (UKAS) and ISO17025.

Ammonia and nitrate, in the nitrification tests, were determined using Merck cell test and Merck Spectroquant Nova 30 photometer according to the manufacturer's instructions.

3. Results

3.1. Study background

As part of a full scale IFAS demonstration programme, at the Oxford Sewage Treatment Works, Thames Water have recently extended the original study to evaluate ways of improving aeration efficiency. This study involves the use of NH₄-N load feed back control in the IFAS process, as an alternative to a set point dissolved oxygen control system and comparison with a conventional activated sludge process.

3.2 Original Design Criteria.

The initial design criteria for the IFAS process and the AS process are summarized in Table 4-1. In the table can observe that even if the flow in the IFAS process is higher than in AS process, the load of $\text{NH}_4\text{-N}$; BOD_5 and TSS is superior in the AS process than in the IFAS process.

3.3 Influent flow variation:

The daily influent flow was measured over a 4 week period in both IFAS and AS processes, in order to establish the flow split between these processes.

In the IFAS process the highest inflow was 232.38 l/s, recorded Wednesday, 22nd July and the minimal flow was 94.217 l/s, recorded Thursday, 4th June. In the AS process the highest inflow was 229.61 l/s, recorded Sunday, 7th June and the minimal flow was 94.22 l/s, recorded Thursday, 22nd July. The data of the highest flow in IFAS process coincide with the data of the minimal flow in AS, this is due because the main flow splits into the two different systems is manually control.

3.4 Variation of BOD_5 and $\text{NH}_4\text{-N}$

The diurnal concentrations of the BOD_5 and $\text{NH}_4\text{-N}$ in the settle sewage were studied on eight separate sampling events, based on hourly samples over a 24 hour period. Composite sampling was also undertaken during the monitoring period of 8th June to 30th July.

During that period study, in the settle sewage the average of ammonia concentration was 41.63 mg/l with a maximal concentration of 49.18 mg/l on the 2nd of July and a minimal concentration of 31.31 mg/l the 8th June. The BOD_5 had an average concentration of 210.53 mg/l with a maximal concentration of 373.3 mg/l the 16th of July and a minimal concentration of 153.45 mg/l the 9th June.

3.5 Comparison of actual loading with design loading

A comparison of the actual loading to the IFAS process and the original design criteria is summarised in Table 4-1.

The following differences between actual and design loading are evident for the IFAS process:

- The $\text{NH}_4\text{-N}$ loading was 80 % higher than the design loading.
- The BOD_5 loading was 123 % higher than the design loading.
- The TSS loading was 111 % higher than the design loading.

For the AS process a similar situation was observed:

- The $\text{NH}_4\text{-N}$ was 30 % higher than the design loading.
- The BOD_5 was 48 % higher the design loading.
- The TSS loading was 72 % higher than design loading.

This significant difference in design and observed loading was attributed to particular operational issues from Thames Water on the sludge stream at the plant. The effect of this was an increase in concentrated sludge liquors being returned to the head of the works and resulted in an increase in process loading .

3.6 Comparison of influent concentrations with typical wastewater

A comparison of the most important ratios between the loading of a typical settled influent (Albertson, 1991) and the loading of the Oxford settled influent have been done. The ratio following ratios have been summarized:

- TCOD/TBOD_5 in Oxford influent is 2.44, (typical settle influent is 1.7-2.1)
- $\text{SBOD}_5/\text{TBOD}_5$ in Oxford influent is 0.48, (typical settle influent is 0.45-0.55)
- SCOD/TCOD in Oxford influent is 0.37, (typical settle influent is 0.45-0.55)
- TSS/TBOD_5 in Oxford influent is 1.4, (typical settle influent is 1.6-1.8)
- TBOD_5/TKN in Oxford influent is 3.94, (typical settle influent is 3.4-4.4)
- TCOD/TKN in Oxford influent is 9.63, (typical settle influent is 6-10)
- $\text{TKN/NH}_4\text{-N}$ in Oxford influent is 1.28, (typical settle influent is 1.4-1.7).

3.7 Process performance of the IFAS system and AS system

The total concentration of $\text{NH}_4\text{-N}$, TBOD_5 and TSS removal efficiency were studied for both of the AS and IFAS lanes. The results for AS process give a 97.4 % removal in $\text{NH}_4\text{-N}$, a 99.6 % BOD_5 removal and a 98.9 % removal in TSS. In the IFAS process give a 94.6 % removal in ammonia, a 98.6 % BOD_5 removal and a 98.2 % removal of TSS. The removal of both configurations are near at the 100 %.

3.8 Nitrification rate testing

The results obtained for the nitrification test compares the efficiency of nitrification of IFAS and AS process. The units for nitrification rate are slightly different for the media, as it is measured per m^2 of protected surface area, compared to the mixed liquor, which is measured per mg of MLSS. As such it was not possible to compare the media nitrification rate with the suspended biomass nitrification rate directly.

From Table 4-2, with a nitrification rate of 0.471 g/gMLSS.d in the AS mixed liquor, 0.362 g/gMLSS.d in the IFAS mixed liquor and 0.594 $\text{g/m}^2\text{.g.d}$ in the biofilm chip, and reviewing the testing results, for the four sampling events, it can be observed that the nitrification rates observed were higher in samples of MLSS from the AS process, than in those from the IFAS process. However if we consider the combined nitrification rate in the media and the nitrification rate in the IFAS process MLSS, the nitrification rate is higher in the IFAS system. This is because with the IFAS processes the slow growing nitrifiers develop on the carrier media, and are retained in the process at low sludge ages, which would otherwise not be sufficient for nitrifier growth. This is the reason for the higher nitrification rate observed in the IFAS process. Also nitrifiers are continuously growing and being knocked off the media into the aeration basin which explains why the nitrification rate in the IFAS mixed liquor is observed at low sludge ages.

3.9 Power consumption

Power logging of the IFAS aeration blowers was carried out from 29th June until the 27th July. The recorded power indicated an average of power consumption of 118.2 kWh

In the AS process, due to power logging failure, reliable data was not available for the aeration blowers. It was however possible to estimate kW consumption based on limited kVA data recorded on the 10th & 11th July, for the AS process. To convert the kVA values to kW, a “Power Factor” (PF), which is the ratio of kW to kVA has been used. This PF was calculated from the power logging data recorded for the IFAS blower monitoring. On this basis the power consumption for the AS process is 116.6 kWh.

3.10 Relationship between power consumption and air flow rate

The derived power consumption figures for the IFAS and AS processes have been compared with the air flow rate during the same period. From the data of the rate of the power consumption and the air flow rate in the IFAS process, a power rate consumption of 0.0170 kWh/m³ of air flow has been calculated. Taking the data of the rate of power consumption and the air flow rate in the AS process, the calculated power rate consumption is 0.0213 kWh/m³ of air flow.

3.11 Relationship between power consumption, m³ of waste wastewater and oxygen required

With the derived factors for kWh/m³ of air flow, the operating data was analysed to obtain the consumption in kWh/m³ of wastewater treated from the data recorded for settled influent wastewater flow and the air flow supply to the process tanks. This was based on results during the period from 8th of June till 30th of July in the IFAS process and from 8th of June till 17th July for the AS process. For this same period the influent NH₄-N and BOD₅ loads to both the IFAS and AS processes were calculated as an actual oxygen requirement (AOR) loading (Michael et al., 2005).

From Figure 4-4 it can be observed that the average consumption in Wh/m^3 wastewater treated, in the IFAS process is 221.9 in Wh/m^3 and in the AS process is 218.5 in Wh/m^3 . This represents a 1.5% difference between the two processes on an equivalent volumetric treatment rate.

From Table 4-3, the relationship between power consumption and AOR load can be observed. The average of power consumption per kg of AOR in the IFAS process is 514.5 Wh/kg AOR and in the AS process is 499.2 Wh/kg AOR . This represents a 3.0% difference between the two processes on an equivalent AOR loading rate.

In summary there is no significant difference in the power consumption between the two processes.

The calculated design aeration requirements for the IFAS process, based on set point DO control, for the AOR loadings observed, has been calculated. These are compared with the actual observed air flow rates under $\text{NH}_4\text{-N}$ feed back control in (Table 4-3).

3.12 Relationship between $\text{NH}_4\text{-N}$ in tank and air flow

To study how effectively the $\text{NH}_4\text{-N}$ feed back control in the IFAS system was selected data during two month periods. The objective was to compare the measured $\text{NH}_4\text{-N}$ concentration in the tank, with the operational air flow controlled by the feedback control philosophy. The air flow being dependent on the $\text{NH}_4\text{-N}$ concentration in the IFAS tank. From reviewing data over the two month period, it was found that the system was working in feed back mode for just over 35 days.

3.13 Over aeration and under aeration

To evaluate the efficiency of the feed back control, excess and deficit of DO in the IFAS tank was studied in relation to the actual DO concentration and the DO set point during the days that the $\text{NH}_4\text{-N}$ load feed back control was operational, with the data registered using a software monitor sensor.

The concentration of DO in excess and deficit in the tank was measured on an hourly basis to evaluate the amount of over and under aeration. Figure 4-1 is an example of that data review.

The study showed that during the 35 days of feed back operation, there was an 14.7 % of over aeration and 9.8 % under aeration.

3.14 Relation with the valve operation and the DO set point

To find a reason for the over and under aeration in the tank of the IFAS process, the rate of valve operation in comparison with the operational DO set point, was compared. This information gives an indication of how well the air delivery system responds to the $\text{NH}_4\text{-N}$ load feed back control. In Figure 4-2 it can be observed that the percentage opening of the valve does not coincide with the DO set point.

From further data review it was concluded that for 57 hrs of operation in feedback control, the valve was working at the inverse position that the set point requires it to be. This represents 6.7 % of the time the IFAS system was in feed back control.

3.15 Flow prediction

To further assess the efficiency of the feed back control system a formula was derived to enable forward prediction of how long it takes the load of ammonia detected in the settle sewage to arrive at the IFAS tank. Figure 4-3 shows the time lag between ammonia concentrations in the settled influent and arrival at the IFAS tank.

Based on data analysis, the relationship is defined by the following equation.

$$4100/x = y$$

where:

x = flow (m^3/sc)

y = time to arrive to the tank (sec)

4. Discussion

The consumption of air flow in the IFAS process was observed to be higher by 25 % (Veolia Water Solutions & Technologies, 2009), than actually required by feed back control system.

4.1 Excess and deficit of aeration in the IFAS system

During the study a comparison was made of the actual DO concentration in the IFAS tank and the DO set point in the system, based on the measured $\text{NH}_4\text{-N}$ concentration. This comparison allowed an assessment of periods when there was an excess or deficit of DO in the tank. It was observed that there were periods with over aeration and some periods with under aeration (Figure 4-1) corresponding to a total of sum of 14.7 % of time the tank was over aerated and 9.8 % was under aerated. .

4.2 Valve operation

To establish the reason for this excess and deficit of air flow, the DO set point was also used to compare with the percentage of the valve open in the system. During the data review, it was observed that there are some periods of time that the valve doesn't operate correctly in comparison with the required air to supply to the process. It was observed that for some periods of the day the valve should be open according to the demand for air flow from the concentration of $\text{NH}_4\text{-N}$ in tank, but the valve was not in the position it should be. This time was quantified at 57 hours during which the valve didn't operate according to the DO set point, and representing 6.71 % of the time period evaluated

The signal commands from the $\text{NH}_4\text{-N}$ feed back control system are in effect, not reflected in the observed system response, due to wrong valve operation.

4.3 Comparison of the power consumption by the IFAS process and AS process

The power required per kg of AOR or energy power for every m³ of wastewater was calculated for the IFAS and AS process. This information was used to compare power consumption in both processes. From the comparison it can be concluded that the IFAS and AS systems have a very small difference in the power consumption.

When comparing the calculated design aeration requirements for the IFAS based on set point DO control for the AOR loadings observed, in comparison with the actual observed air flow rates under NH₄-N feed back control, on average there is a 24 % difference between the DO control and the actual rates observed in practice under feed back NH₄-N control.

This indicates the significant reduction that can be obtained with using feed back control as opposed to DO set point control for the IFAS process. This could be further improved by increasing the efficiency of the air delivery system in response to feed back control.

4.4 Flow prediction

There is a delay in executing the valve operation and miss-interpretation of the NH₄-N feed back control signals as to the required concentration of DO in the IFAS tank. For these reasons it is suggested that the signal for operation of the valve be advised in advance, based on the time the increase in NH₄-N load is detected in the settle sewage. This will help to avoid excess and deficit of air flow going to the system and improve energy efficiency.

To assist in the development of the feed forward control, an equation has been derived to enable prediction of how long it takes the settled NH₄-N load to reach the IFAS tank.

Conclusion

Over a two month study, the principle conclusions are as follow:

- Compared to the calculated design aeration requirements for set point DO control for the observed AOR loadings, the IFAS system in $\text{NH}_4\text{-N}$ feed back control requires 24% less air.
- The power consumption per m^3 of influent treated and kg AOR loading are comparable for the IFAS under feed back control and the AS process under DO set point control.
- An analysis of the feed back control operation indicates that there is an excess and deficit of DO in the tank due to a different demand of air flow to the target set point. As a consequence the feed back control system is not operating as efficiently as it could.
- Data analysis indicates that the reason for the this extra/deficit air flow consumption is because the air delivery supply system does not operate quickly enough to respond to system demands. In particular the valve positioning is frequently in the wrong position.
- Prediction of ammonia load to the works will allow feed forward control of aeration system as opposed to feed back control. The efficiency of the $\text{NH}_4\text{-N}$ feed back control system would benefit from future research in development of feed forward control.
- By optimising the $\text{NH}_4\text{-N}$ control system further improvements in aeration efficiency could be obtained to those already indicated by the comparison with DO set point operation. Further investigation into this area is recommended.

Acknowledgment

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Source: Veolia Water Solutions & Technologies, 2008b, p 50.

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Figures.

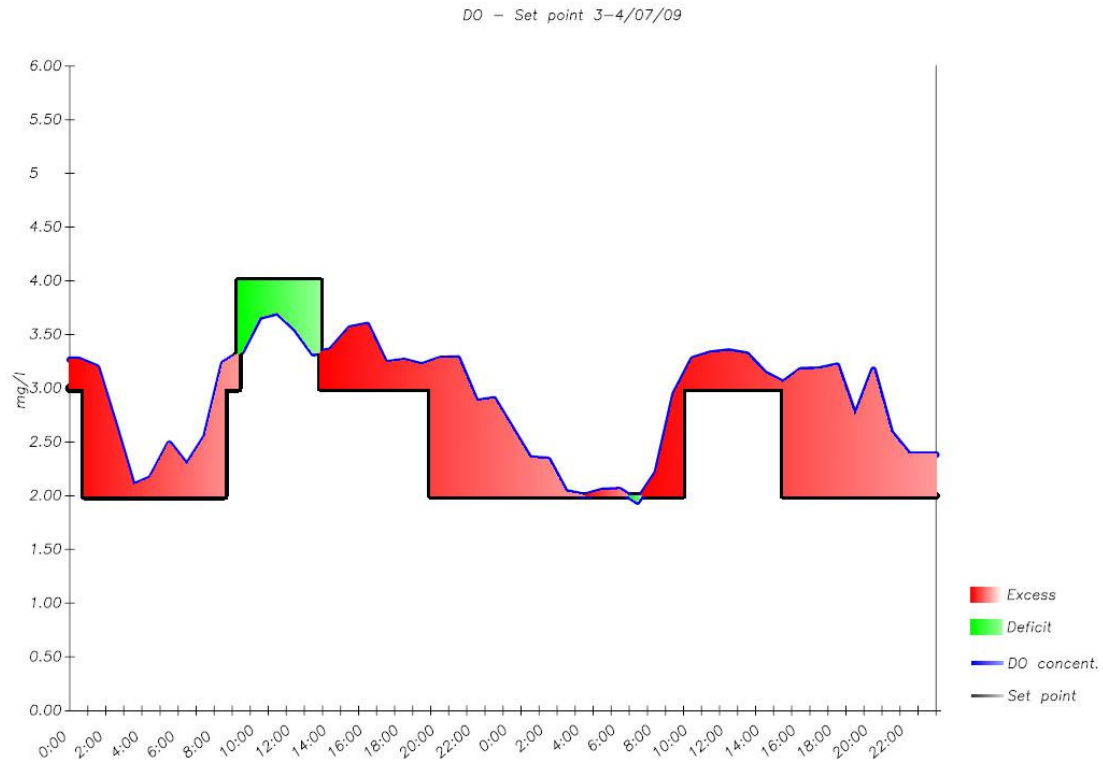


Figure 4-1: Excess and deficit of aeration when the feedback control system is in a good working order

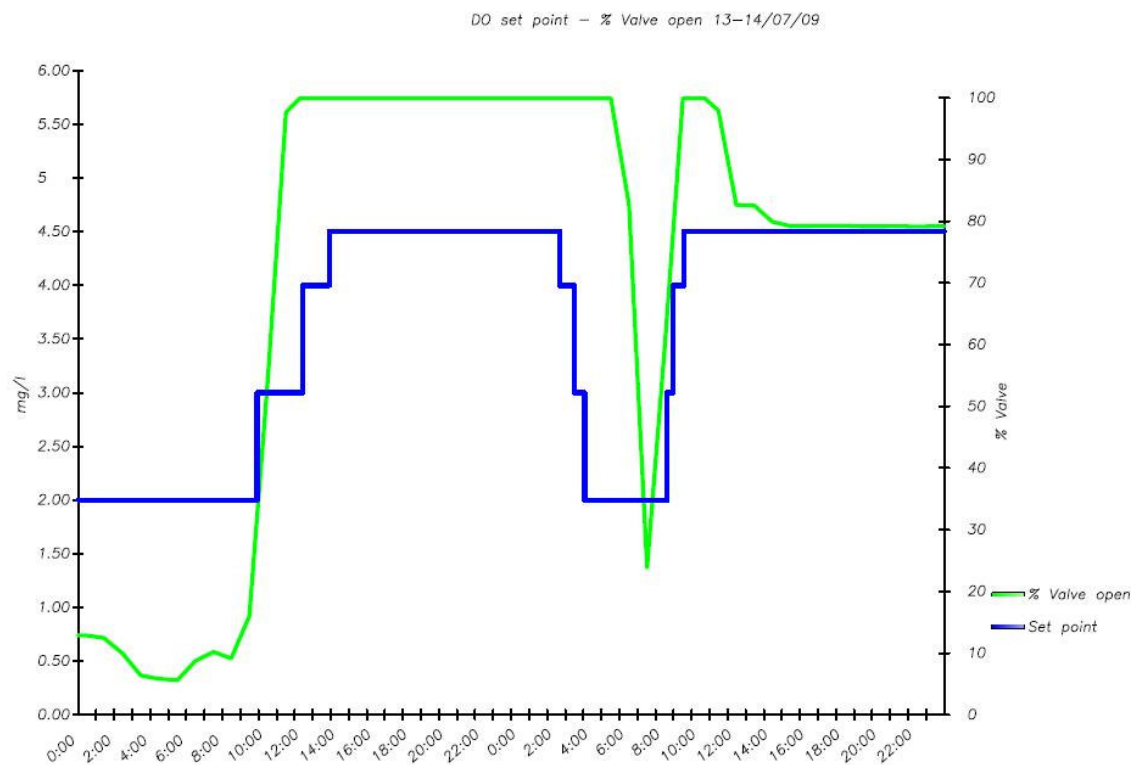


Figure 4-2: Percentage valve of air flow open in tank and DO set point over a period of 48h.

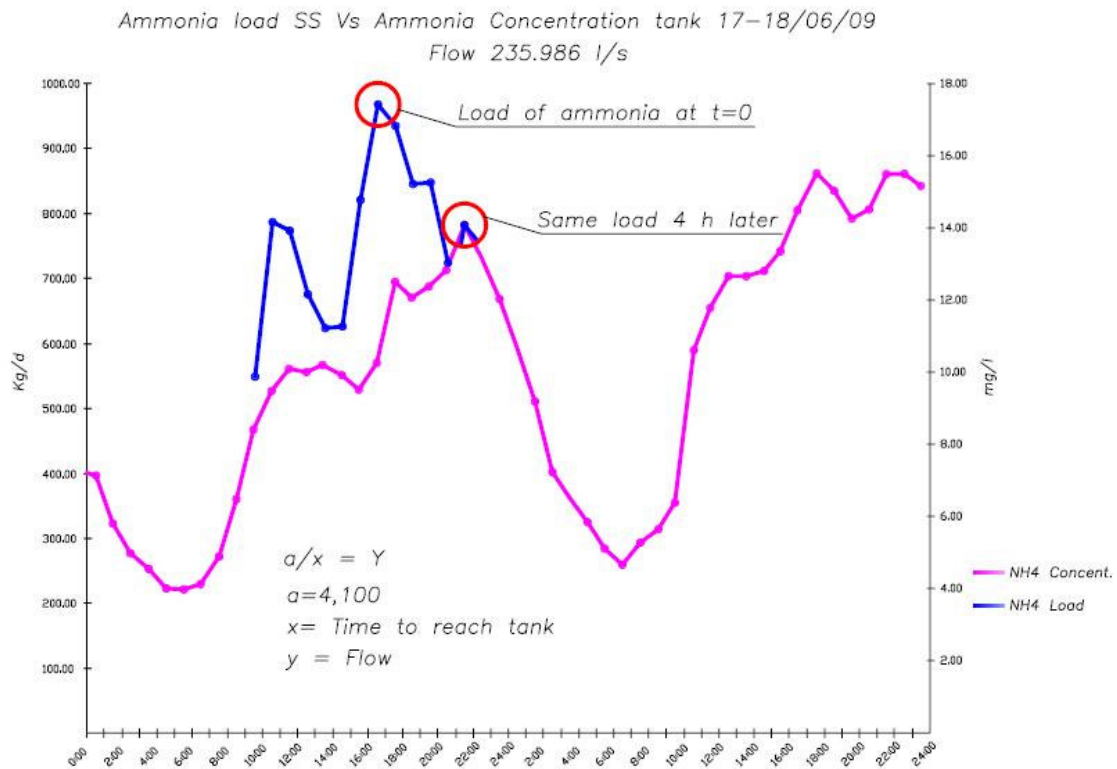


Figure 4-3: Time lag between the load ammonia is detected in the settle sewage till arrive at the tank as concentration of ammonia

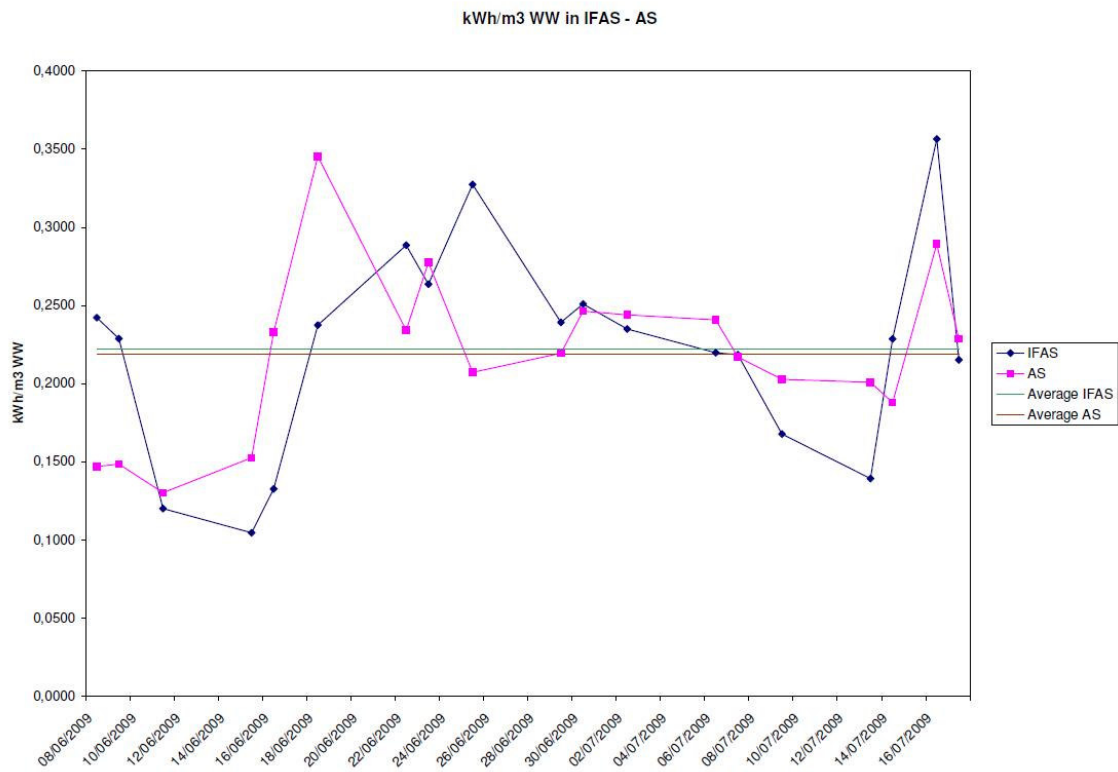


Figure 4-4: Total and average of power consumption per m³ of wastewater arriving at the IFAS and AS process

Tables.

Table 4-1: IFAS and AS lanes design criteria and actual received flows and loadings of ammonia, BOD₅ and TSS during a 60 day period

Process	Parameter	Unit	Design	Received Average	Max	Min
IFAS						
	Flow	l/s	168.646	153.124	232.376	94.217
	NH ₄ -N	kg/d	323.0	581.9	774.4	423.3
	BOD ₅	Kg/d	1,298.0	2,897.5	5,344.6	2,144.9
	TSS	Kg/d	1,574.0	3,328.5	7,295.5	1,916.5
AS						
	Flow	l/s	155.509	144.137	229.612	71.656
	NH ₄ -N	Kg/d	423.0	548.5	910.4	263.8
	BOD ₅	Kg/d	1,849.0	2,735.9	4,858.2	1,209.4
	TSS	Kg/d	1,800.0	3,096.8	6020.1	1,432.2

Table 4-2: Nitrification rate taste of the MLSS in the AS process, the MLSS in IFAS process and the media

24th June		Jar 1 : 4L AS process 2 Mix Liquor + 6L Settle sewage				Jar 2: 4L IFAS process Mix Liquor + 6L Settle sewage				Jar 3: 200 Biofilm chip + 2L Final effluent + 8L Settle sewage			
	Time [min]	DO	Temp	NH ₄	NO ₃	DO	Temp	NH ₄	NO ₃	DO	Temp	NH ₄	NO ₃
	0	4.26	20.3	25.5	2.8	4	20.4	26.6	0.5	3.98	20.4	35.6	2.1
	20	3.96	20.1	24.3		3.94	20.1	25.4		4.1	20.1	34.3	
	40	4.07	19.9	22.4		4.12	19.9	24.5		3.9	19.9	33.8	
	60	4.06	19.8	21.3	9.1	4.09	19.8	24	3.4	3.96	19.8	33.1	5.8
	80	4.25	19.8	17.9		4.13	19.8	23.4		4.12	19.8	31.8	
	100	4.12	19.8	20		4.2	19.8	21.2		4.04	19.8	30.5	
	120	4.1	19.8	14.4	14.8	4.08	19.9	18.5	6.2	3.94	20	29.6	8.5
	140	4.08	19.9	12.3		4.09	19.9	18		4.19	20	28.1	
	160	4.04	19.9	10.1		4.04	20	18.7		4.31	20	25.9	
	180	3.97	19.9	12		4.04	20	15.4	9	4.06	20	23.9	12.1
Nitrification rate (mg/l/m)		0.088				0.06				0.062			
Nitrification rate		0.471	g/(gMLSS.d)			0.362	g/(gMLSS.d)			0.594	g/(m ² .g.d)		
MLSS [g/L]		0.269				0.24				0			

Table 4-3: relationship between power consumption, AOR load and m³ wastewater arriving at the IFAS and AS process

IFAS process						AS process				
Data	AOR (kg/h)	Air flow (m ³ air/h)	Consump kWh/m ³ air	Consump kWh/m ³ WW	Consump. kWh/kg AOR	AOR (kg/h)	Air flow (m ³ air/h)	Consump kWh/m ³ air	Consump kWh/m ³ WW	Consump. kWh/kg AOR
8-jun	202.77	8,806.59	0.016977	0.24	0.74	258.46	5,431.00	0.021314	0.15	0.45
9-jun	213.87	8,222.24	0.016977	0.23	0.65	265.32	5,265.00	0.021314	0.15	0.42
11-jun	284.59	4,760.56	0.016977	0.12	0.28	321.71	4,861.00	0.021314	0.13	0.32
15-jun	337.23	3,960.23	0.016977	0.10	0.20	387.20	5,532.00	0.021314	0.15	0.30
16-jun	244.06	5,282.13	0.016977	0.13	0.37	151.30	5,348.00	0.021314	0.23	0.75
18-jun	261.24	8,632.88	0.016977	0.24	0.56	158.66	5,846.00	0.021314	0.35	0.79
22-jun	200.40	9,057.79	0.016977	0.29	0.77	196.15	4,898.00	0.021314	0.23	0.53
23-jun	239.60	9,150.00	0.016977	0.26	0.65	188.79	5,607.00	0.021314	0.28	0.63
25-jun	174.47	7,263.93	0.016977	0.33	0.71	254.14	4,802.00	0.021314	0.21	0.40
29-jun	205.25	7,312.30	0.016977	0.24	0.60	209.61	5,460.00	0.021314	0.22	0.56
30-jun	203.92	7,728.58	0.016977	0.25	0.64	197.25	5,808.00	0.021314	0.25	0.63
2-jul	225.14	7,073.83	0.016977	0.23	0.53	231.92	5,886.00	0.021314	0.24	0.54
6-jul	250.25	6,988.38	0.016977	0.22	0.47	218.99	5,286.00	0.021314	0.24	0.51
7-jul	266.83	7,302.79	0.016977	0.22	0.46	273.96	5,907.00	0.021314	0.22	0.46
9-jul	222.81	5,488.34	0.016977	0.17	0.42	213.25	5,006.00	0.021314	0.20	0.50
13-jul	221.94	4,445.03	0.016977	0.14	0.34	220.55	5,012.00	0.021314	0.20	0.48
14-jul	301.00	7,979.34	0.016977	0.23	0.45	310.65	5,216.00	0.021314	0.19	0.36
16-jul	255.90	8,294.04	0.016977	0.36	0.55	281.29	5,856.00	0.021314	0.29	0.44
17-jul	376.60	8,268.33	0.016977	0.22	0.37	310.23	5,769.00	0.021314	0.23	0.40
20-jul	246.62	7,451.15	0.016977	0.22	0.51					
21-jul	264.88	7,908.50	0.016977	0.20	0.51					
23-jul	287.40	5,539.60	0.016977	0.12	0.33					
24-jul	239.42	7,360.71	0.016977	0.19	0.52					
27-jul	216.24	6,385.87	0.016977	0.22	0.50					
29-jul	258.07	7,294.05	0.016977	0.21	0.48					
30-jul	244.01	6,790.89	0.016977	0.18	0.47					
Avera	247.87	7,105.70		0.21373	0.515	244.71	5,410.32		0.21850	0.499

Appendix

Appendix A: Air flow and concentration of $\text{NH}_4\text{-N}$

Appendix B: Excess and deficit of aeration when the feedback control system is operational

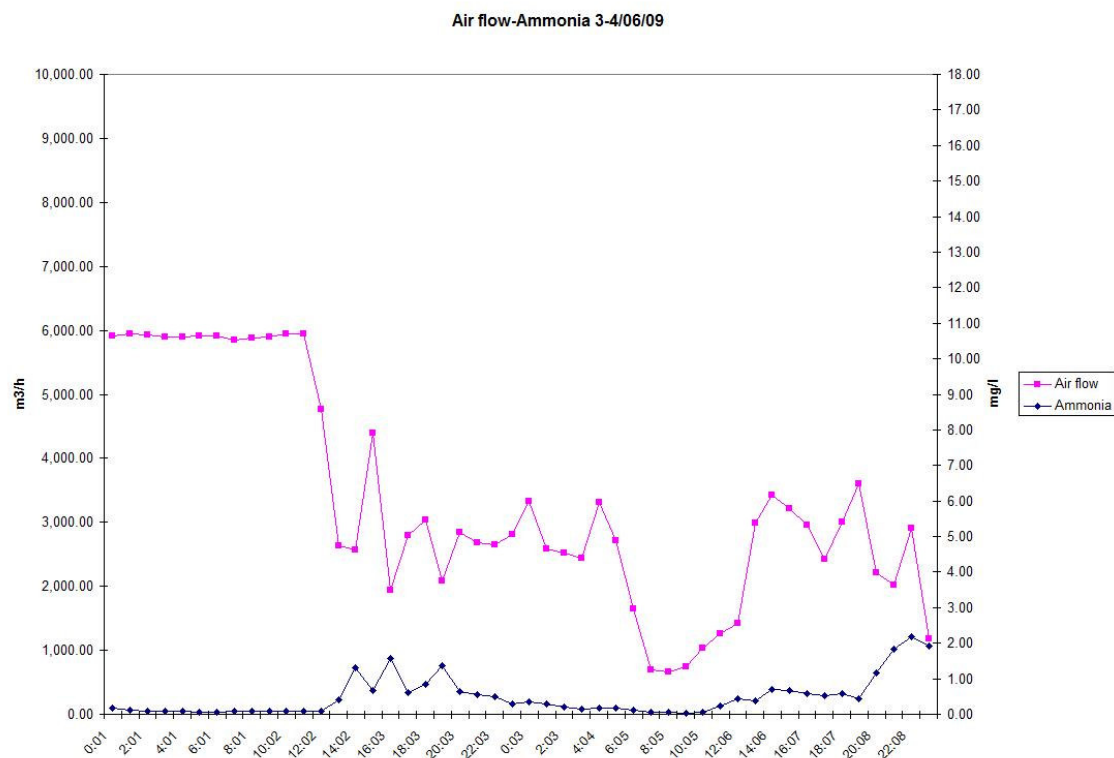
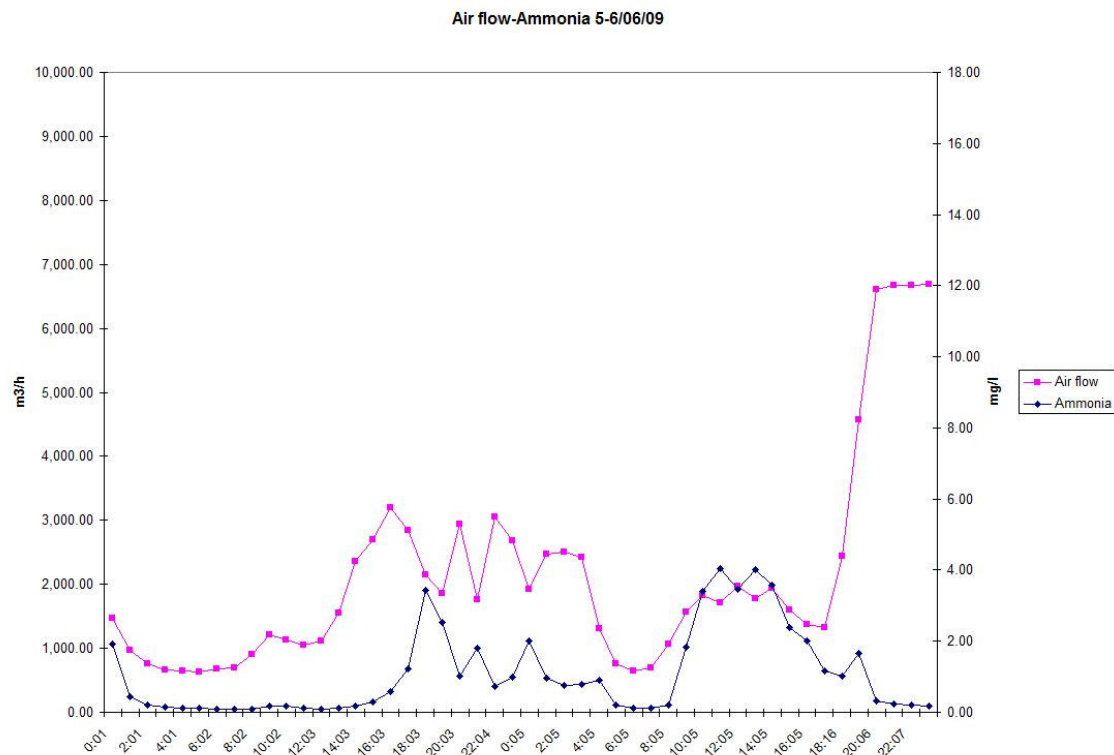
Appendix C: Percentage valve of air flow open in tank and DO set point

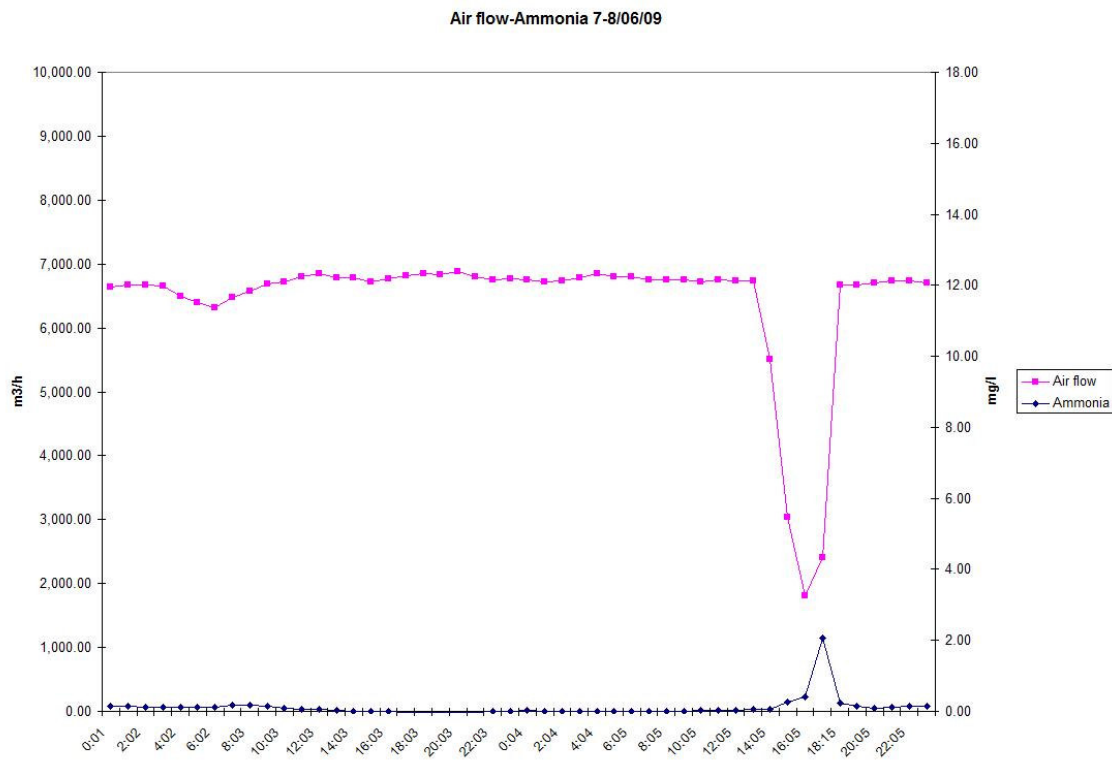
Appendix D: Total and average of power consumption per m^3 of wastewater arriving at the IFAS and AS process

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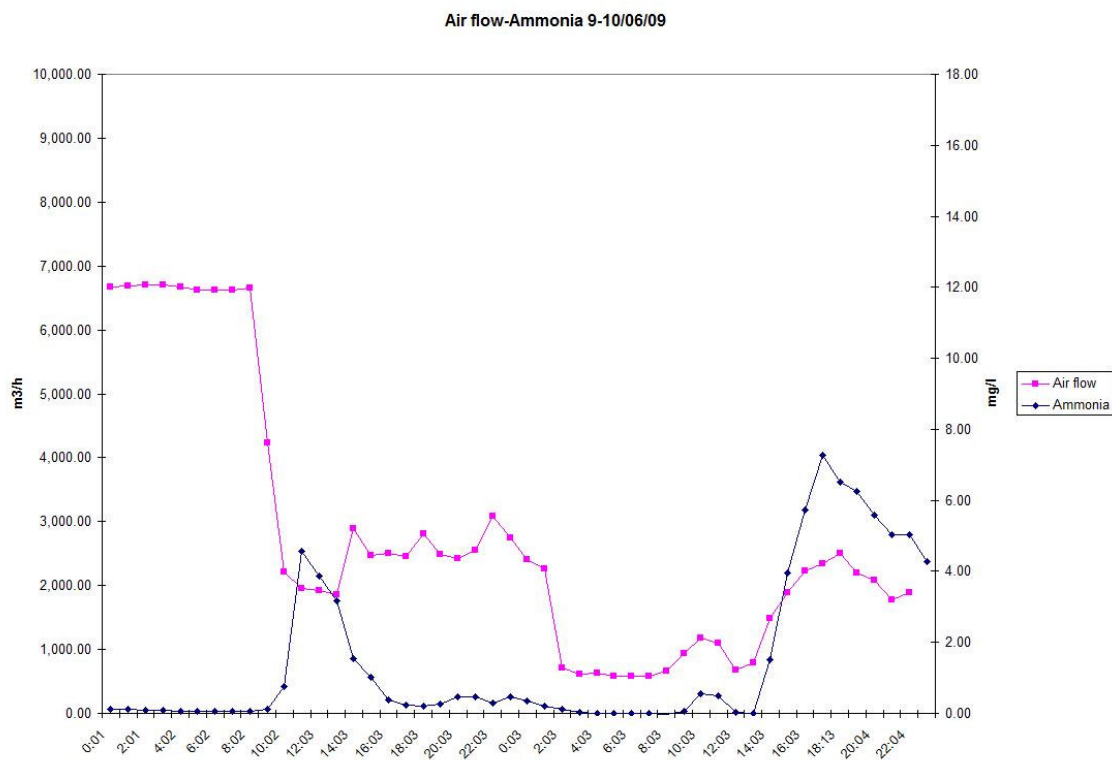
Appendix E: Theoretical air flow, real air flow, power consumption, AOR load and m^3 wastewater arriving at the IFAS and AS process

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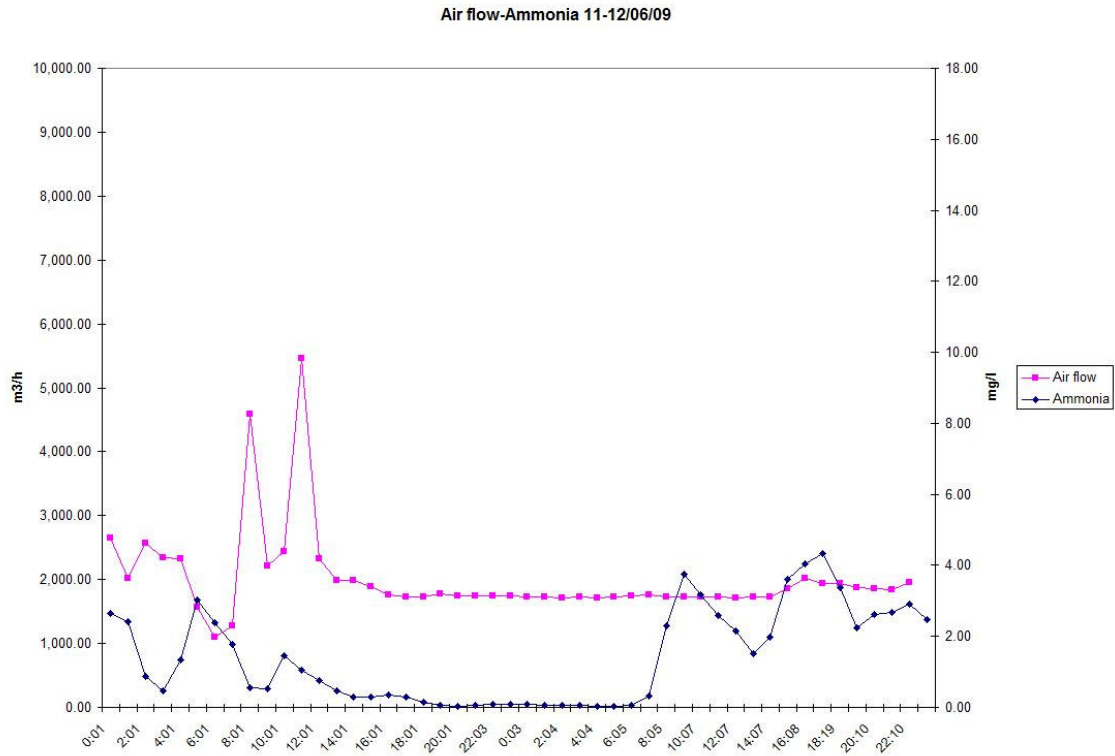
Appendix A: Air flow and concentration of $\text{NH}_4\text{-N}$ Air flow and concentration of $\text{NH}_4\text{-N}$ from 3rd till 4th of JuneAir flow and concentration of $\text{NH}_4\text{-N}$ from 5th till 6th of June



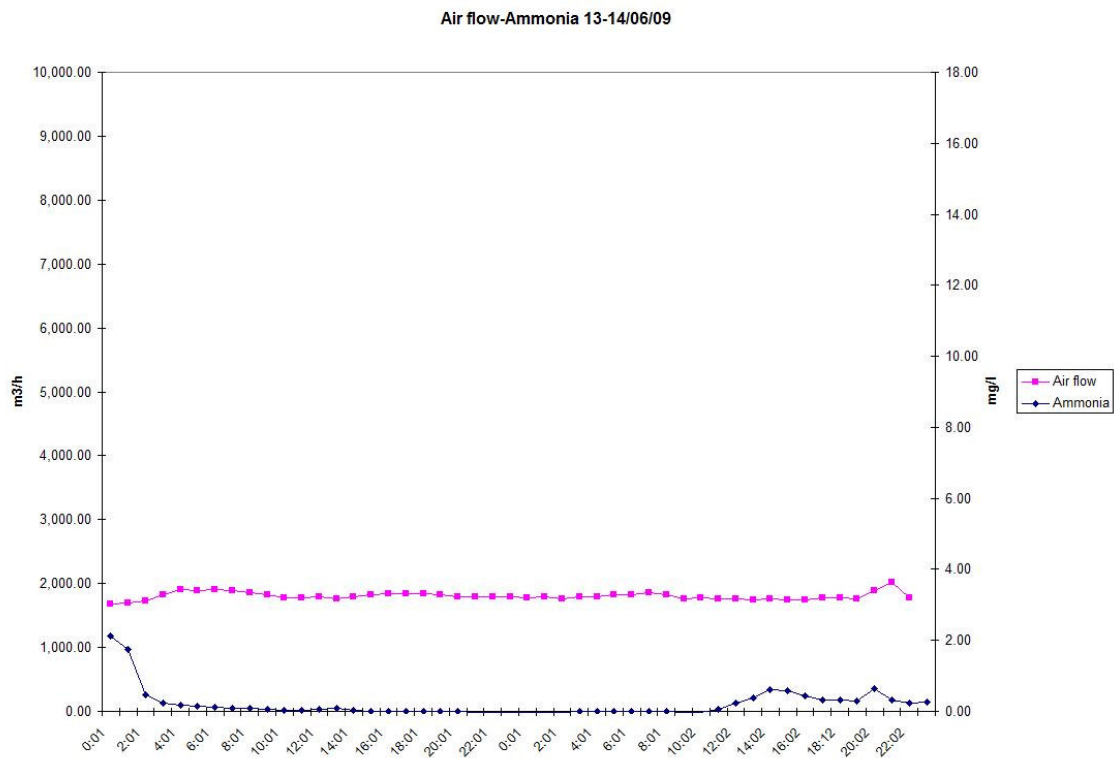
Air flow and concentration of $\text{NH}_4\text{-N}$ from 7th till 8th of June



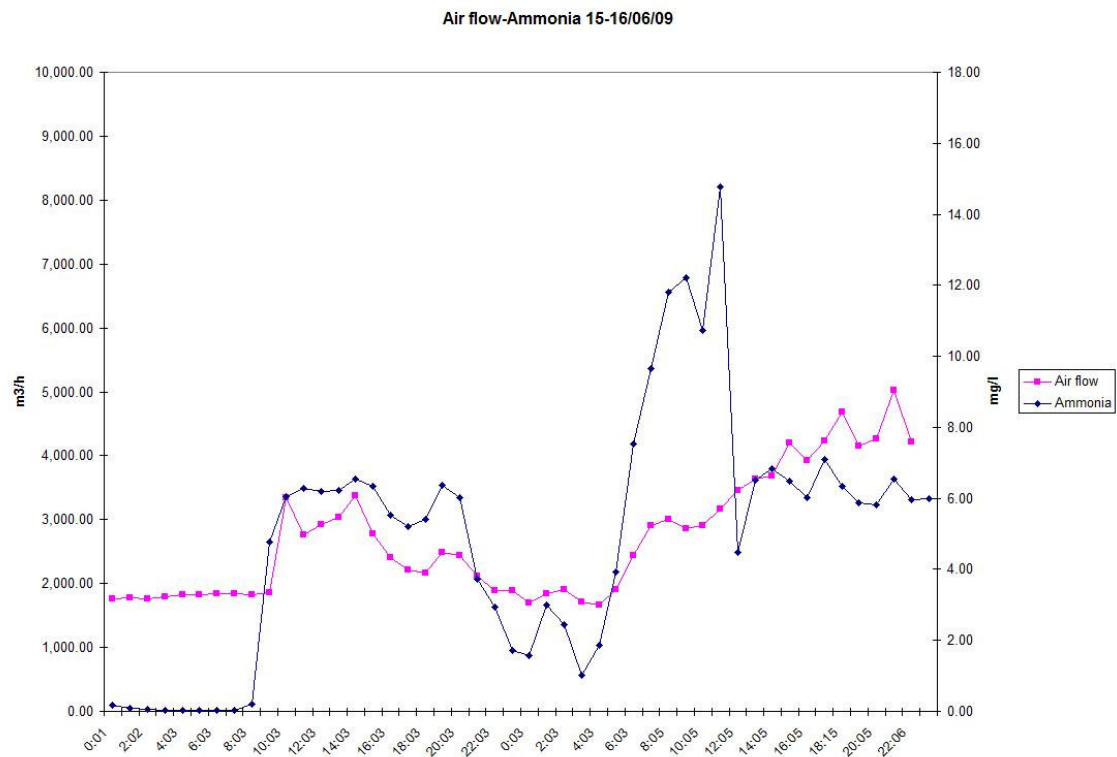
Air flow and concentration of $\text{NH}_4\text{-N}$ from 9th till 10th of June



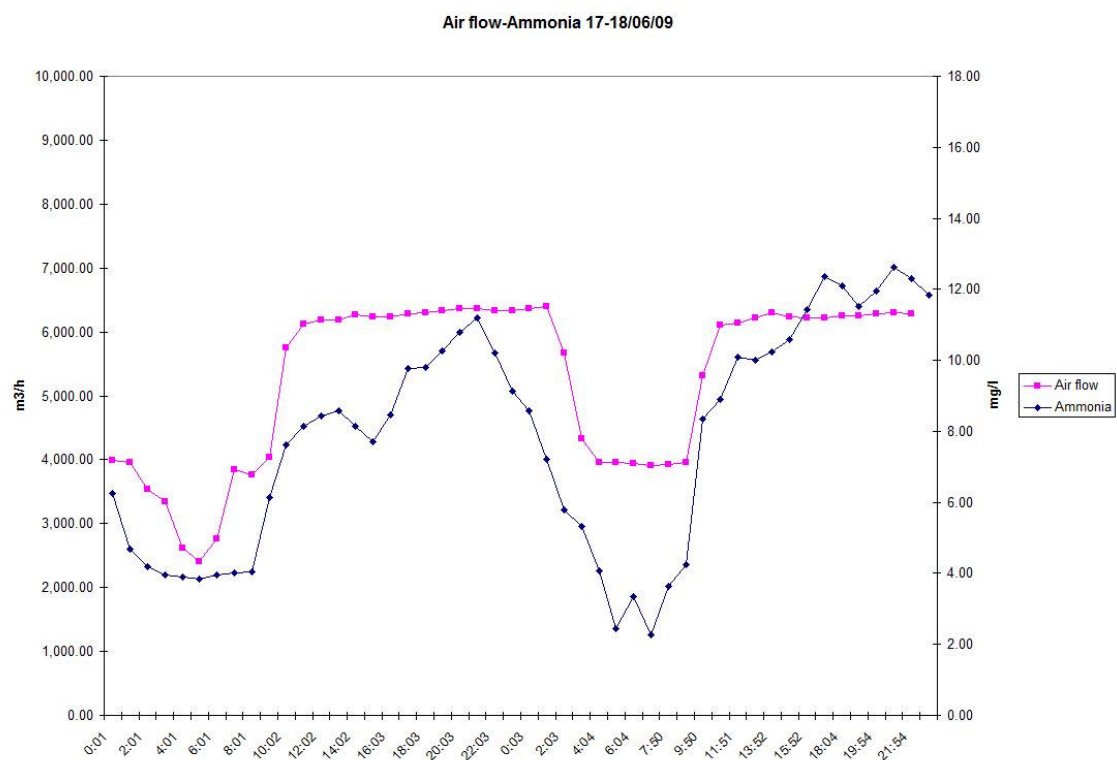
Air flow and concentration of $\text{NH}_4\text{-N}$ from 11th till 12th of June



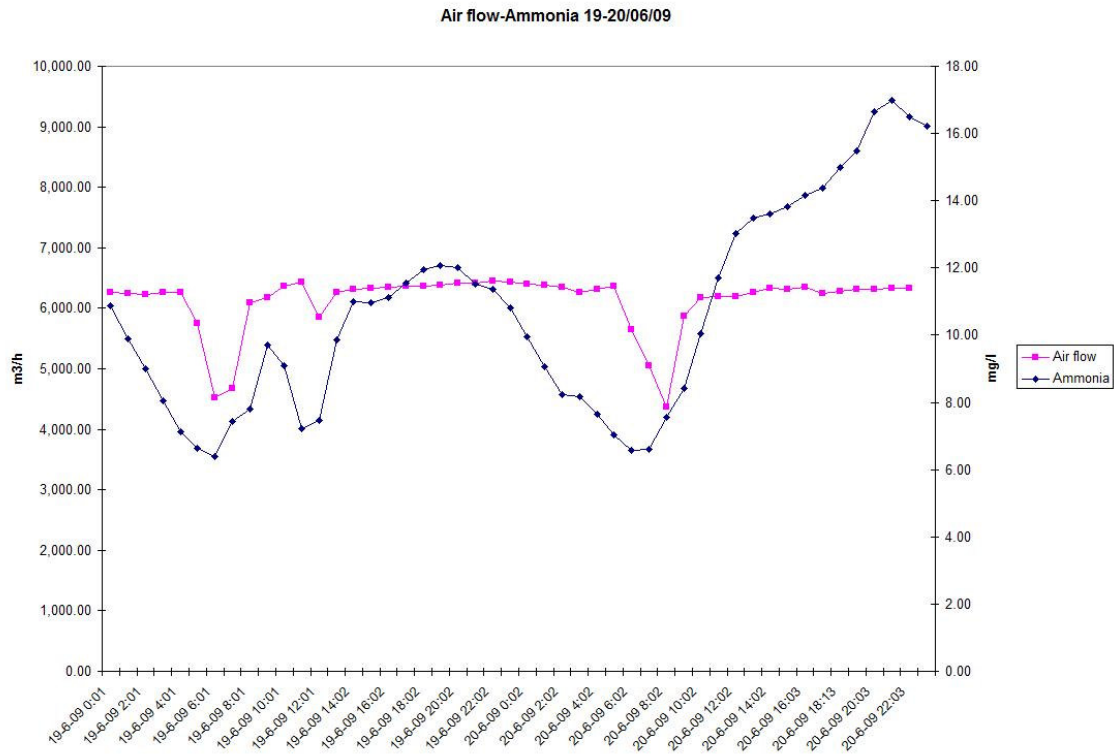
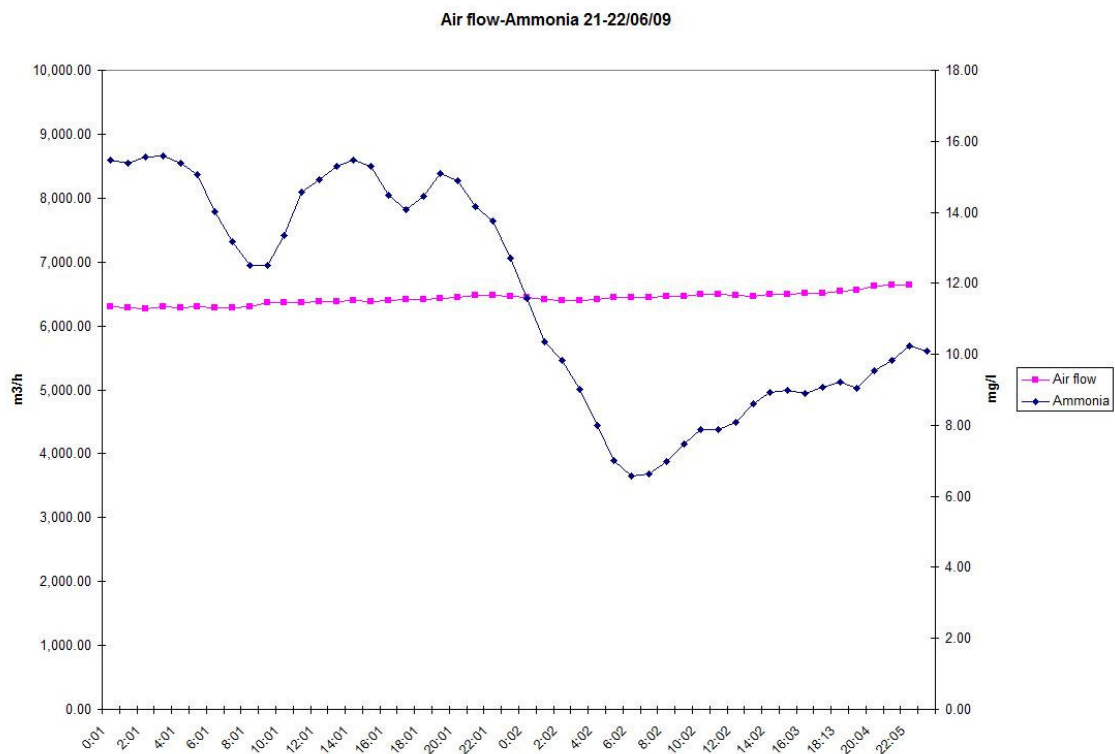
Air flow and concentration of $\text{NH}_4\text{-N}$ from 13th till 14th of June

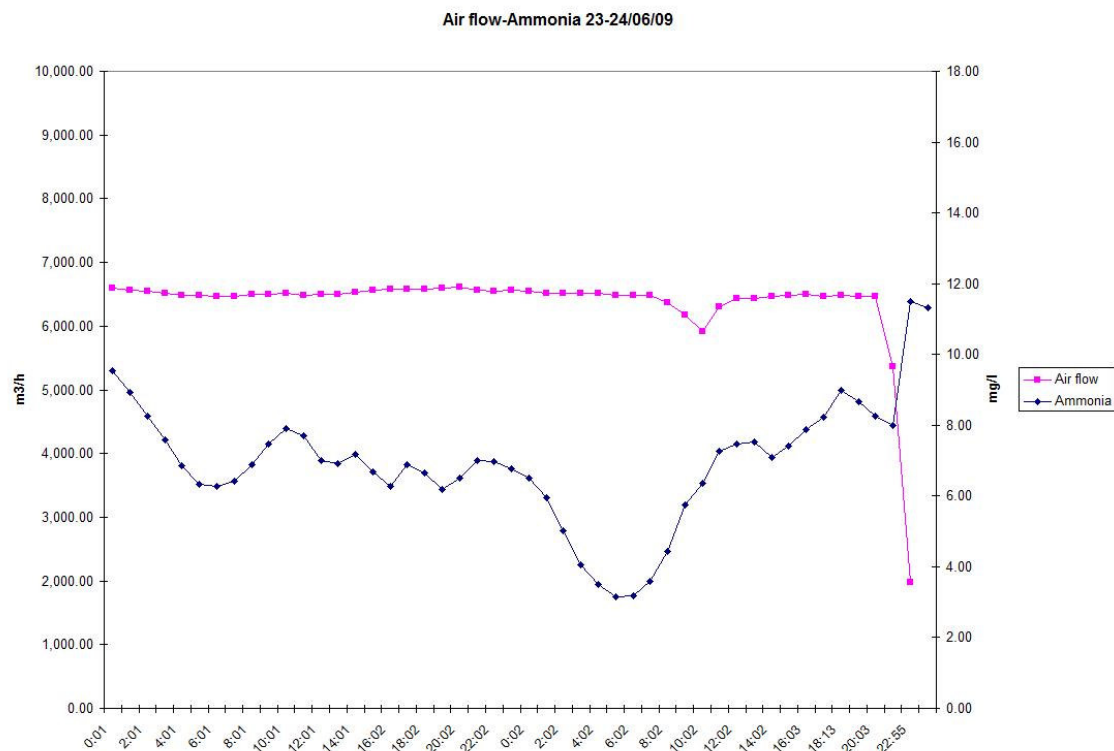


Air flow and concentration of $\text{NH}_4\text{-N}$ from 15th till 16th of June

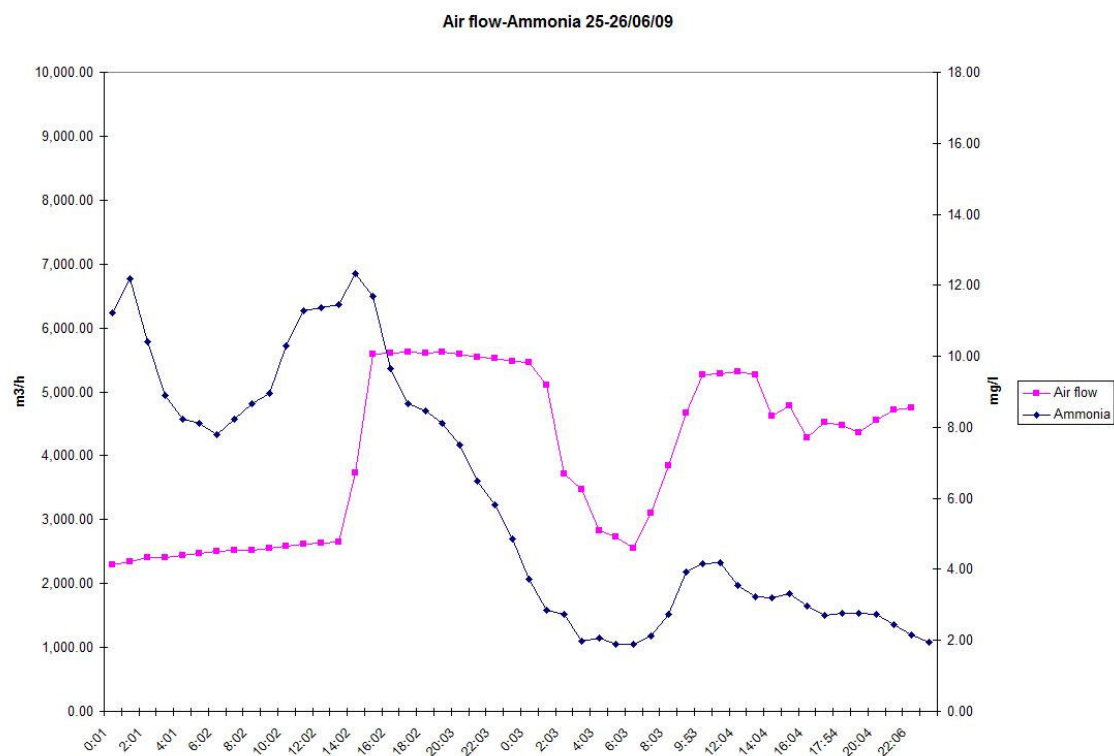


Air flow and concentration of $\text{NH}_4\text{-N}$ from 17th till 18th of June

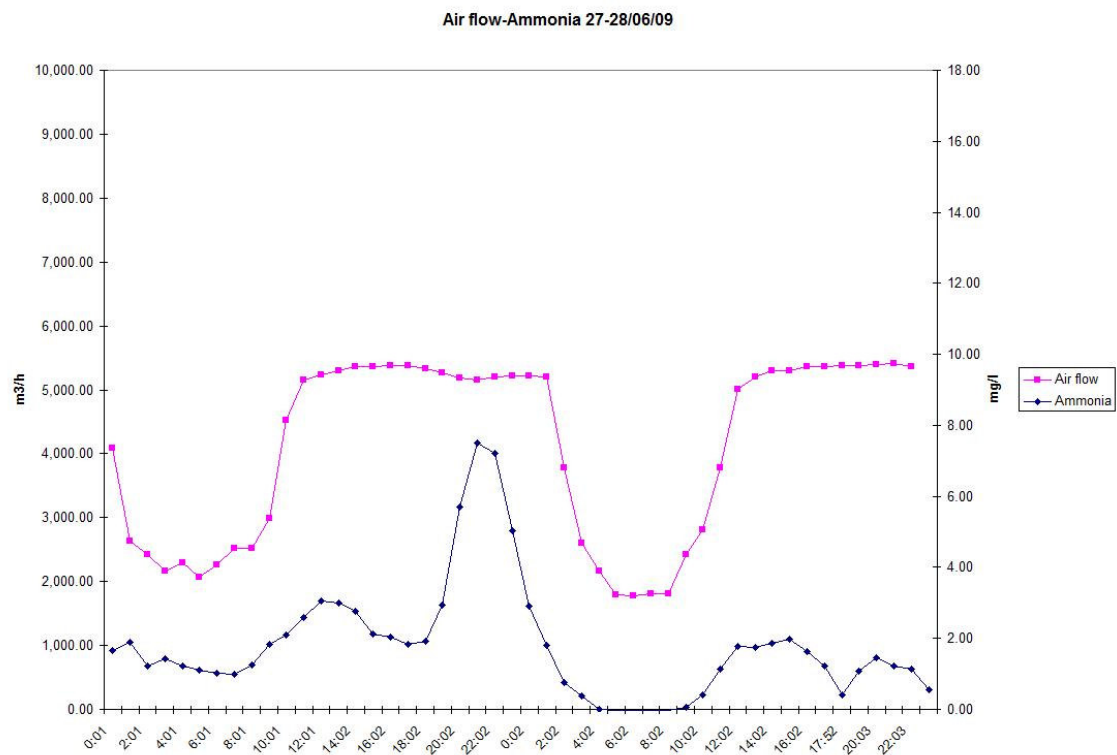




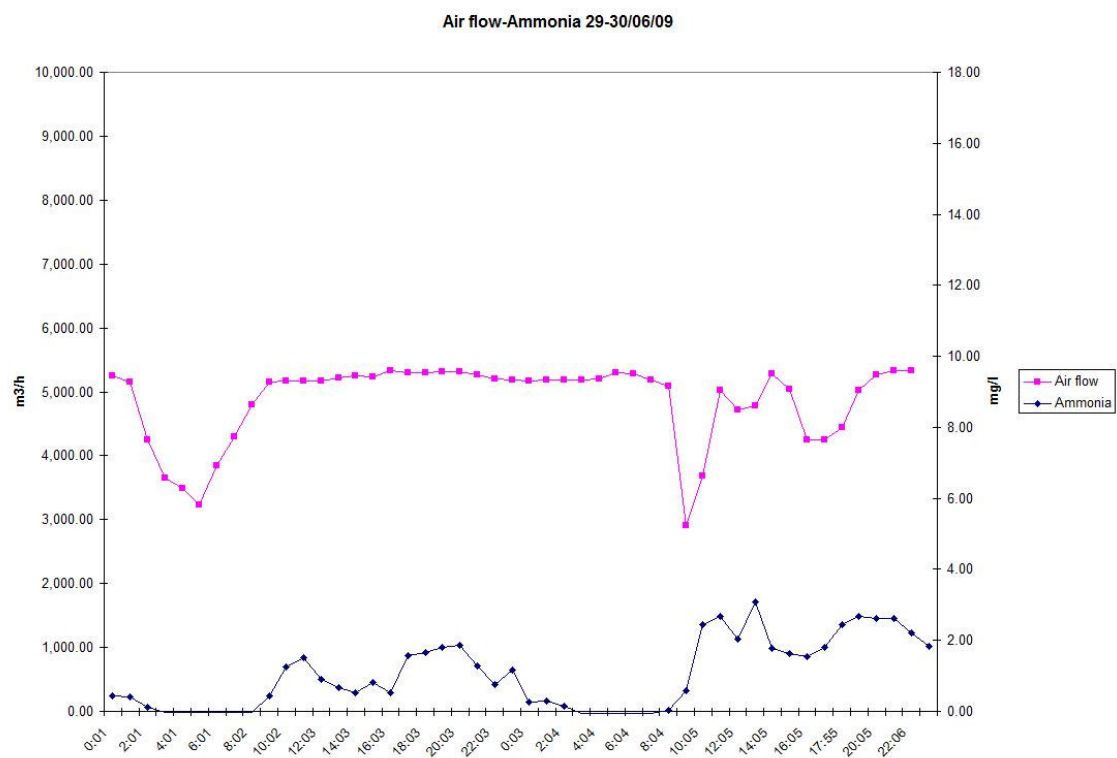
Air flow and concentration of $\text{NH}_4\text{-N}$ from 23rd till 24th of June



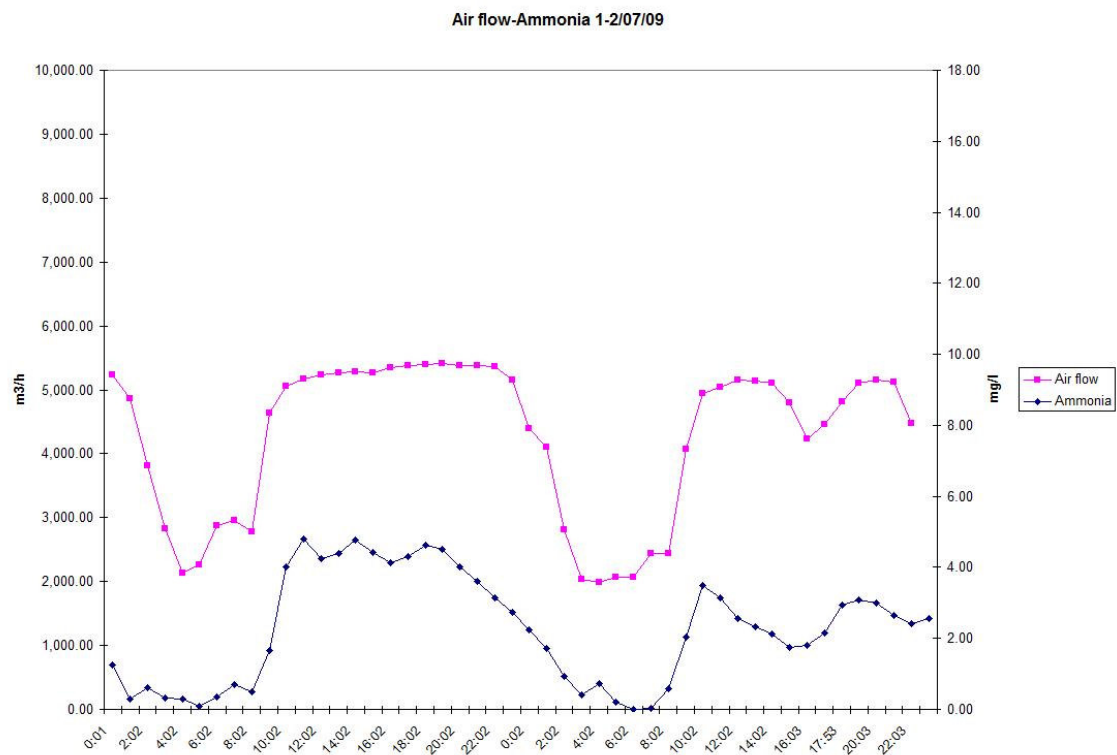
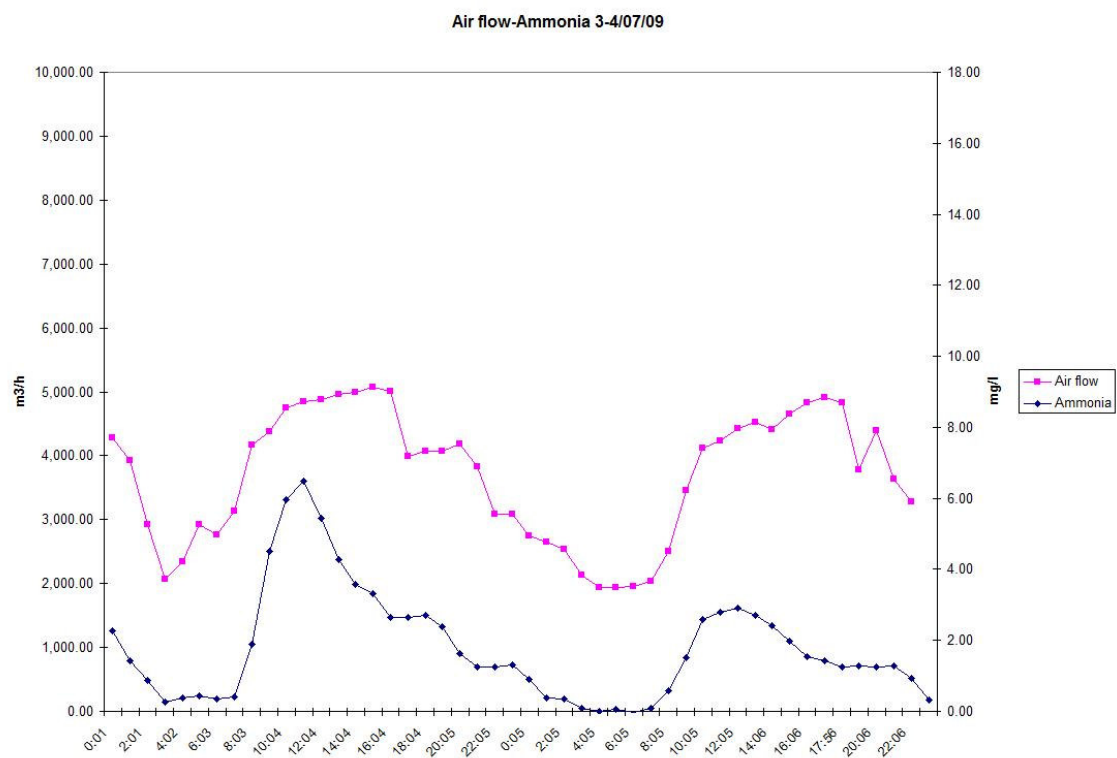
Air flow and concentration of $\text{NH}_4\text{-N}$ from 25th till 26th of June

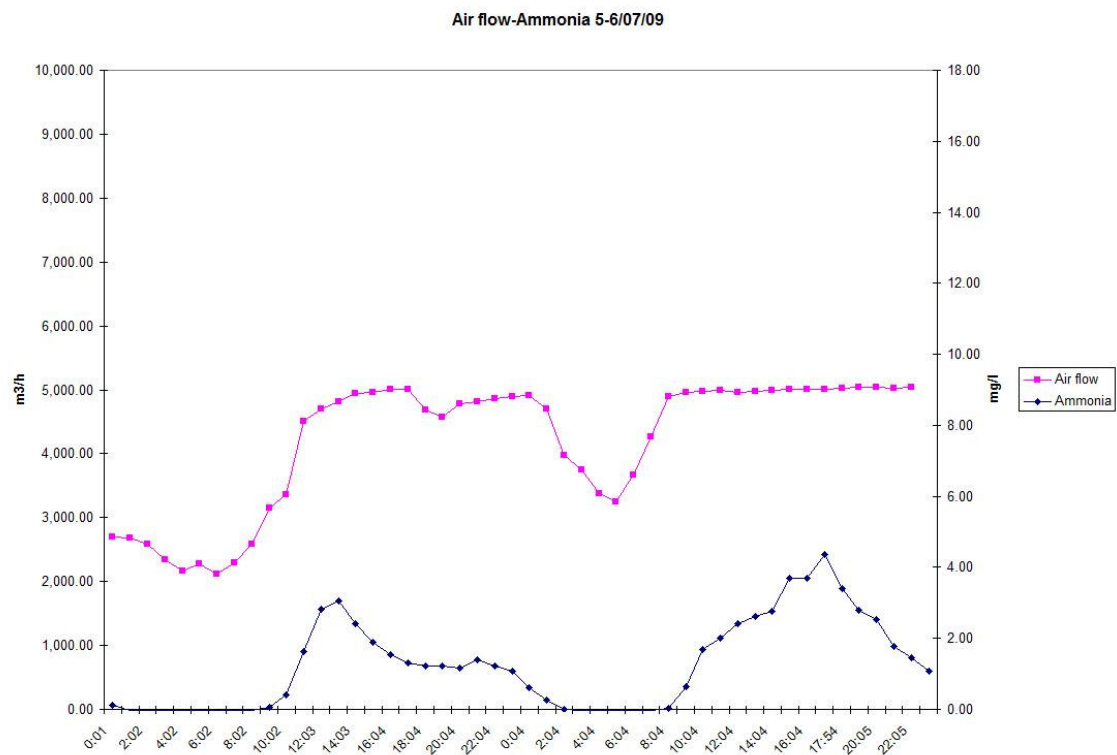
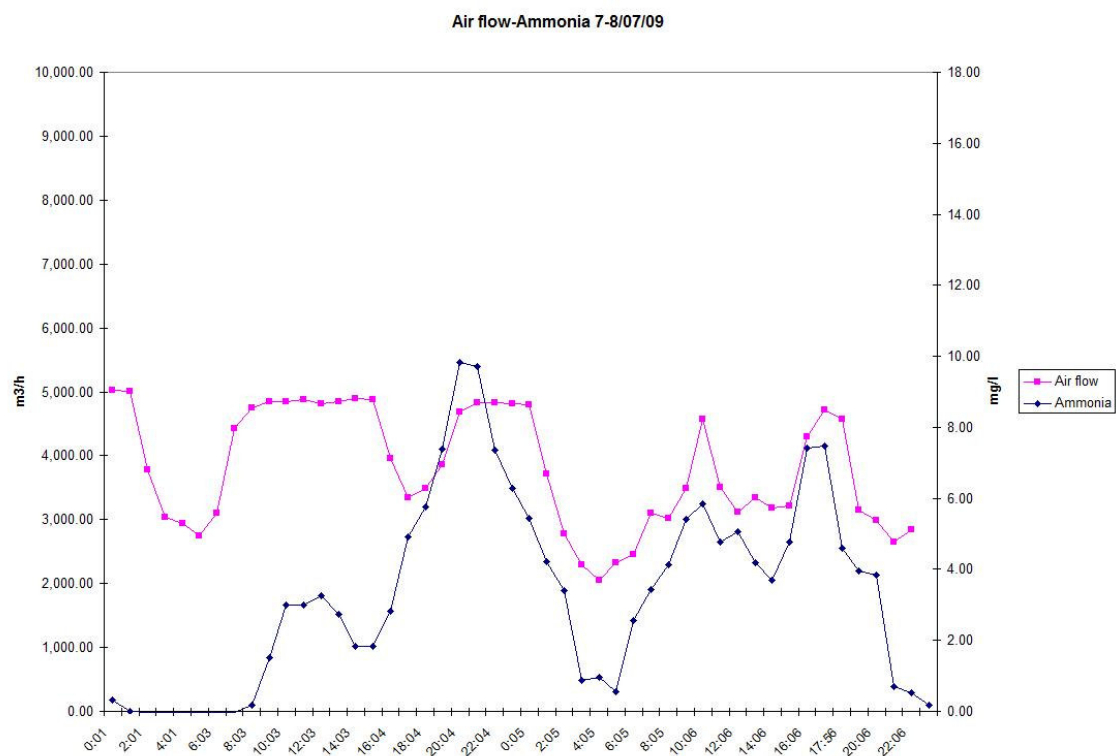


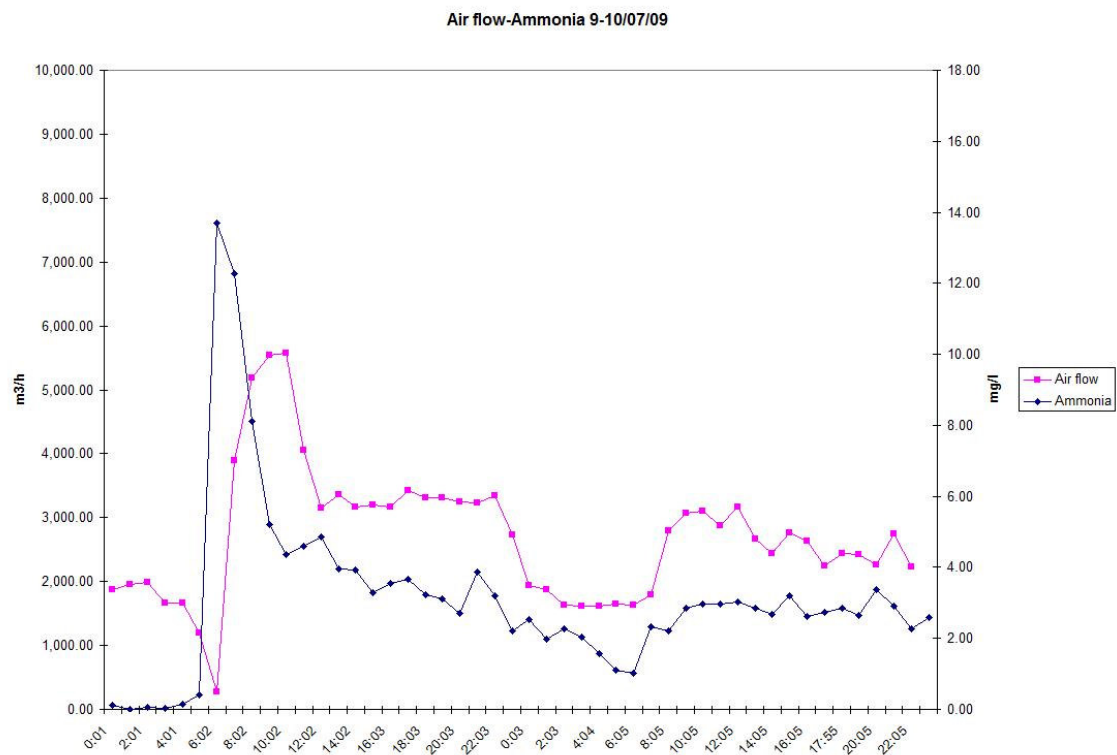
Air flow and concentration of $\text{NH}_4\text{-N}$ from 27th till 28th of June



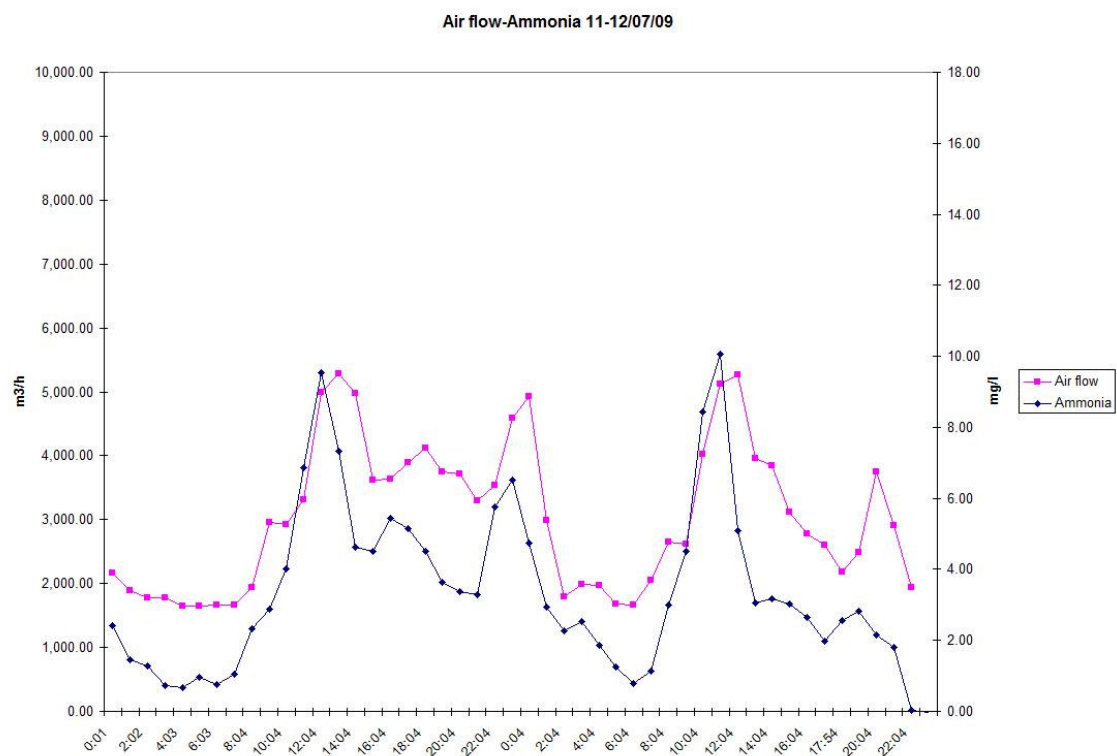
Air flow and concentration of $\text{NH}_4\text{-N}$ from 29th till 30th of June



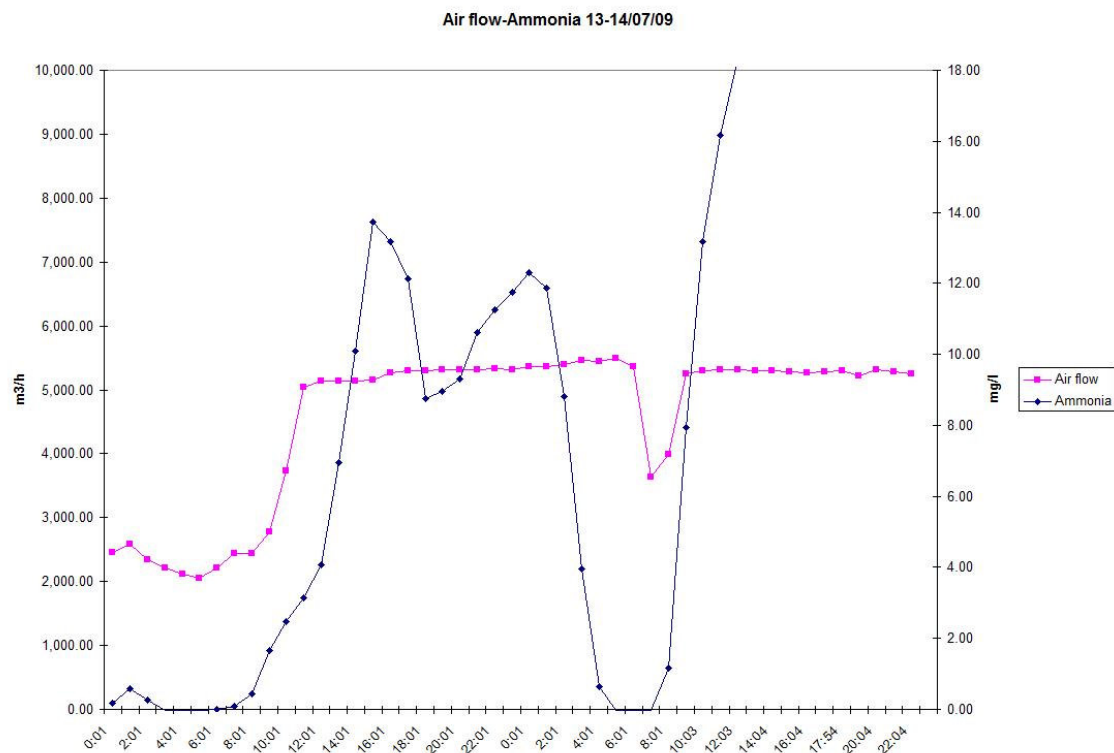
Air flow and concentration of $\text{NH}_4\text{-N}$ from 5th till 6th of JulyAir flow and concentration of $\text{NH}_4\text{-N}$ from 7th till 8th of July



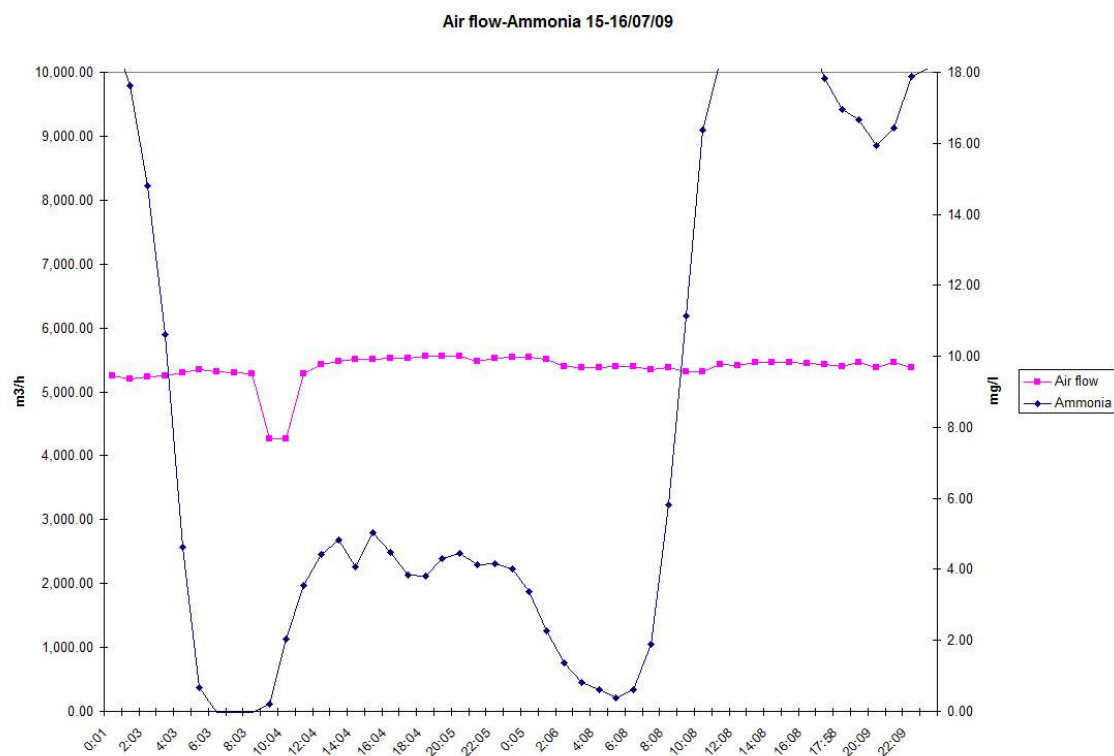
Air flow and concentration of $\text{NH}_4\text{-N}$ from 9th till 10th of July



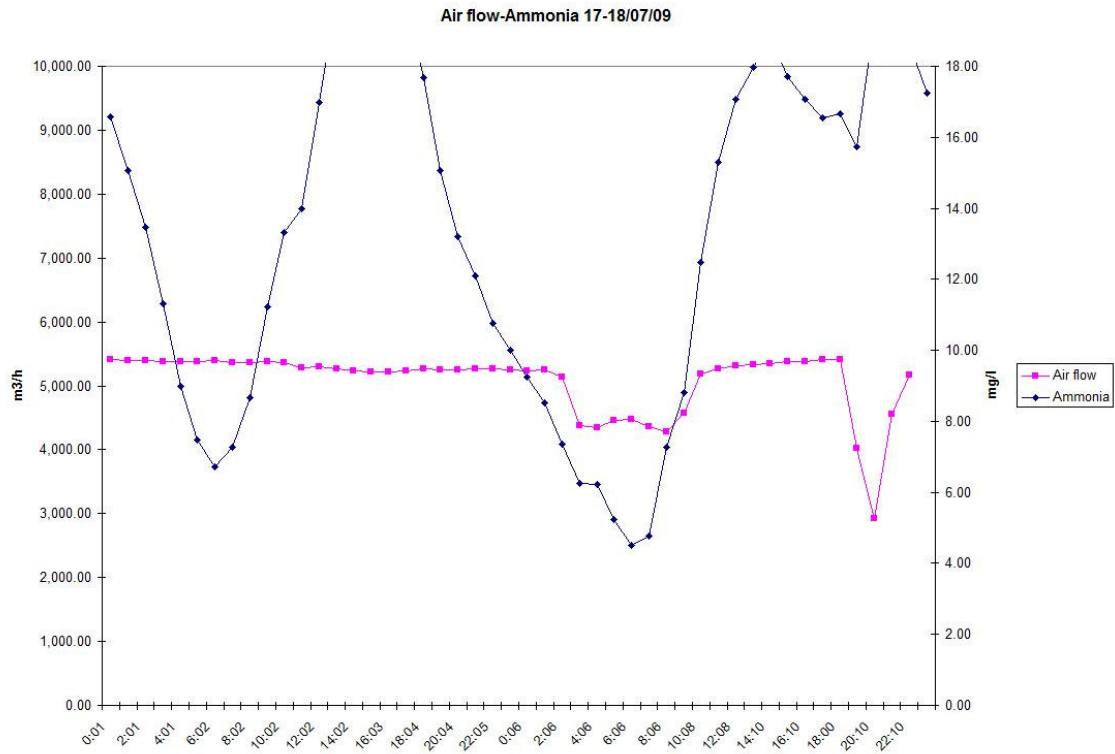
Air flow and concentration of $\text{NH}_4\text{-N}$ from 11th till 12th of July



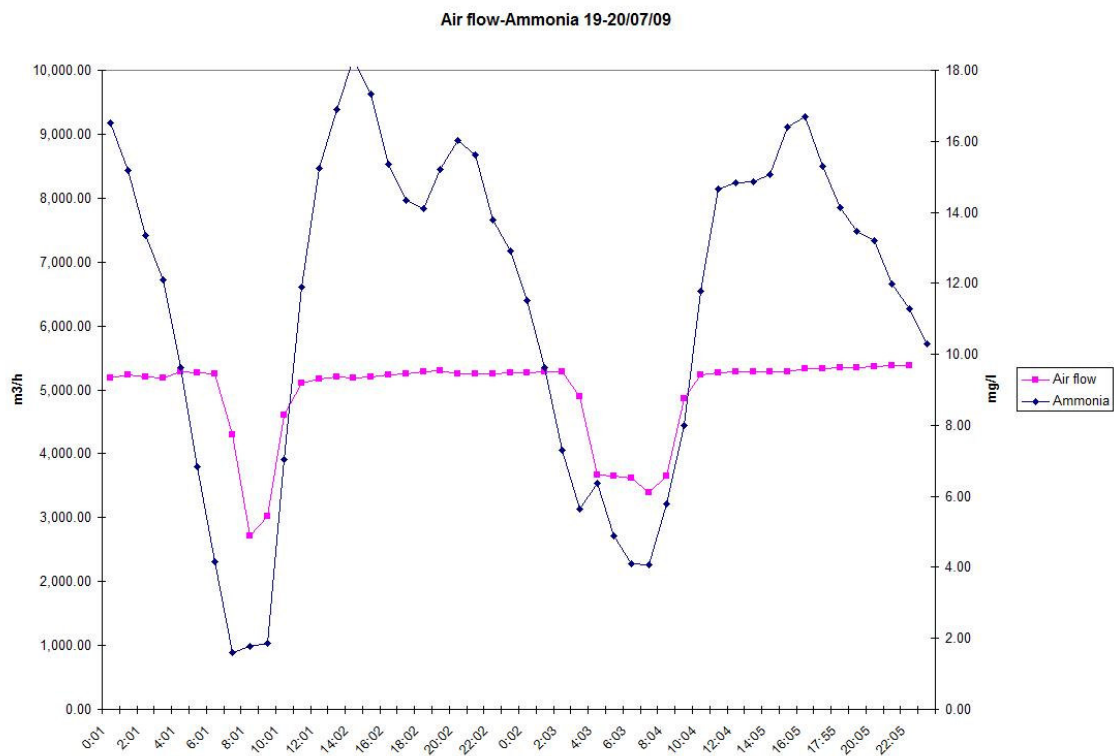
Air flow and concentration of $\text{NH}_4\text{-N}$ from 13th till 14th of July



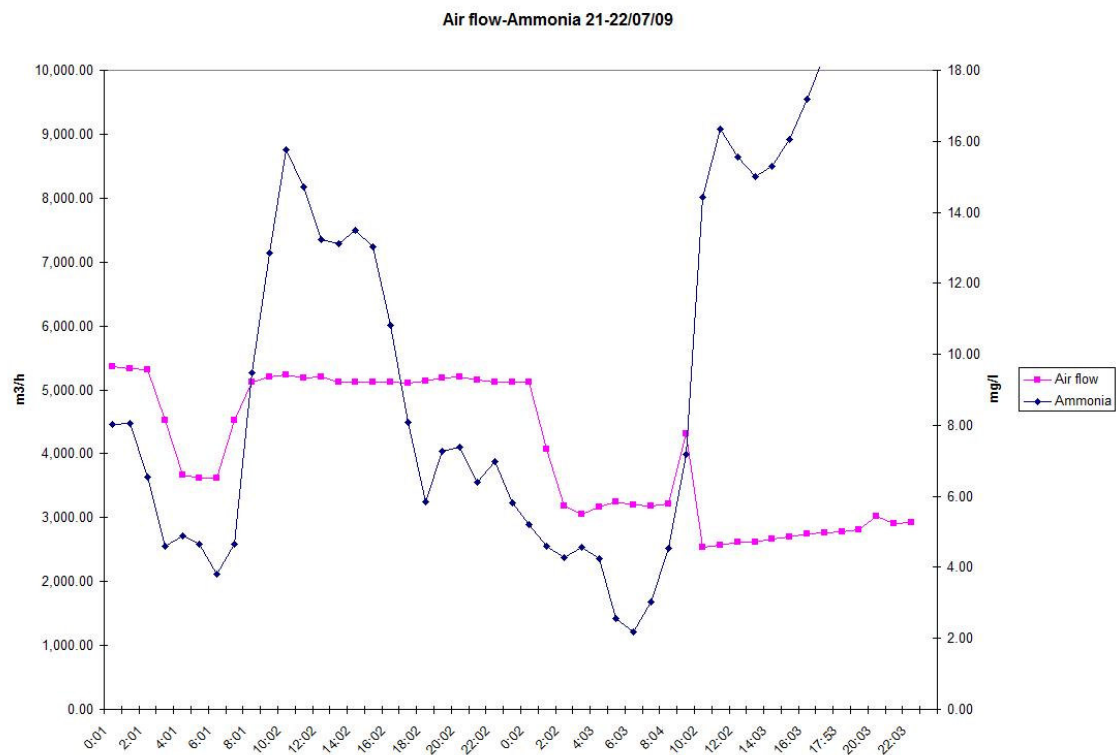
Air flow and concentration of $\text{NH}_4\text{-N}$ from 15th till 16th of July



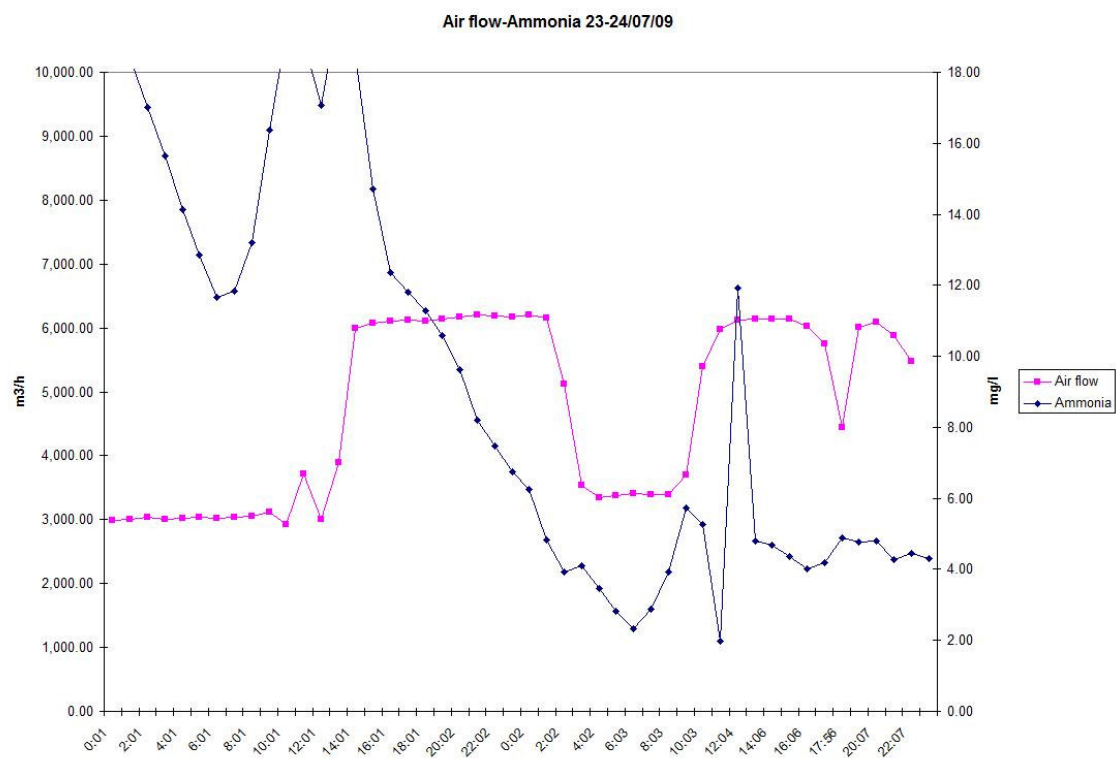
Air flow and concentration of $\text{NH}_4\text{-N}$ from 17th till 18th of July



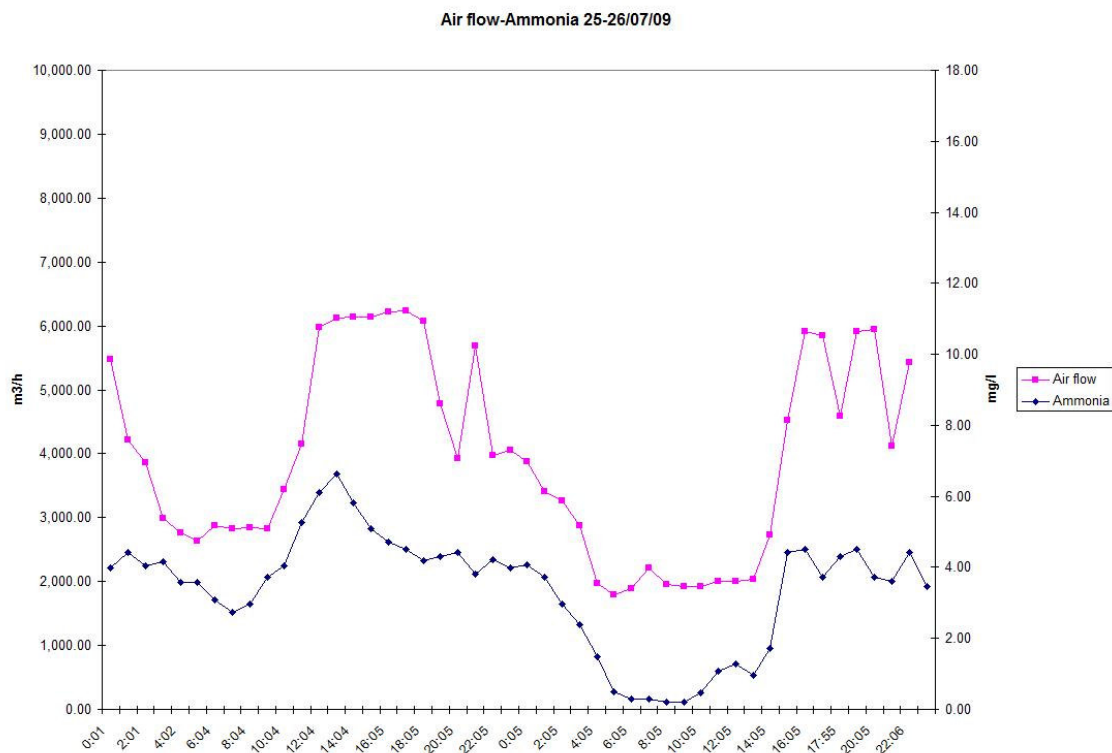
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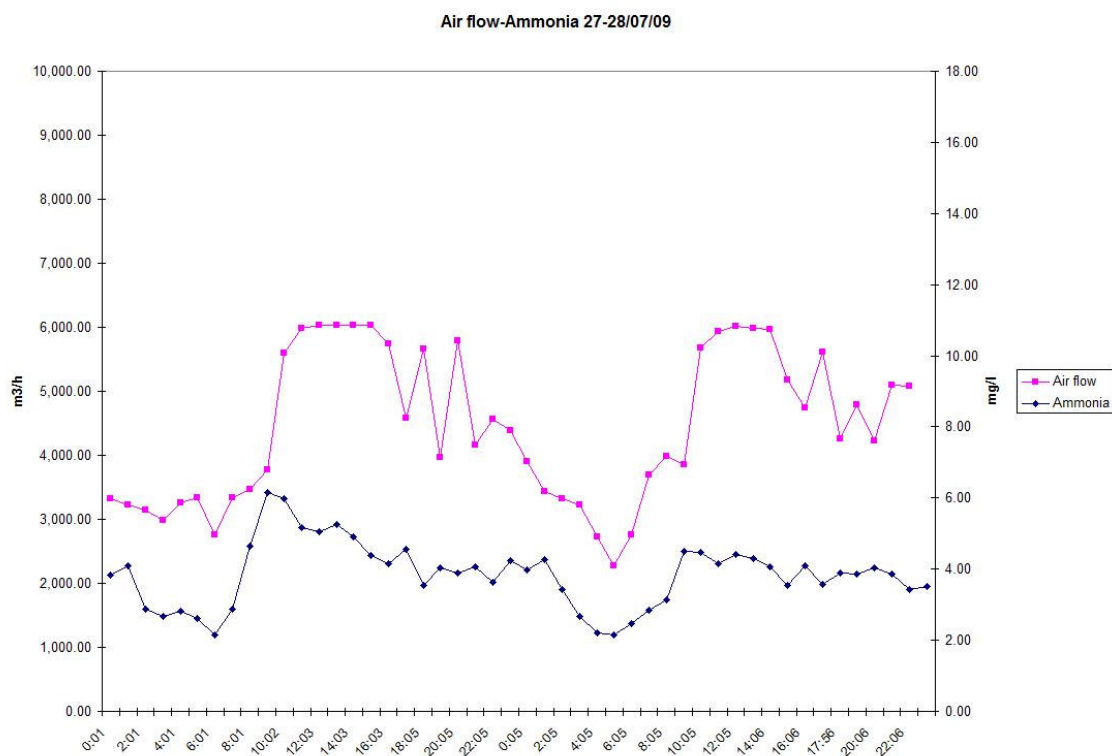
Air flow and concentration of $\text{NH}_4\text{-N}$ from 21st till 22nd of July



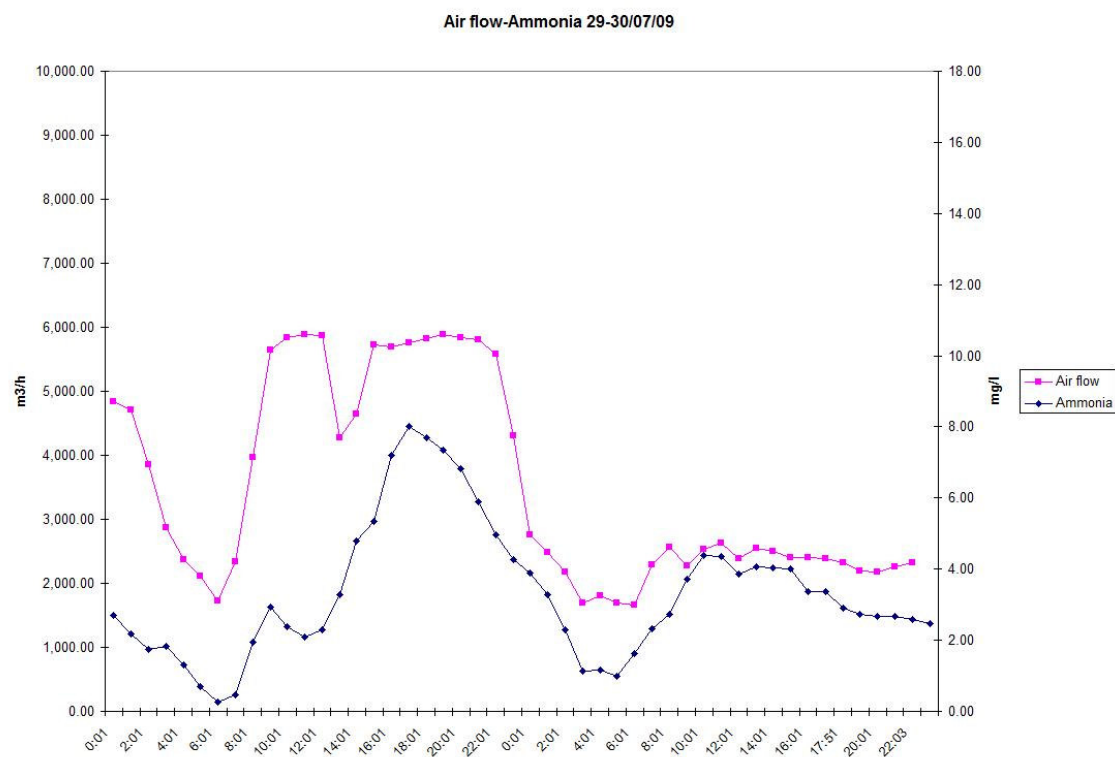
Air flow and concentration of $\text{NH}_4\text{-N}$ from 23rd till 24th of July



Air flow and concentration of $\text{NH}_4\text{-N}$ from 25th till 26th of July

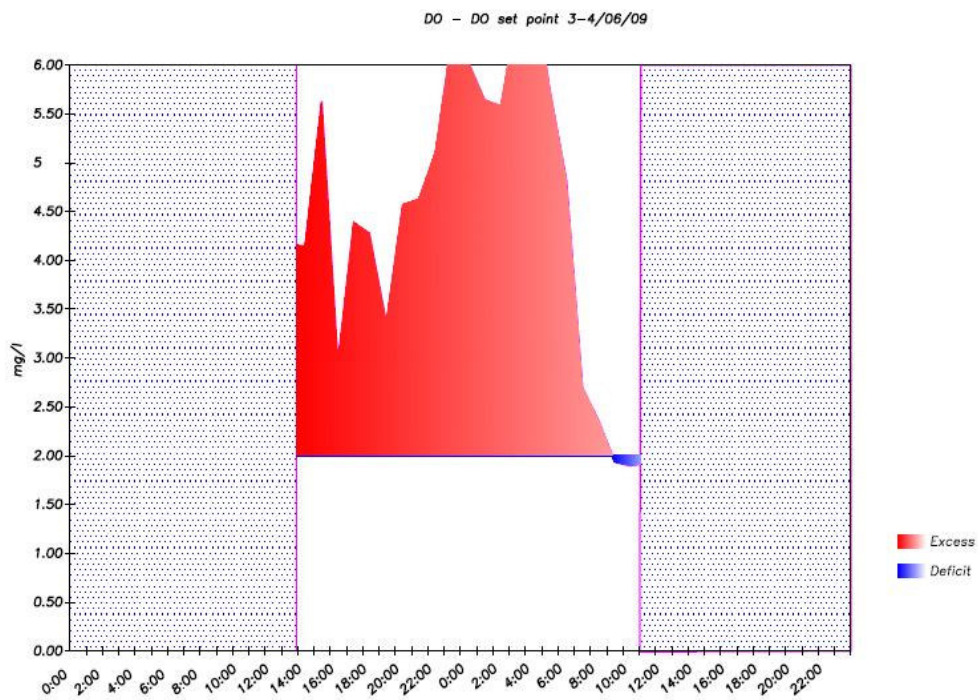


Air flow and concentration of $\text{NH}_4\text{-N}$ from 27th till 28th of July

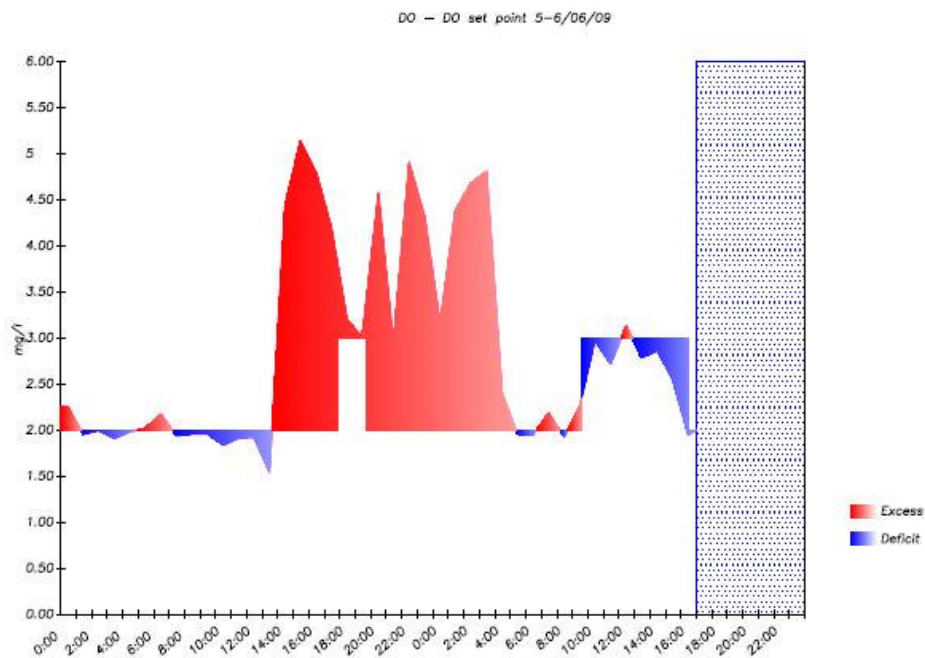


Air flow and concentration of $\text{NH}_4\text{-N}$ from 29th till 30th of July

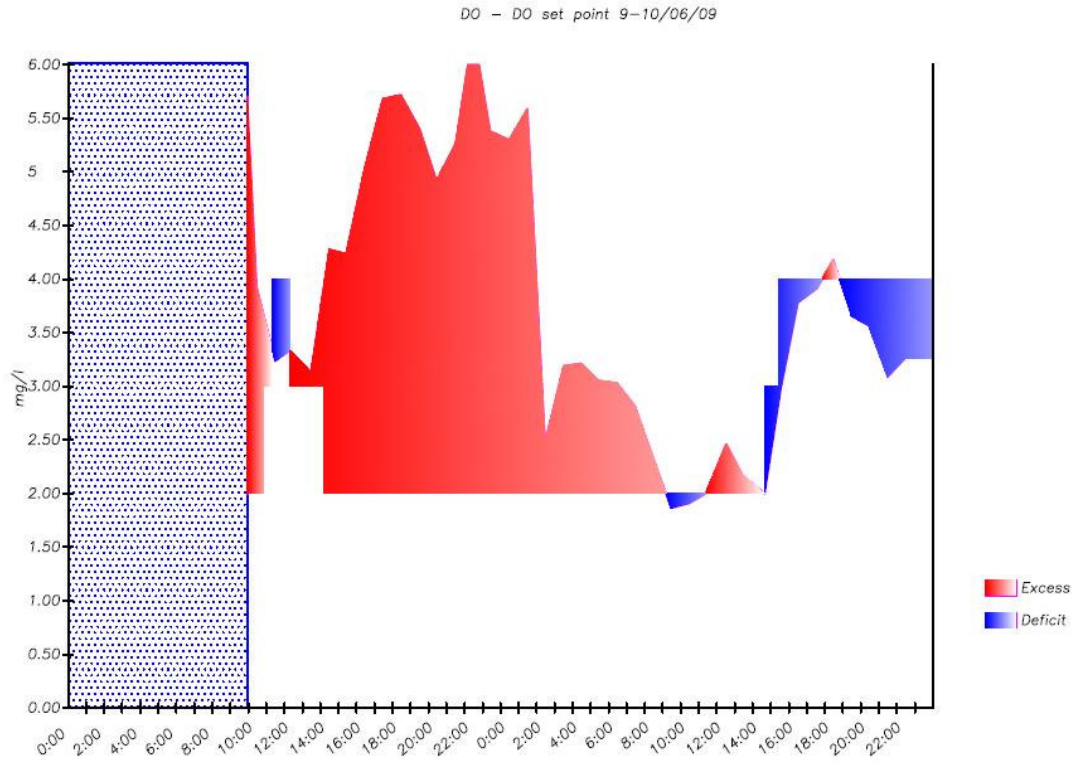
Appendix B: Excess and deficit of aeration when the feedback control system is operational



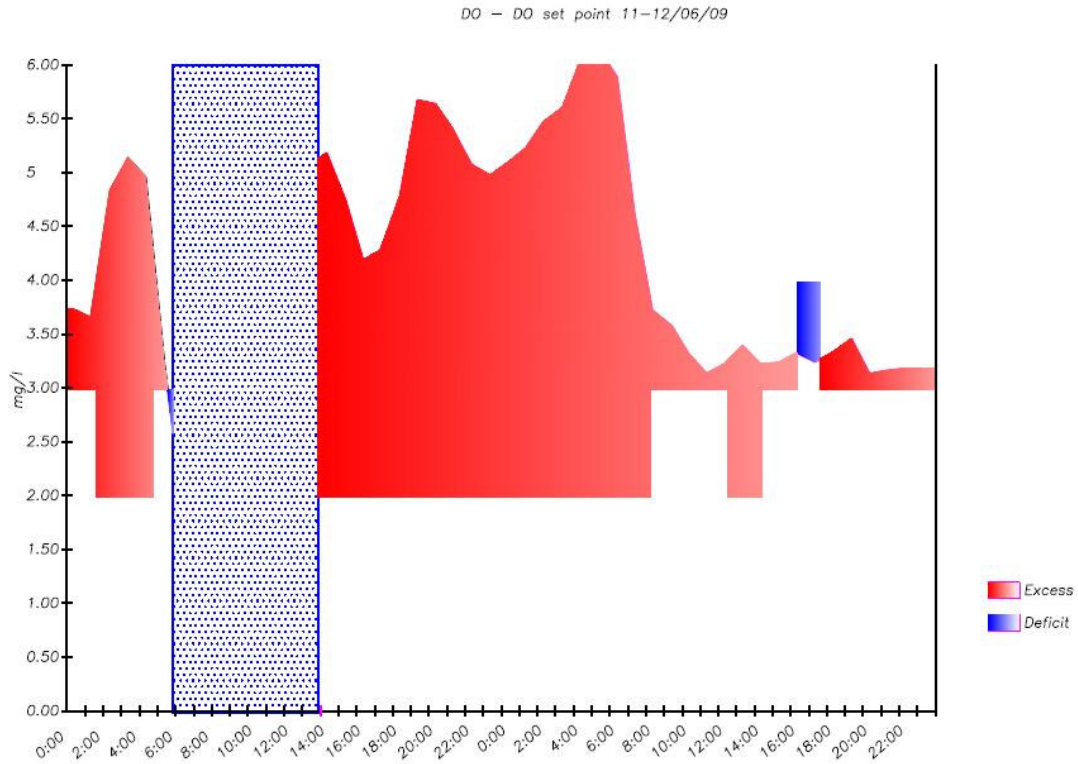
Excess and deficit of aeration the 3rd and 4th June, when the feedback control system is operational.



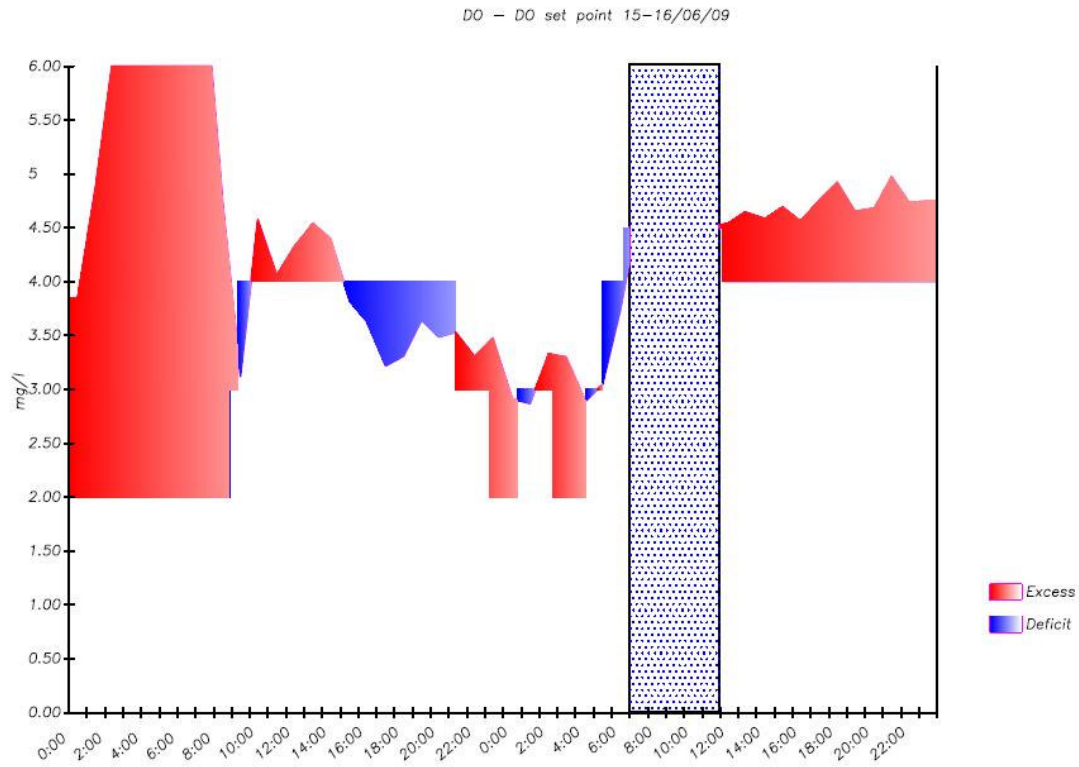
Excess and deficit of aeration the 5th and 6th June, when the feedback control system is operational.



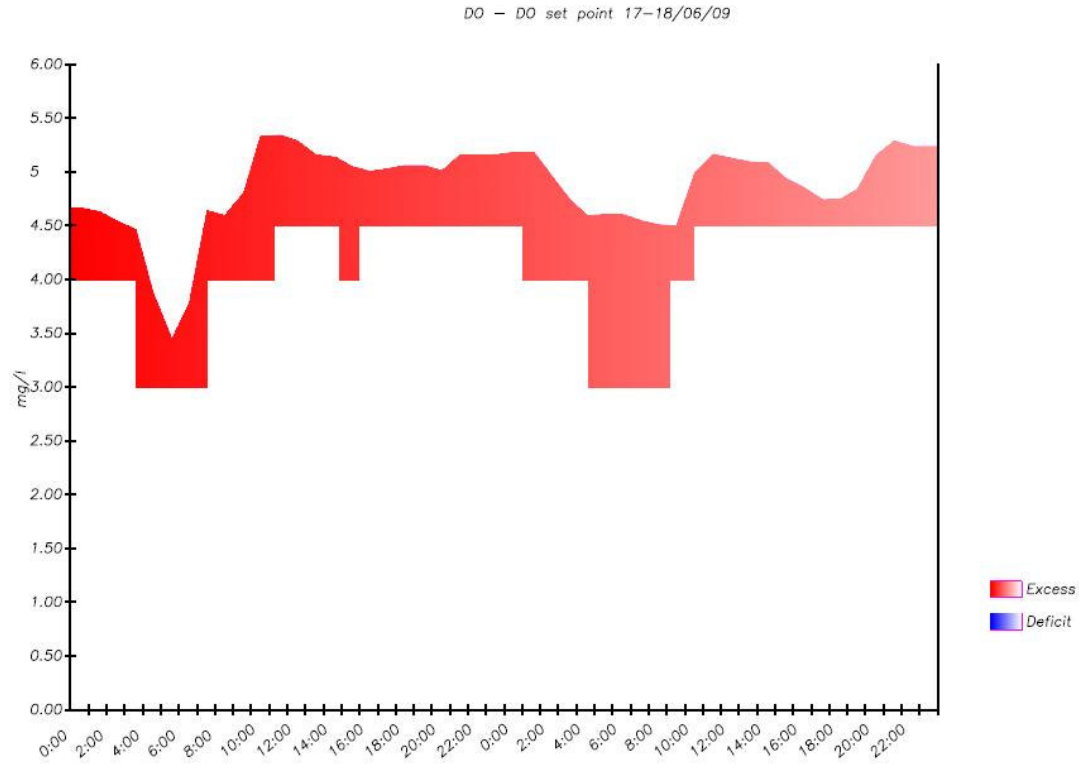
Excess and deficit of aeration the 9th and 10th June, when the feedback control system is operational



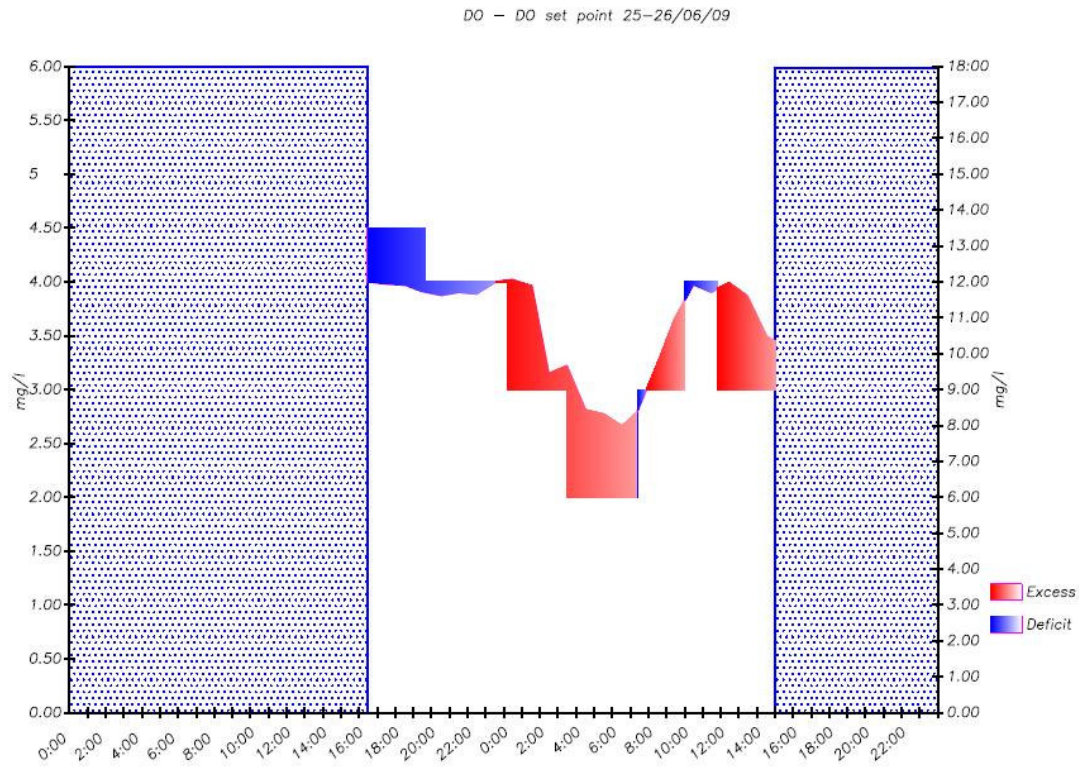
Excess and deficit of aeration the 11th and 12th June, when the feedback control system is operational



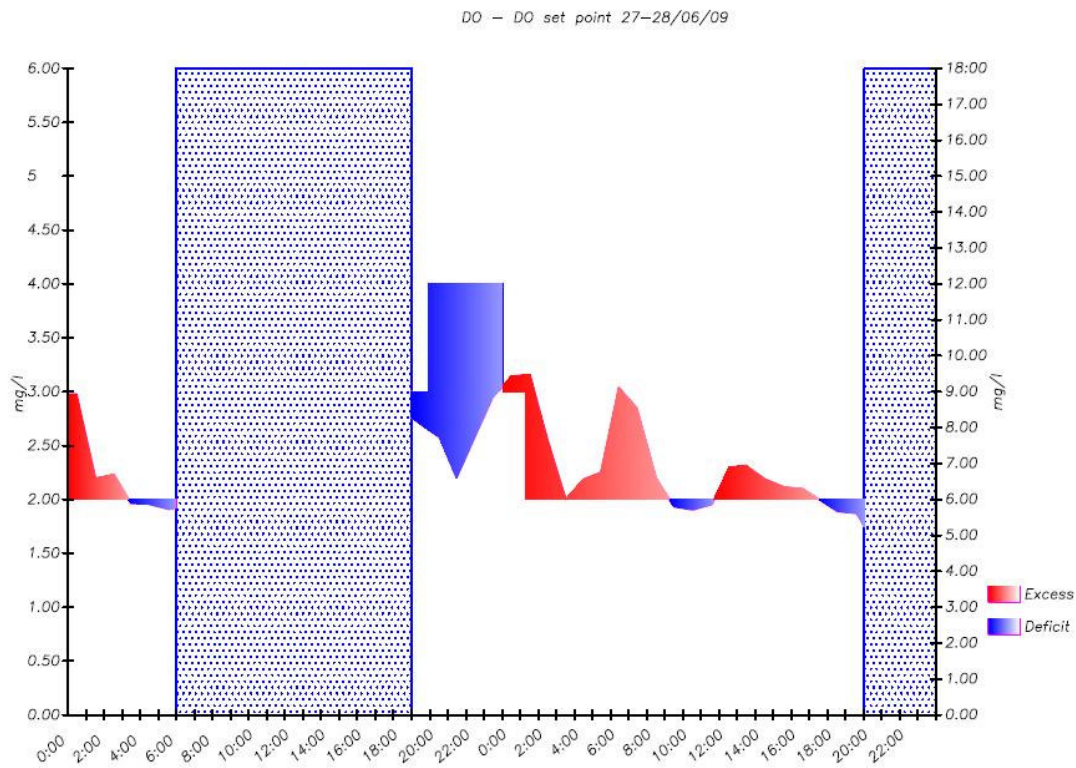
Excess and deficit of aeration the 15th and 16th June, when the feedback control system is operational.



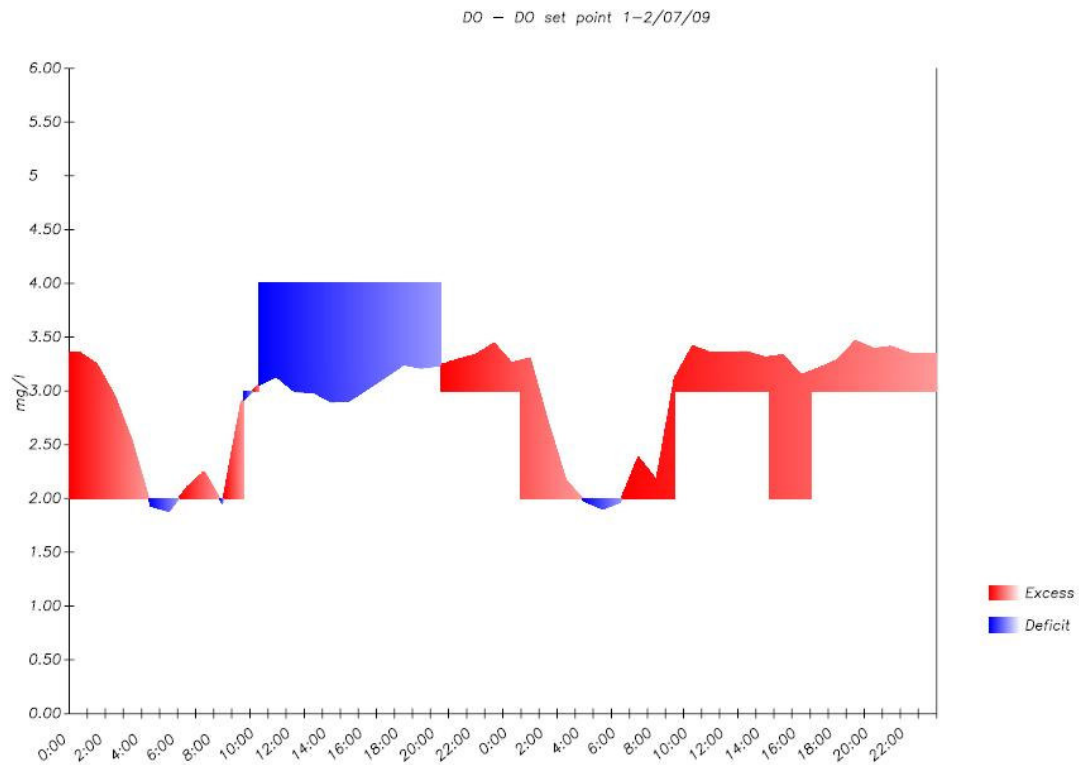
Excess and deficit of aeration the 17th and 18th June, when the feedback control system is operational.



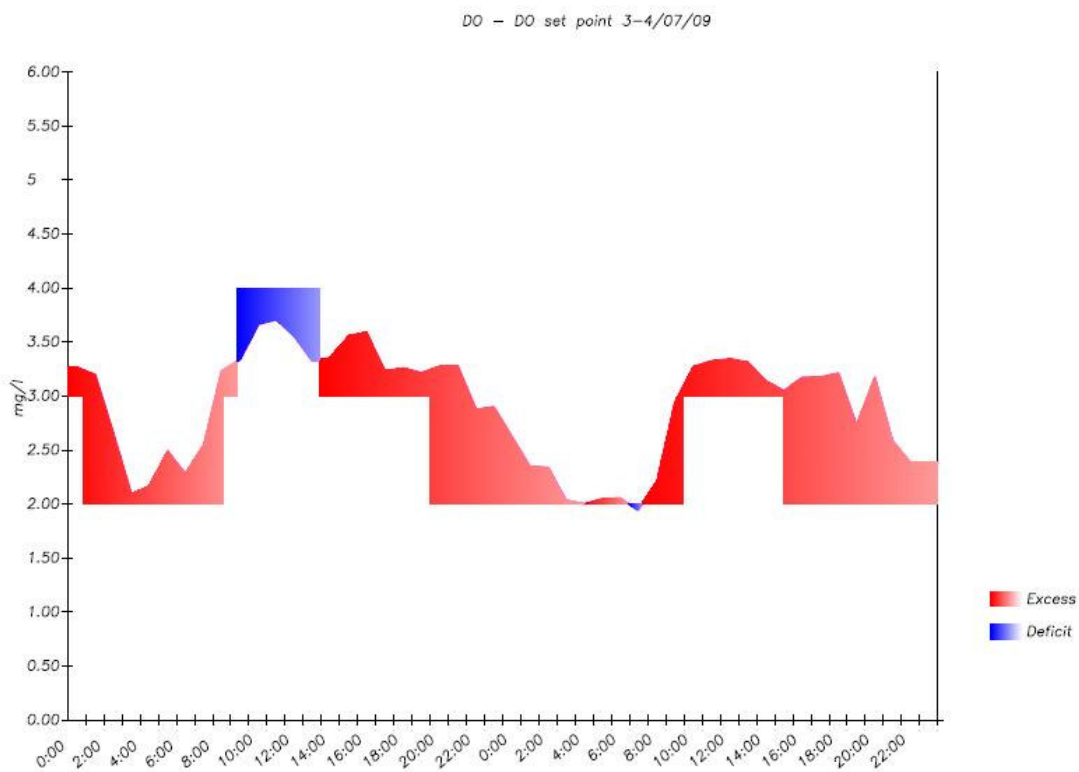
Excess and deficit of aeration the 25th and 26th June, when the feedback control system is operational.



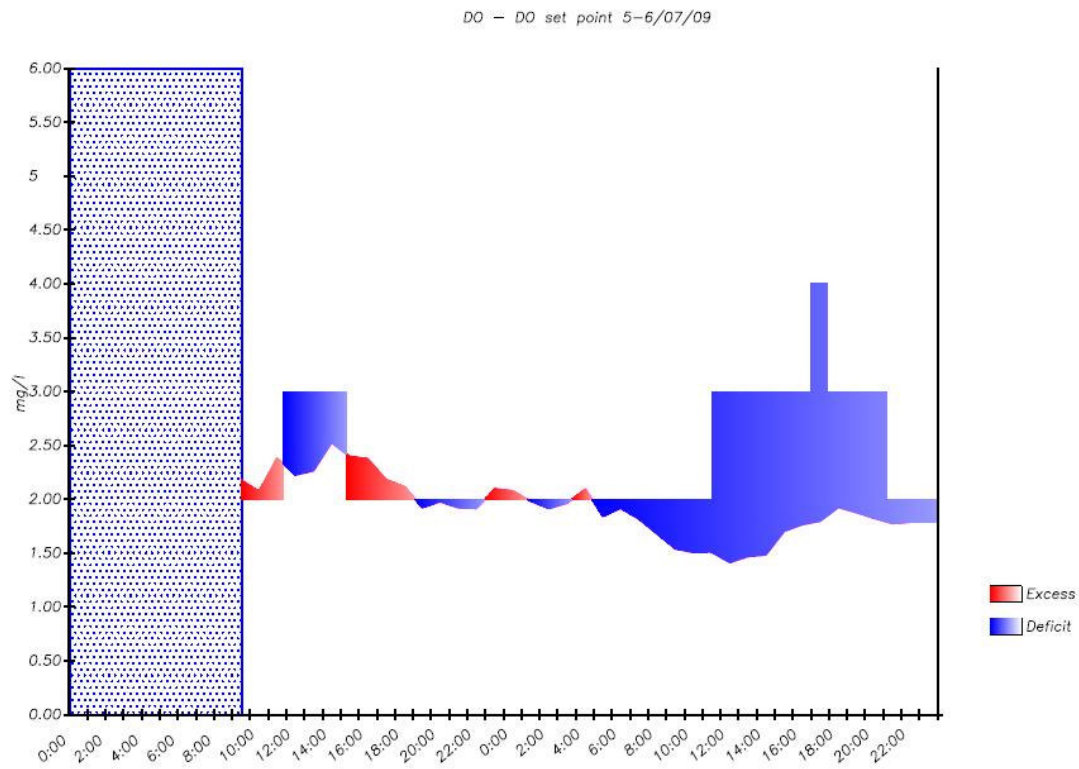
Excess and deficit of aeration the 27th and 28th June, when the feedback control system is operational.



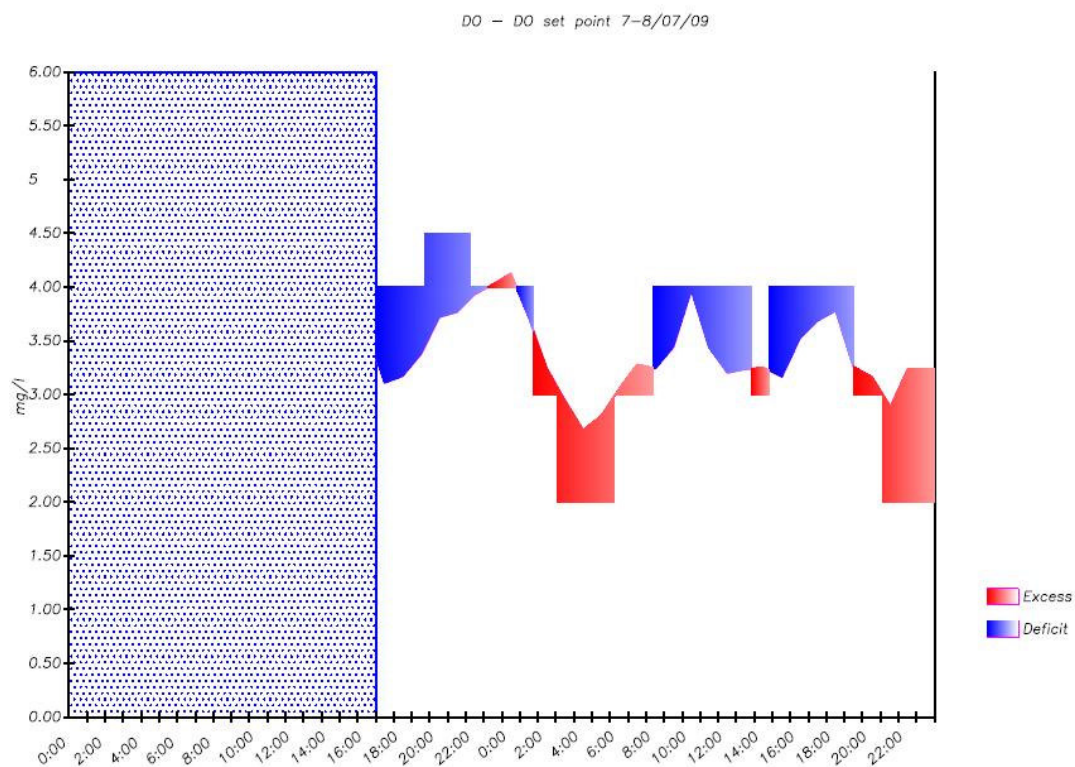
Excess and deficit of aeration the 1st and 2nd July, when the feedback control system is operational.



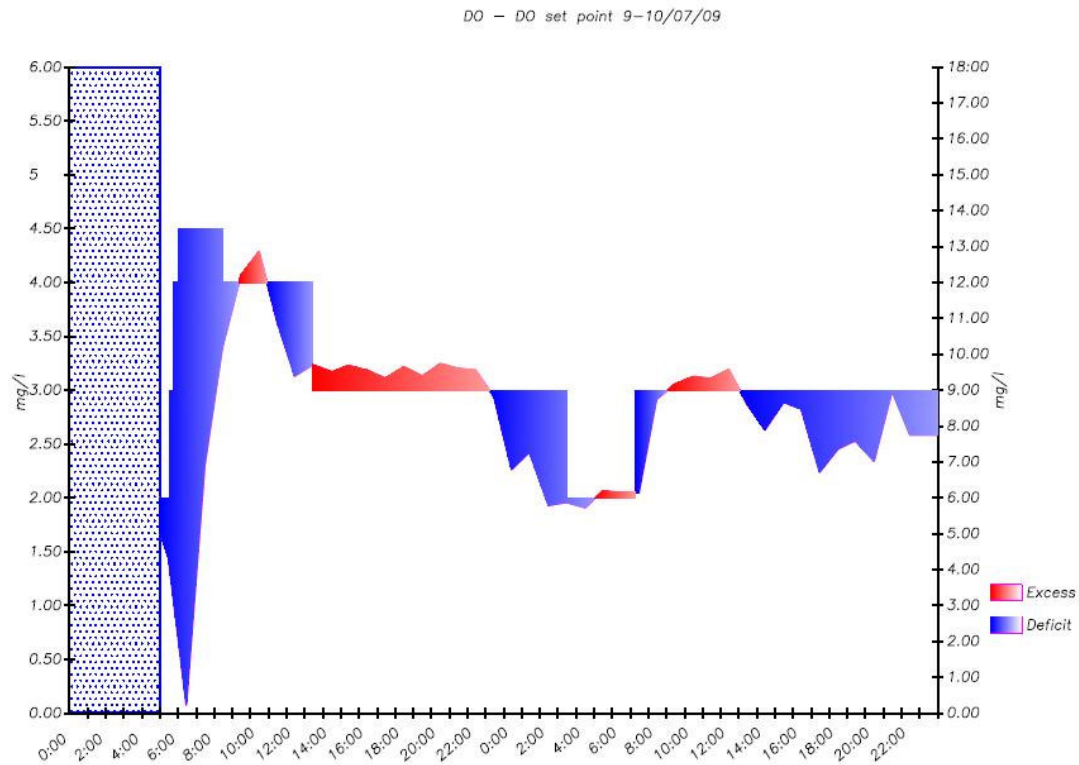
Excess and deficit of aeration the 3rd and 4th July, when the feedback control system is operational.



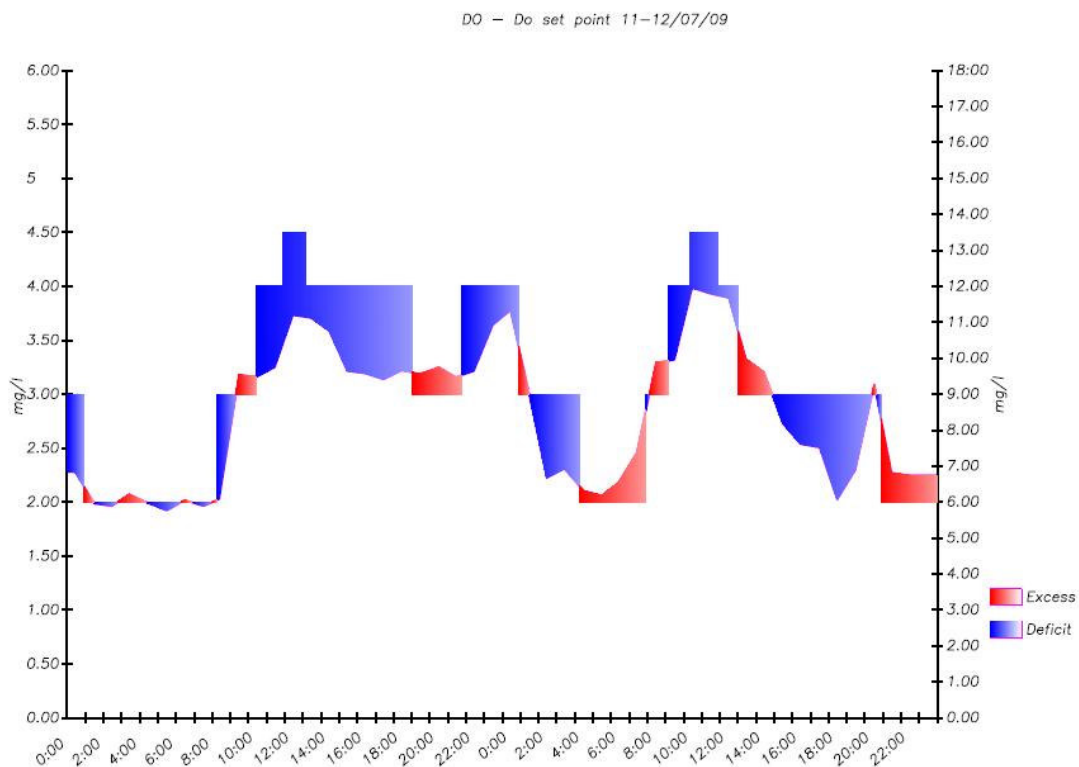
Excess and deficit of aeration the 5th and 6th July, when the feedback control system is operational.



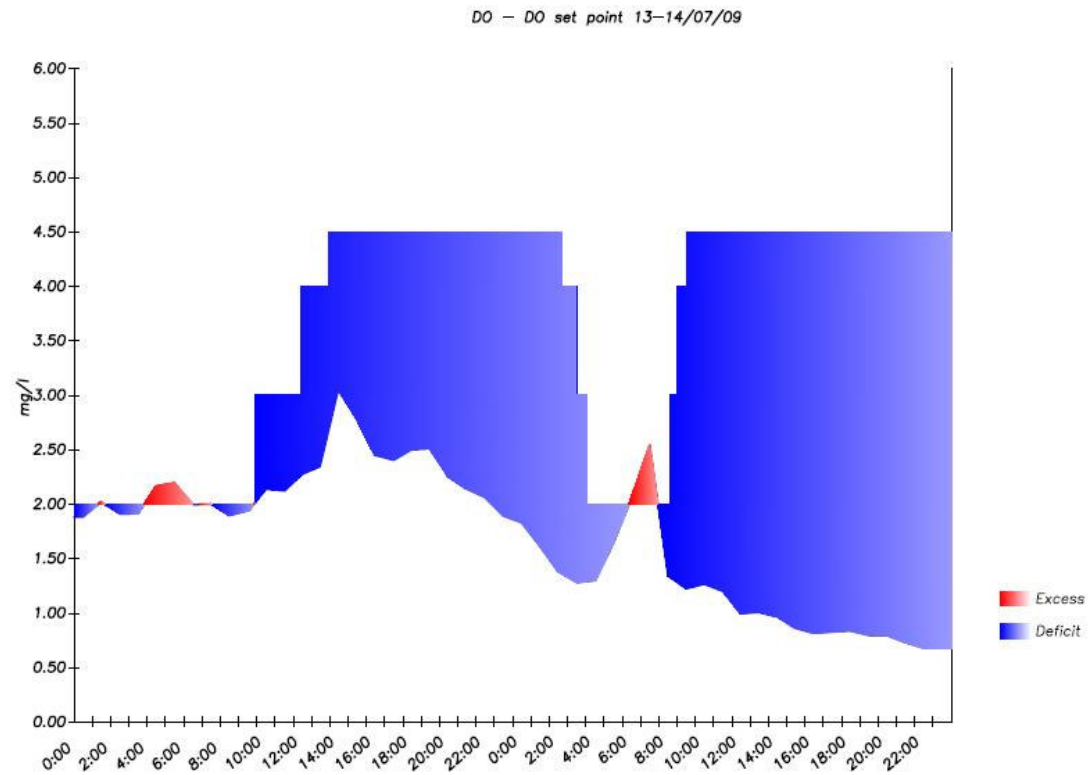
Excess and deficit of aeration the 7th and 8th July, when the feedback control system is operational.



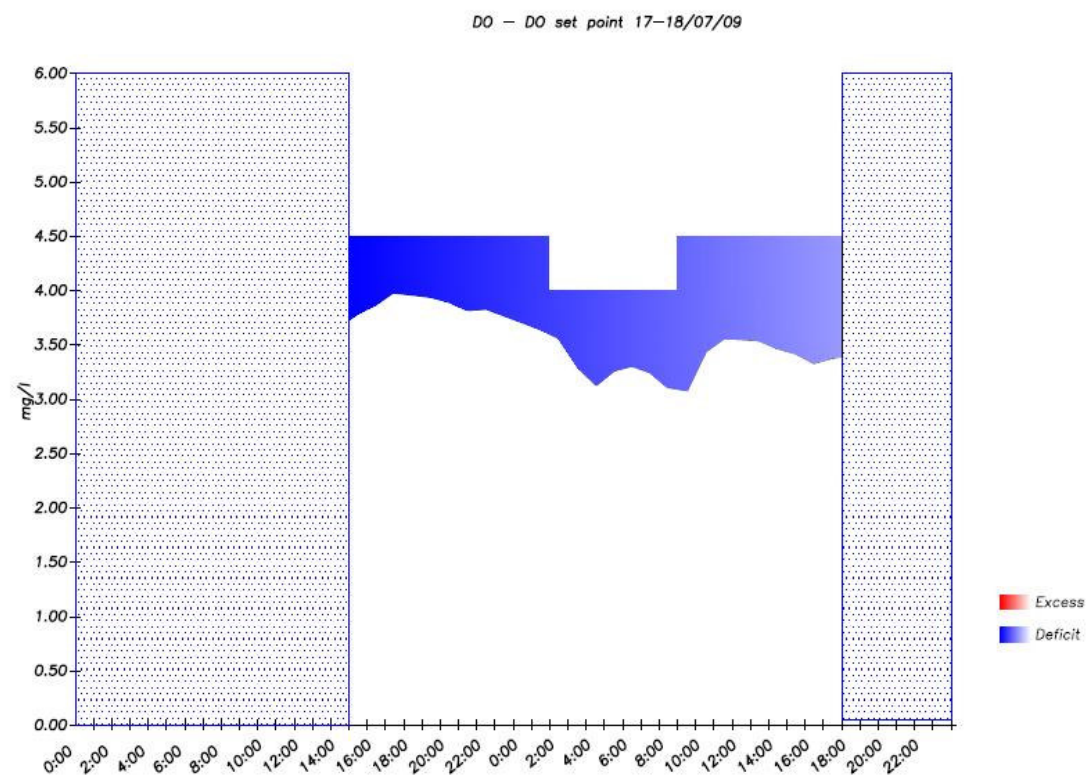
Excess and deficit of aeration the 9th and 10th July, when the feedback control system is operational.



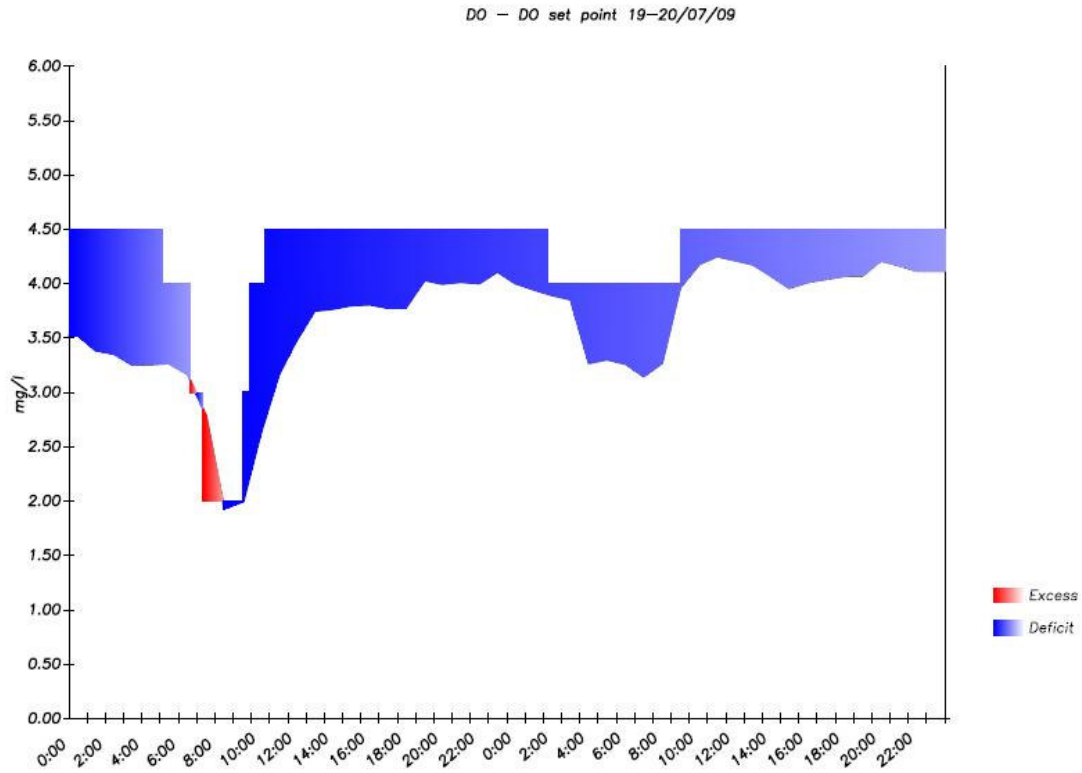
Excess and deficit of aeration the 11th and 12th July, when the feedback control system is operational.



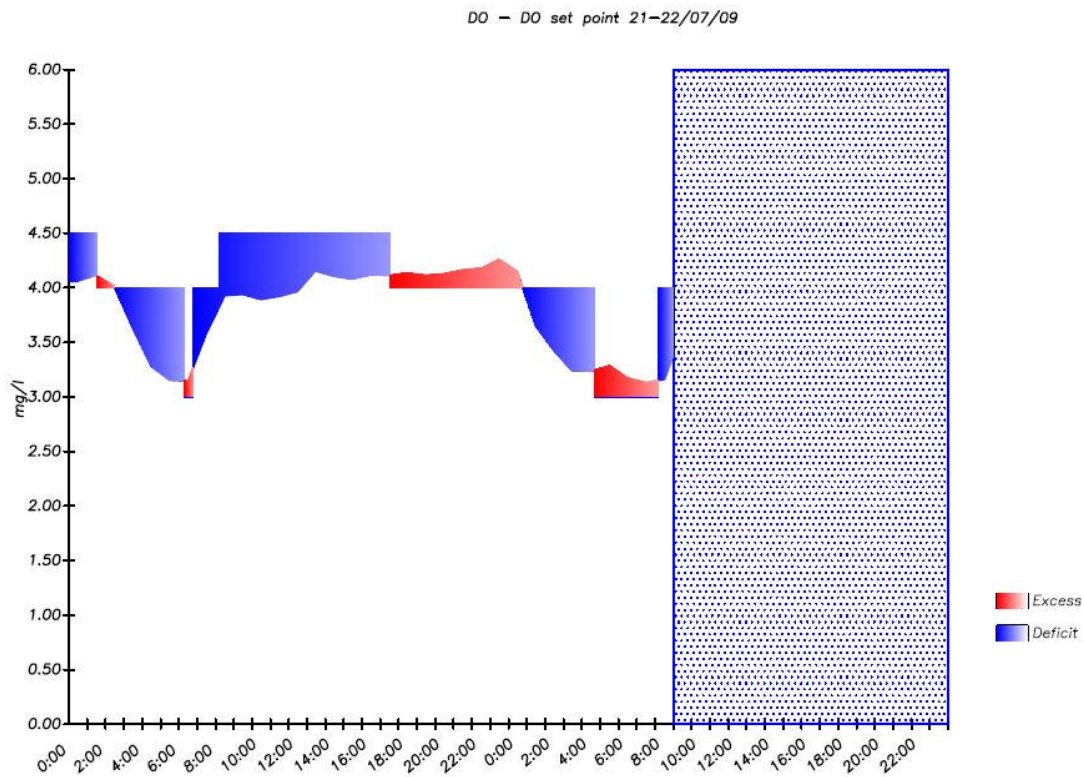
Excess and deficit of aeration the 13th and 14th July, when the feedback control system is operational.



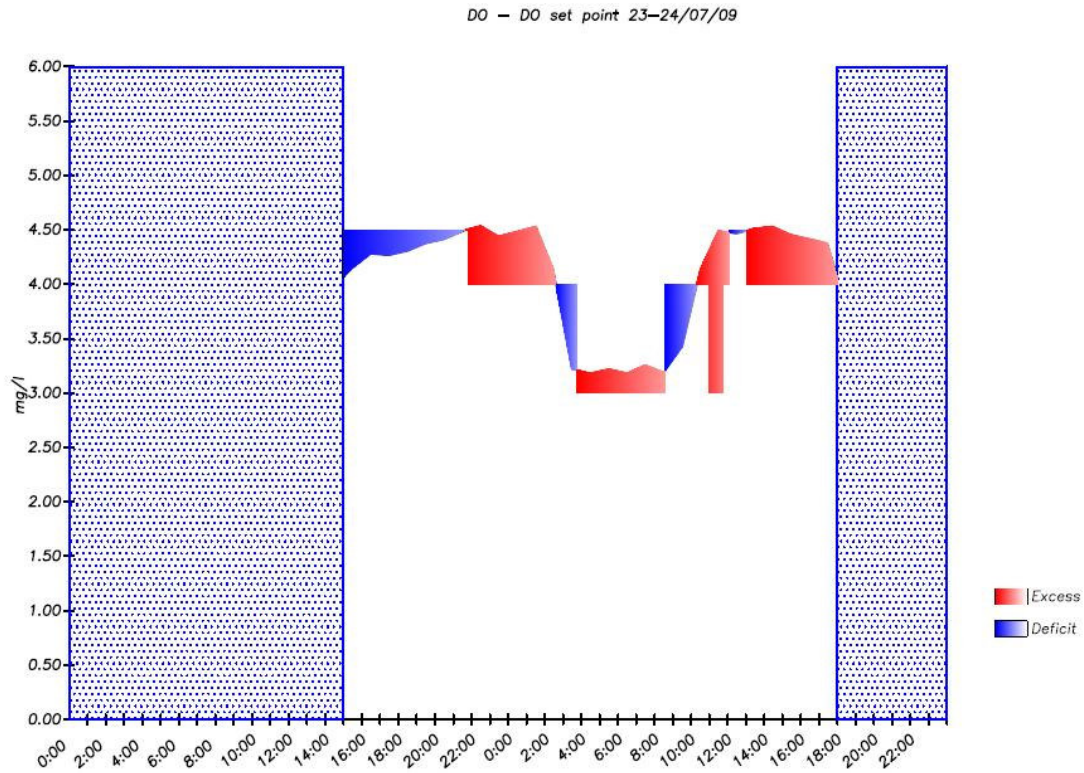
Excess and deficit of aeration the 17th and 18th July, when the feedback control system is operational.



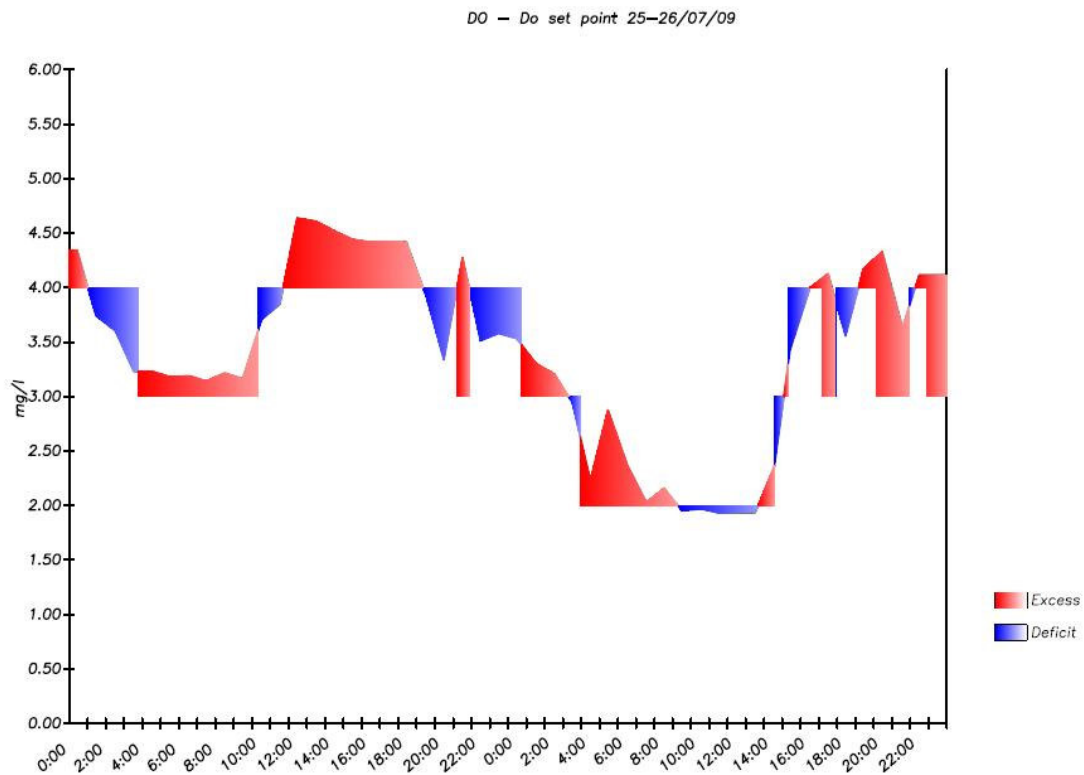
Excess and deficit of aeration the 19th and 20th July, when the feedback control system is operational.



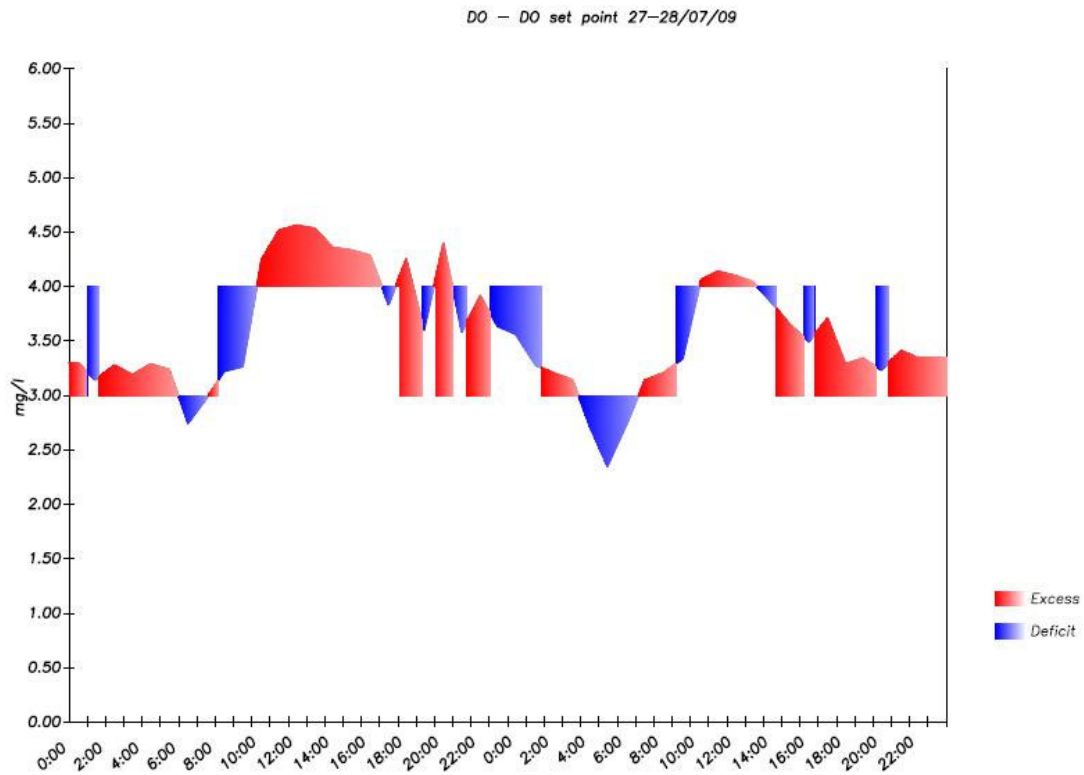
Excess and deficit of aeration the 21st and 22nd July, when the feedback control system is operational.



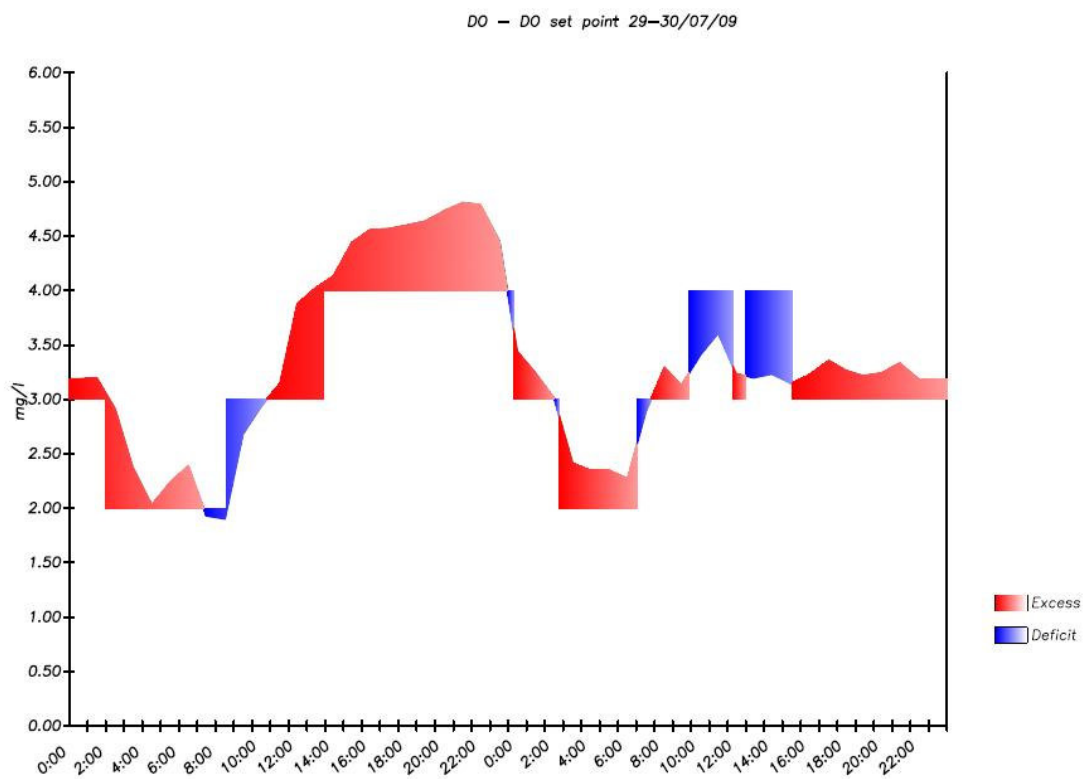
Excess and deficit of aeration the 23rd and 24th July, when the feedback control system is operational.



Excess and deficit of aeration the 25th and 26th July, when the feedback control system is operational.

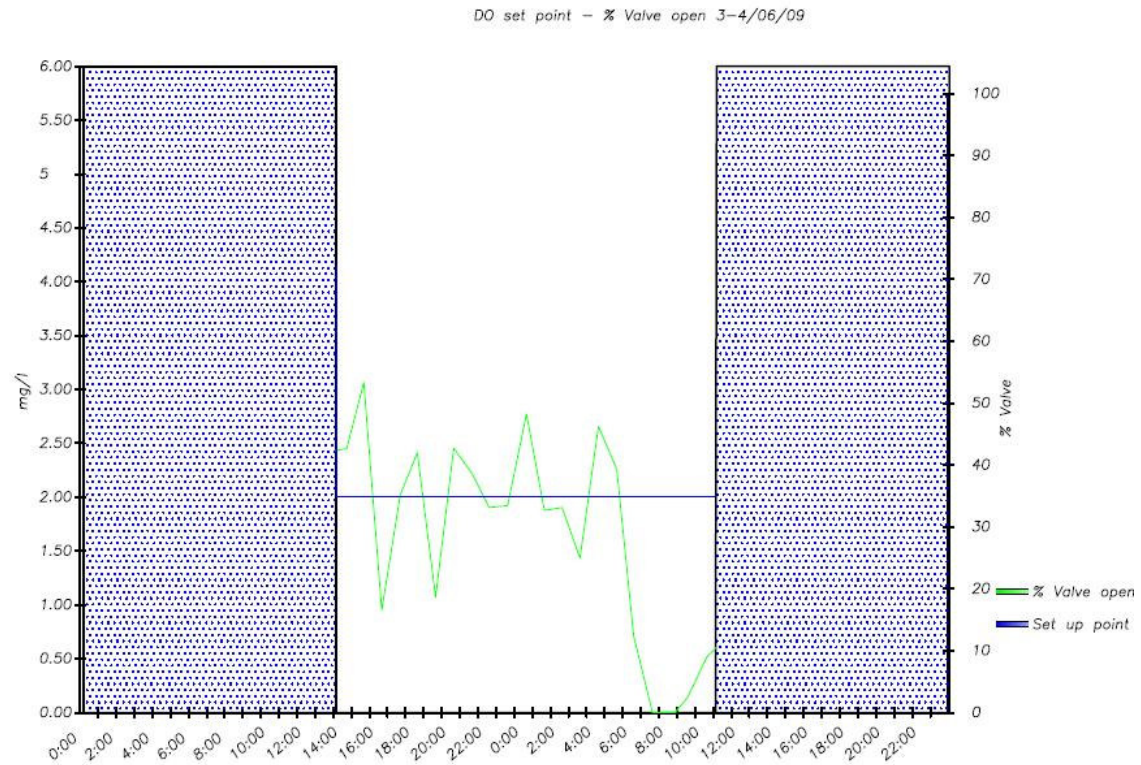
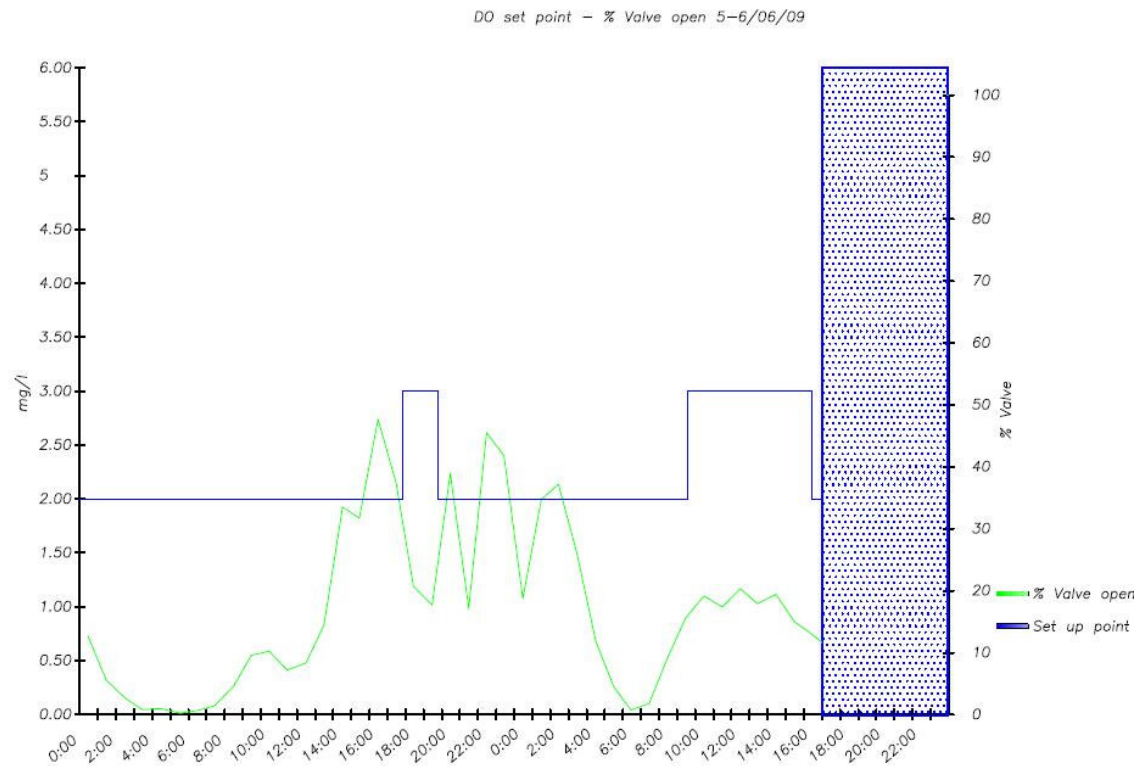


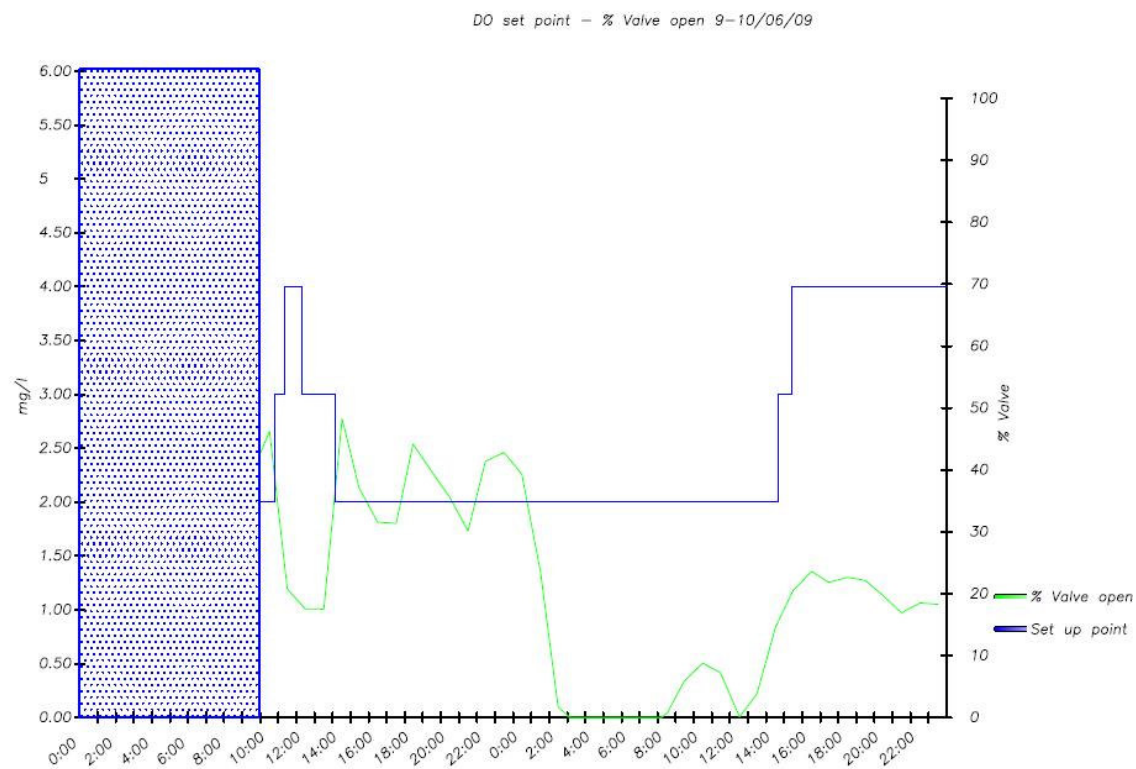
Excess and deficit of aeration the 27th and 28th July, when the feedback control system is operational.



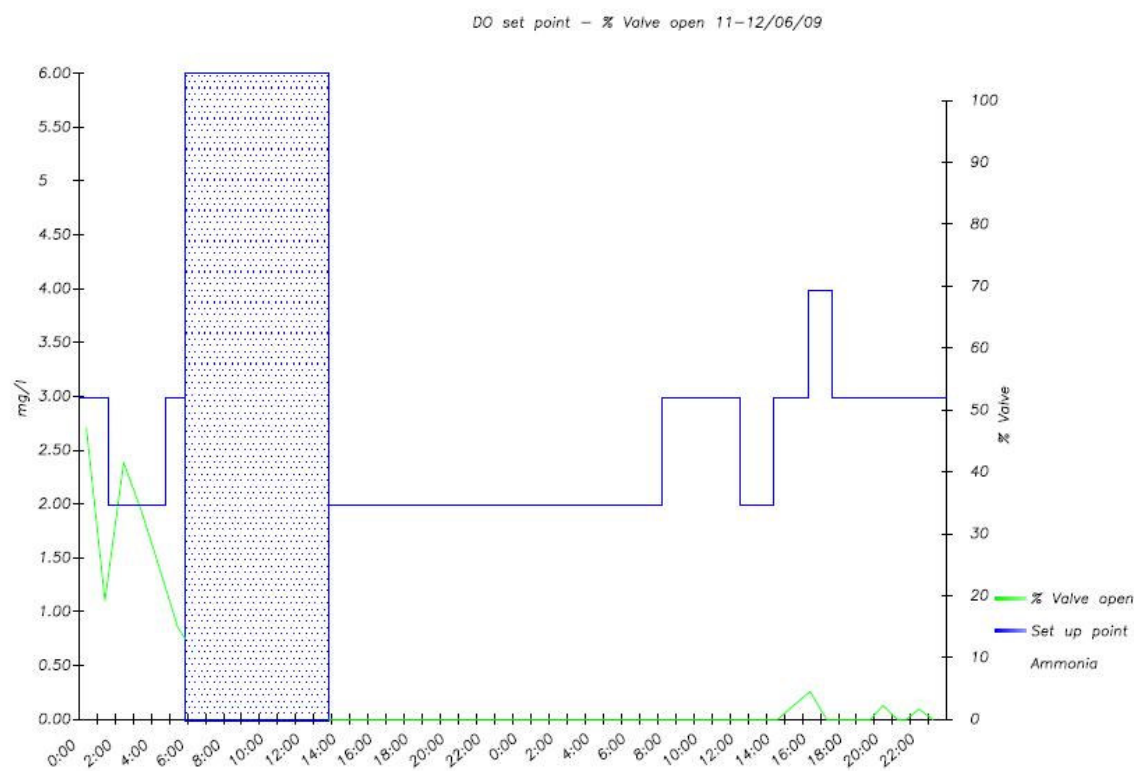
Excess and deficit of aeration the 29th and 30th July, when the feedback control system is operational.

Appendix C : Percentage valve of air flow open in tank and DO set point

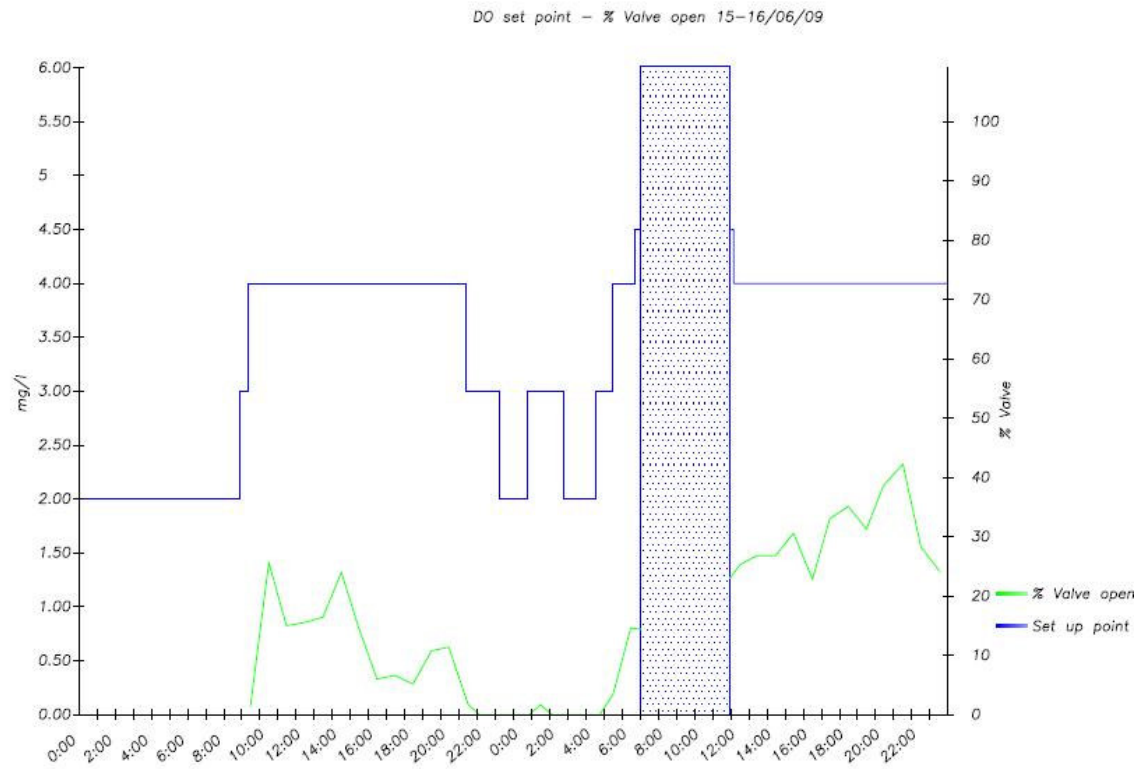
Percentage valve of air flow open in tank and DO set point from 3rd till 4th JunePercentage valve of air flow open in tank and DO set point from 5th till 6th June



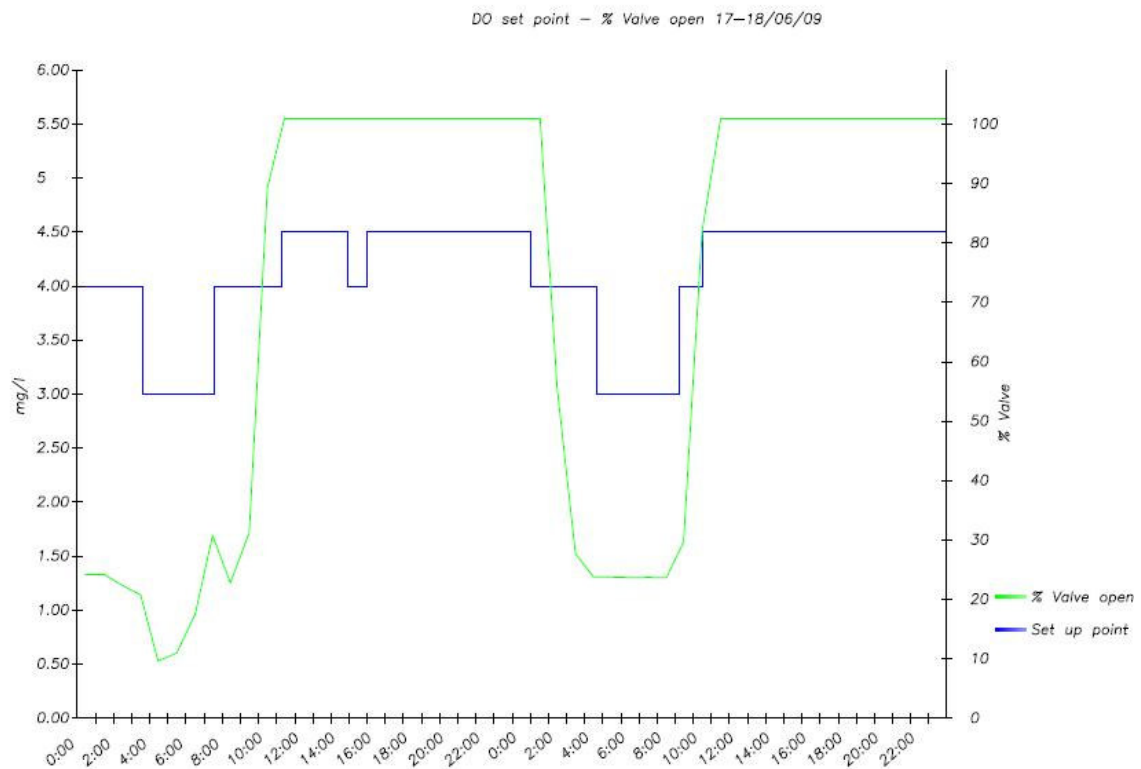
Percentage valve of air flow open in tank and DO set point from 9th till 10th June



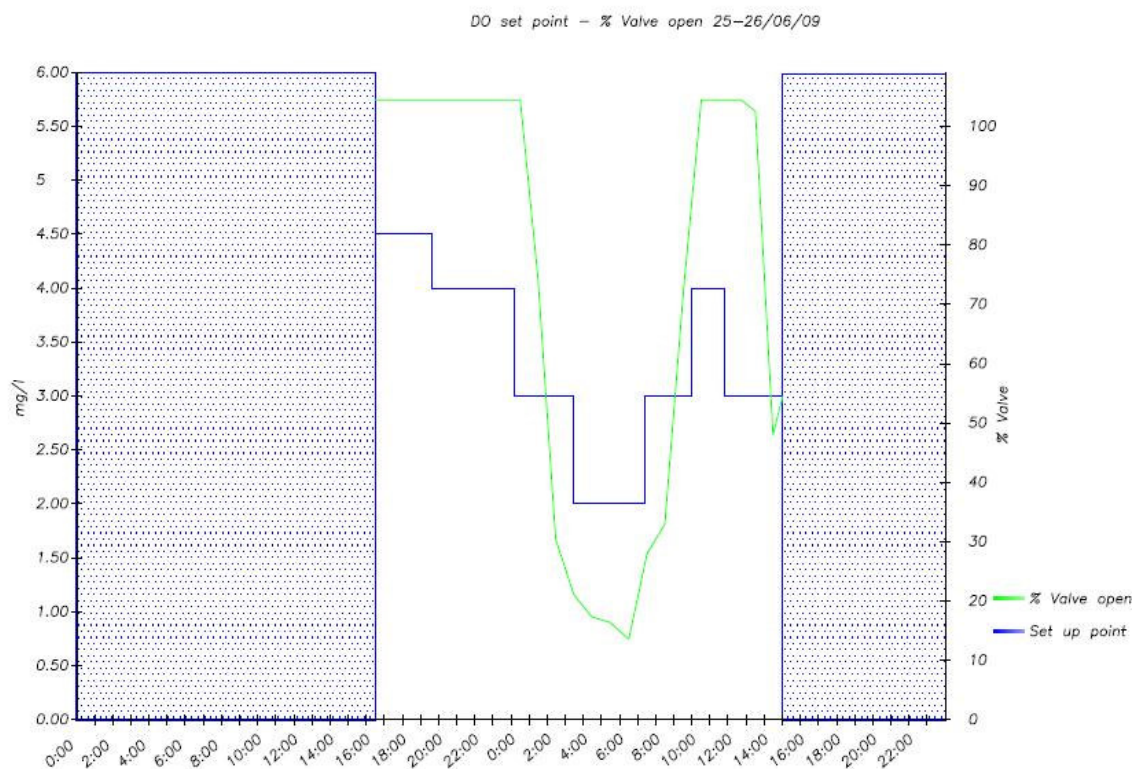
Percentage valve of air flow open in tank and DO set point from 11th till 12th June



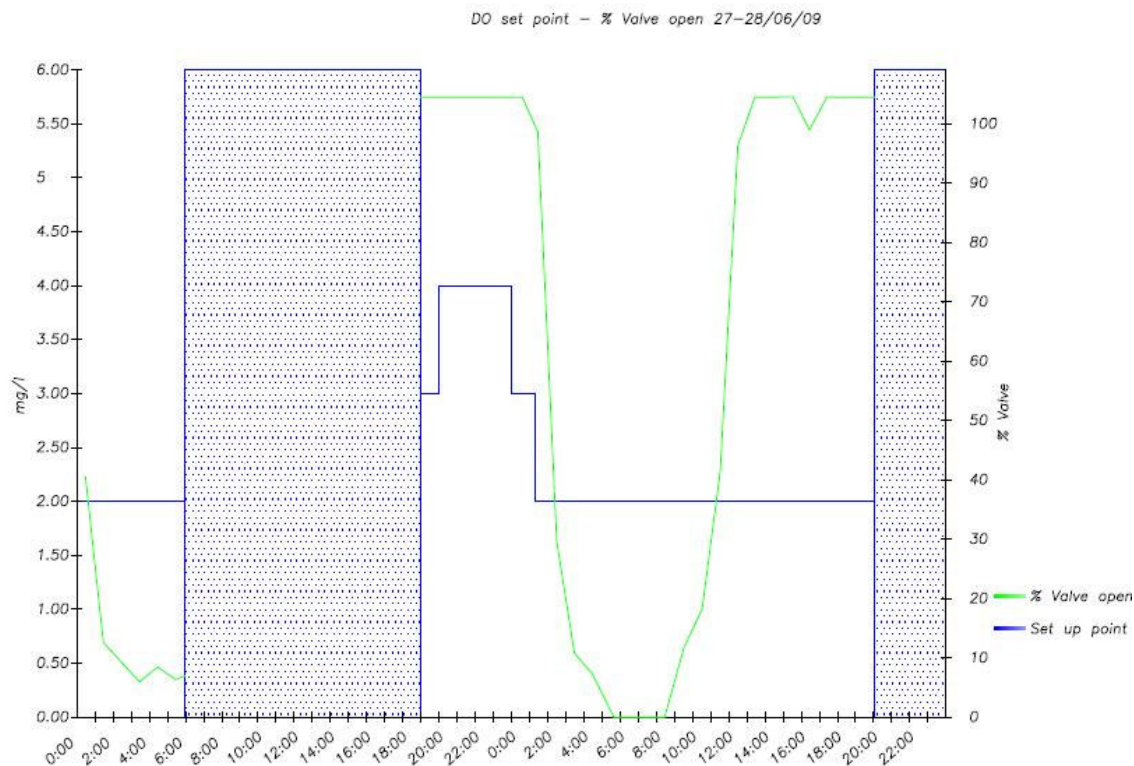
Percentage valve of air flow open in tank and DO set point from 15th till 16th June



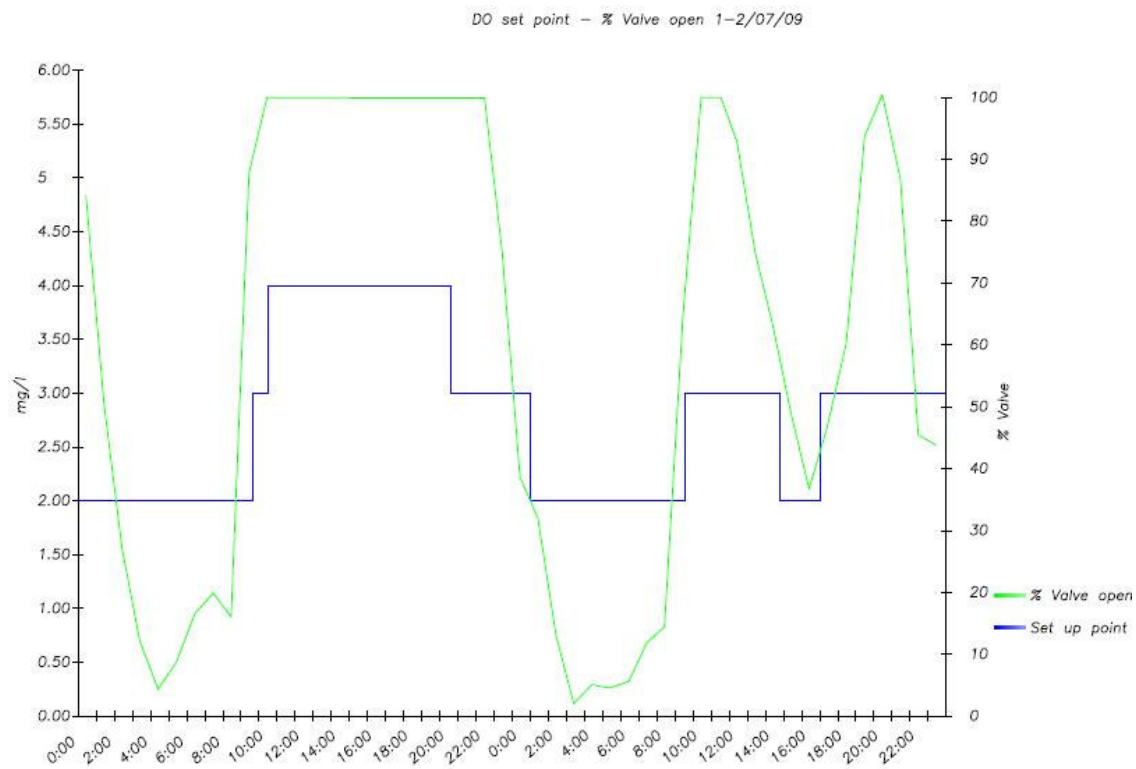
Percentage valve of air flow open in tank and DO set point from 17th till 18th June



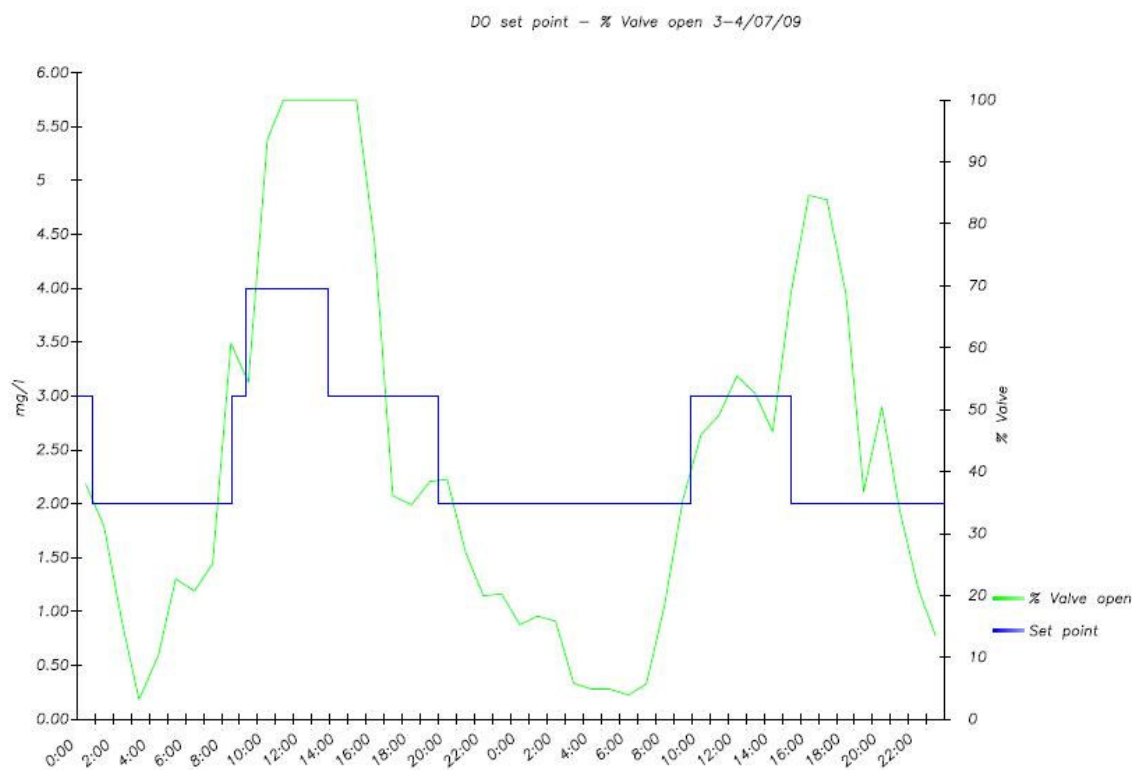
Percentage valve of air flow open in tank and DO set point from 25th till 26th June



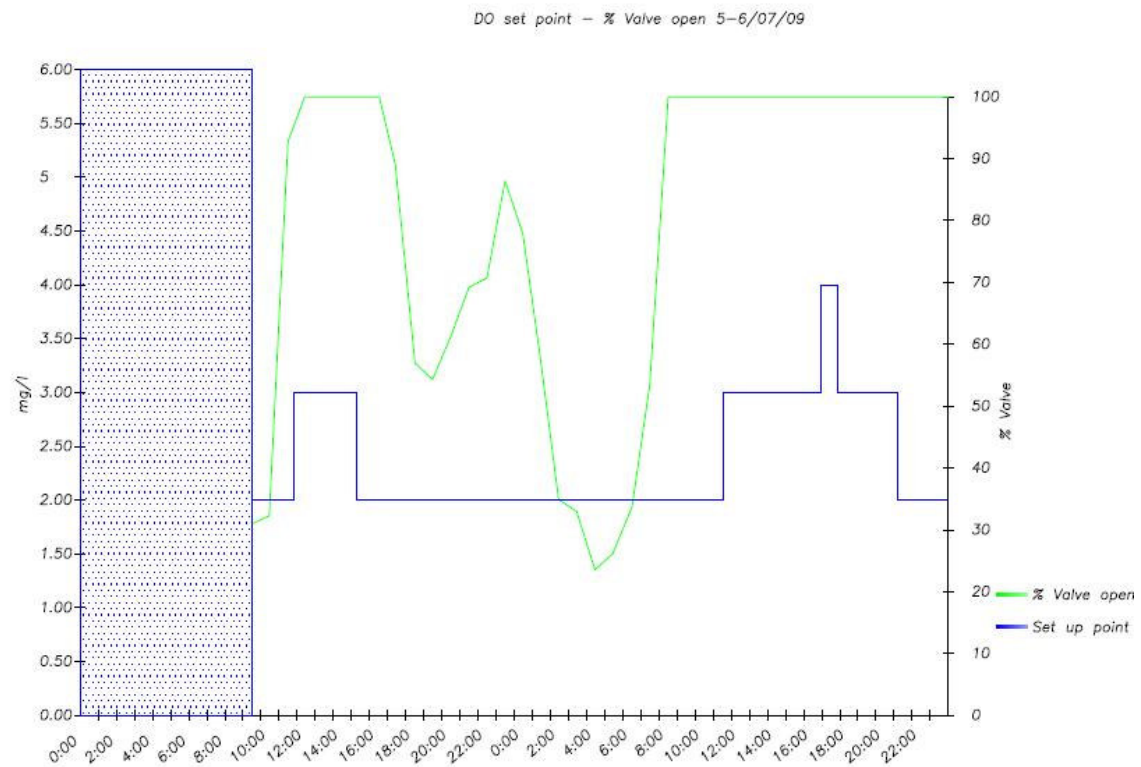
Percentage valve of air flow open in tank and DO set point from 27th till 28th June



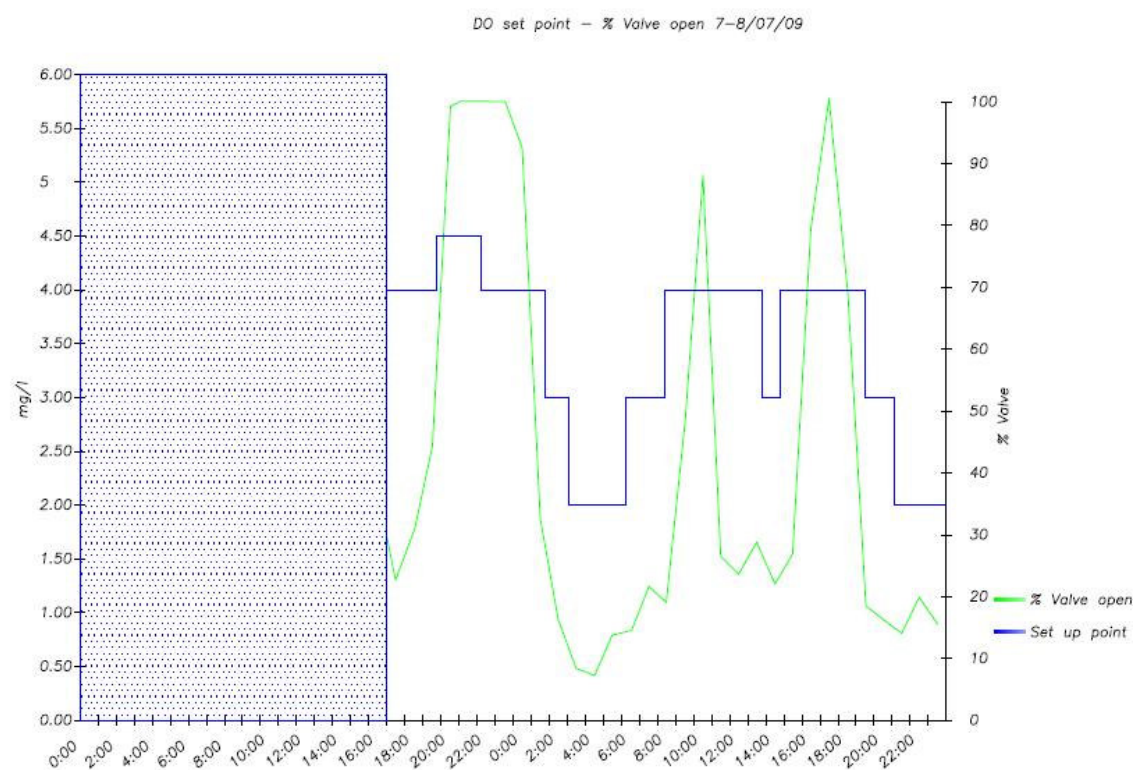
Percentage valve of air flow open in tank and DO set point from 1st till 2nd July



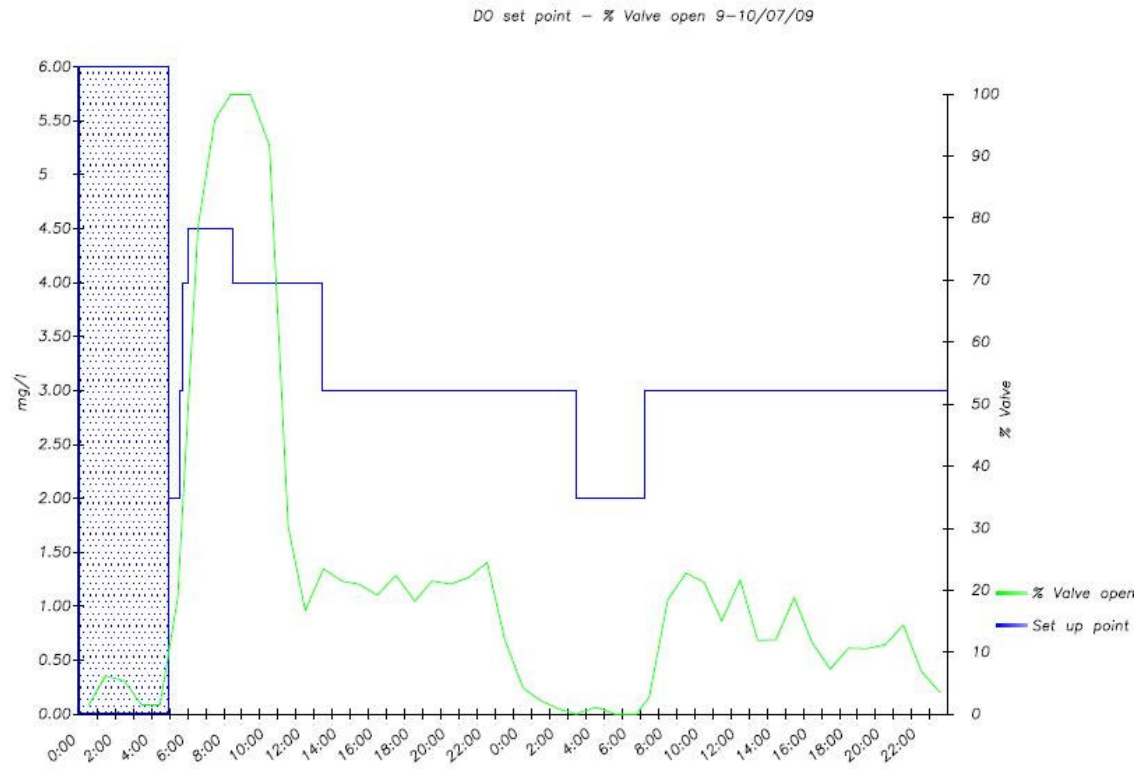
Percentage valve of air flow open in tank and DO set point from 3rd till 4th July



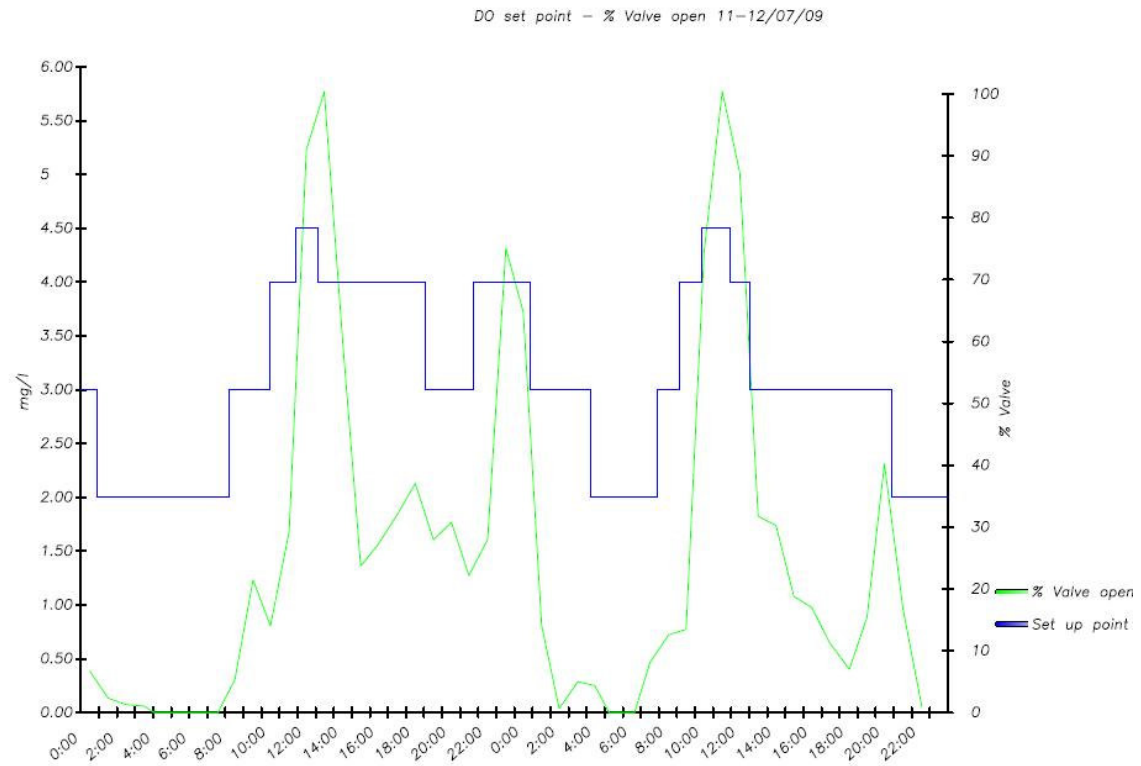
Percentage valve of air flow open in tank and DO set point from 5th till 6th July



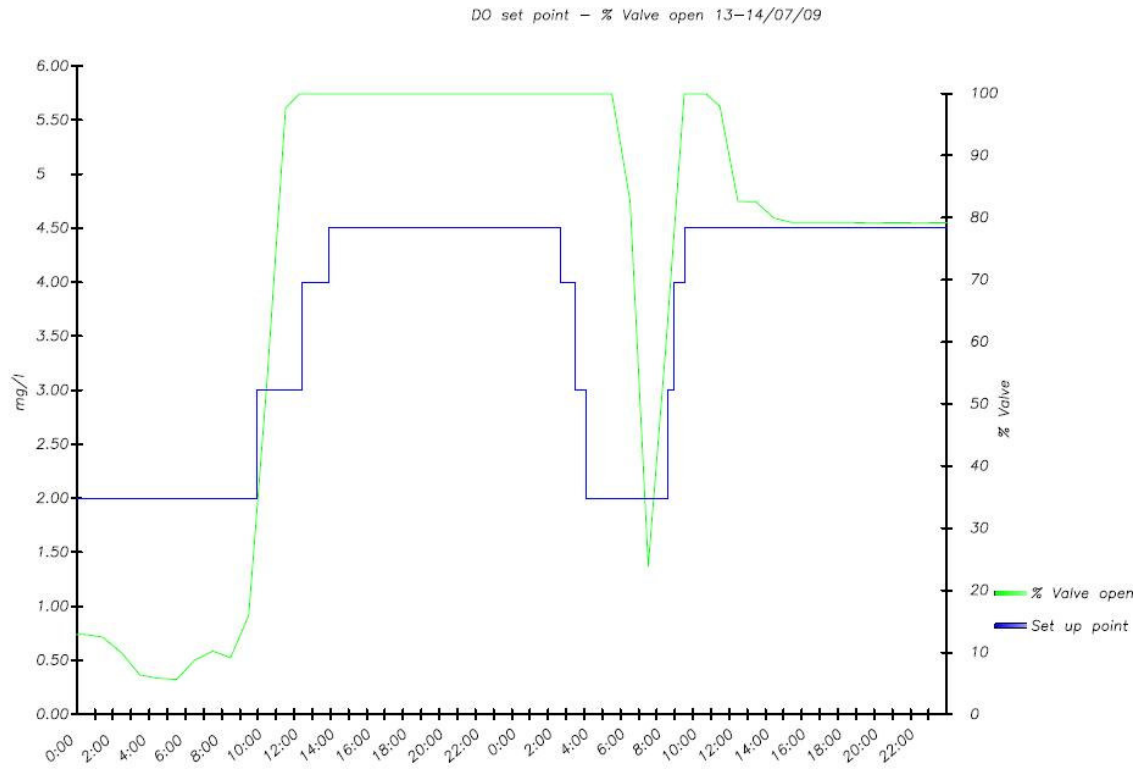
Percentage valve of air flow open in tank and DO set point from 7th till 8th July



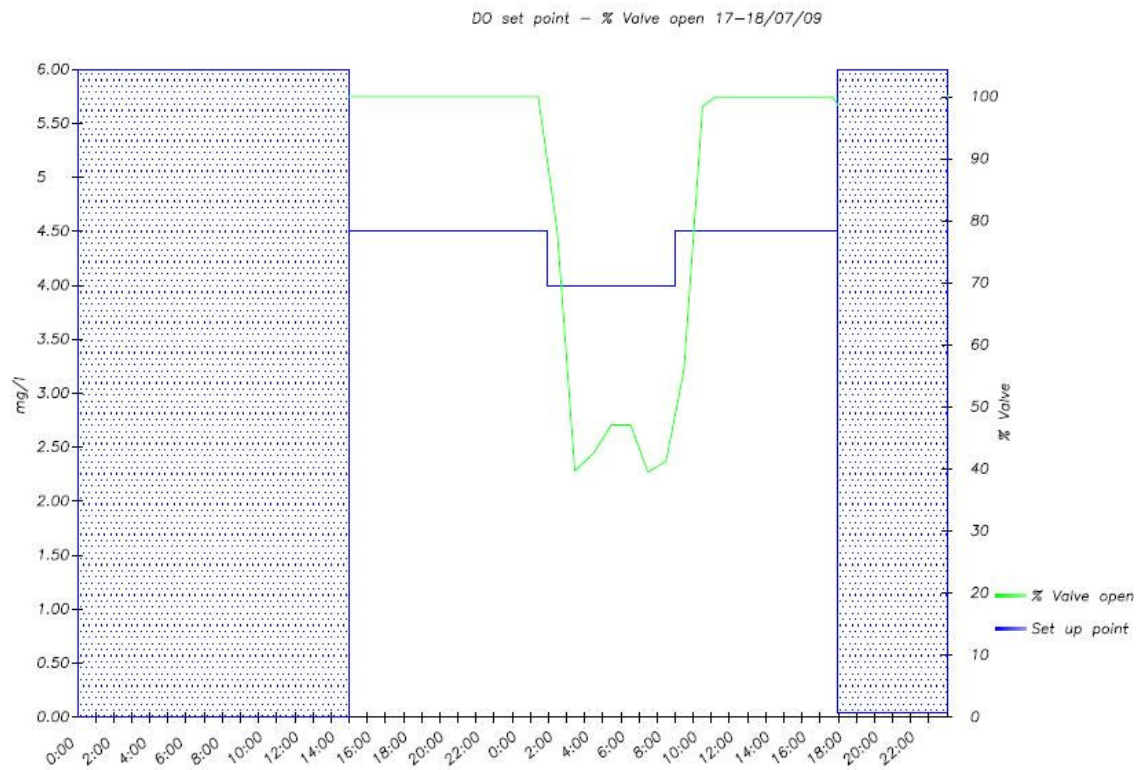
Percentage valve of air flow open in tank and DO set point from 9th till 10th July



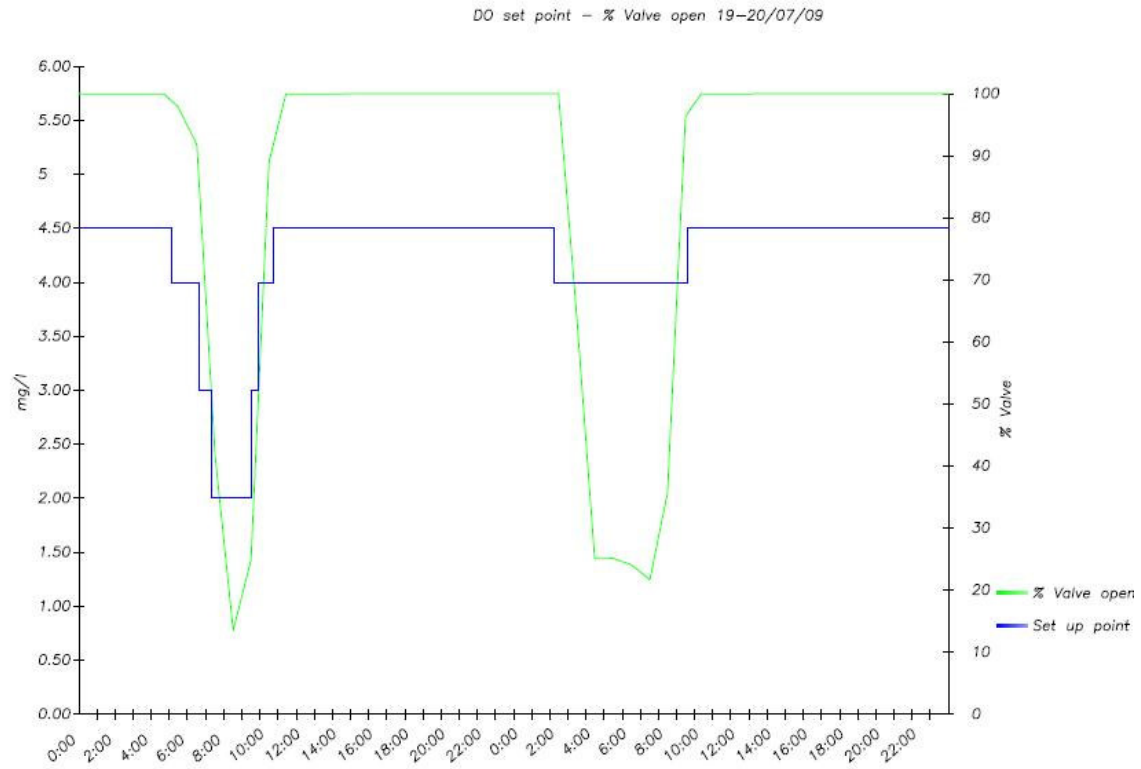
Percentage valve of air flow open in tank and DO set point from 11th till 12th July



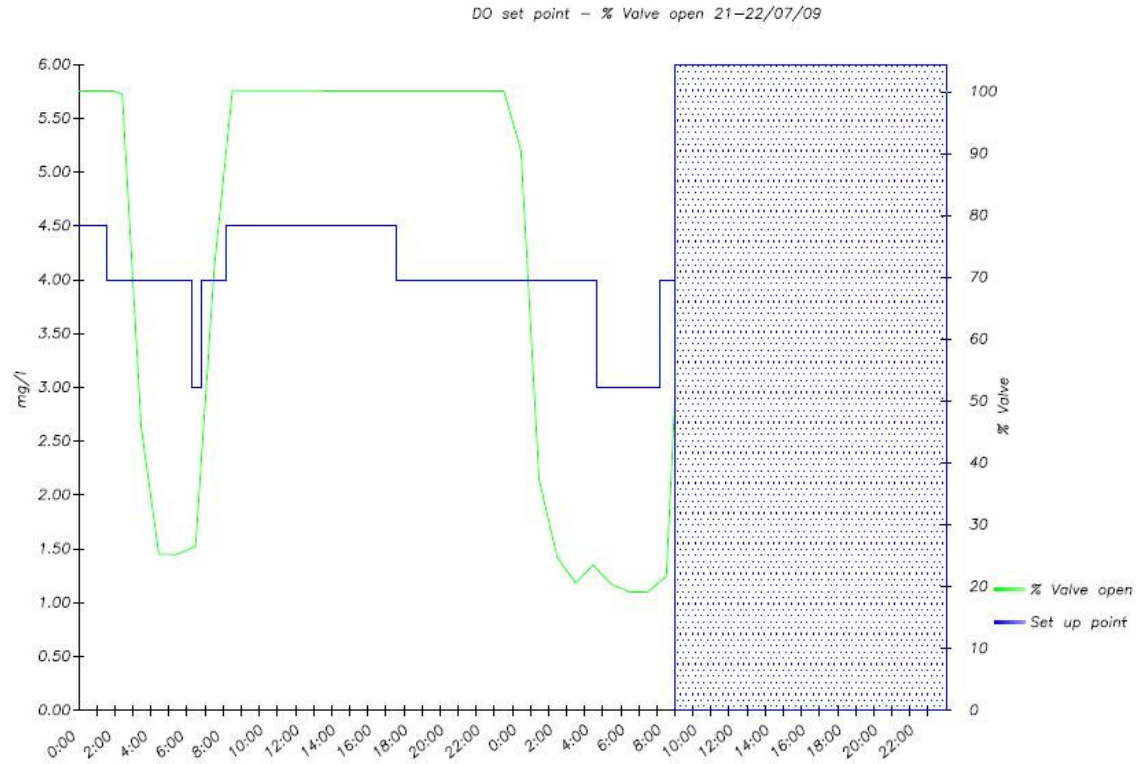
Percentage valve of air flow open in tank and DO set point from 13th till 14th July



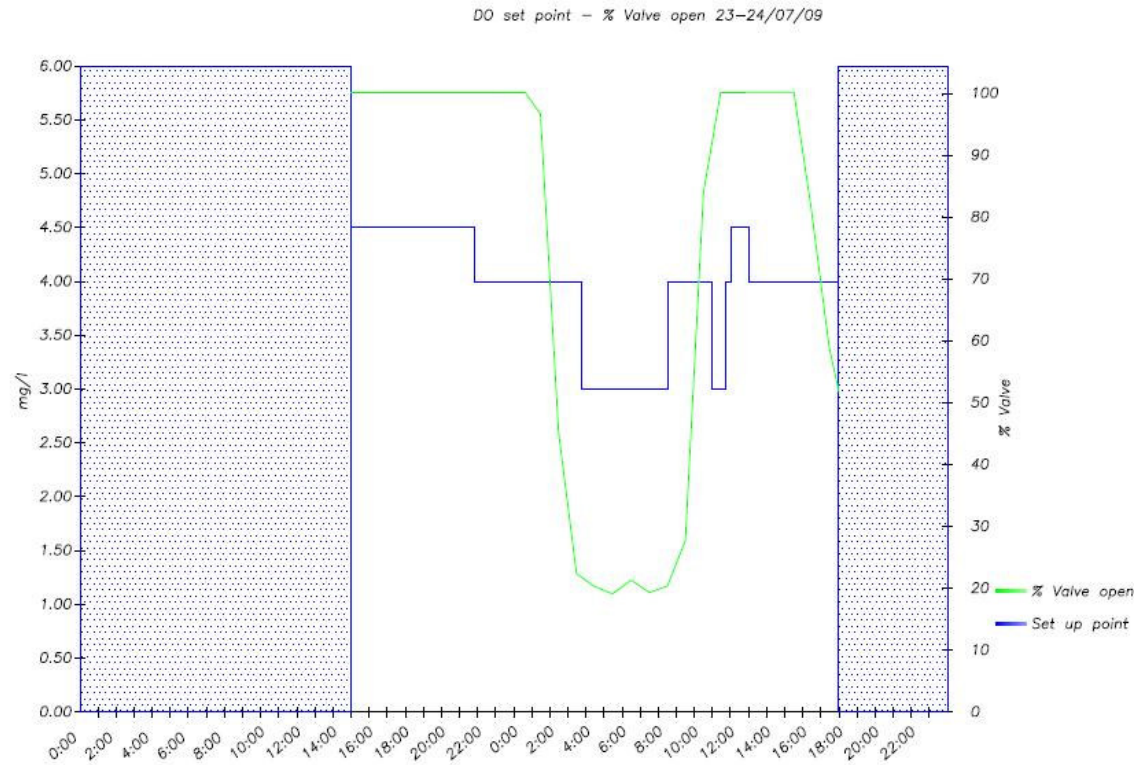
Percentage valve of air flow open in tank and DO set point from 17th till 18th July



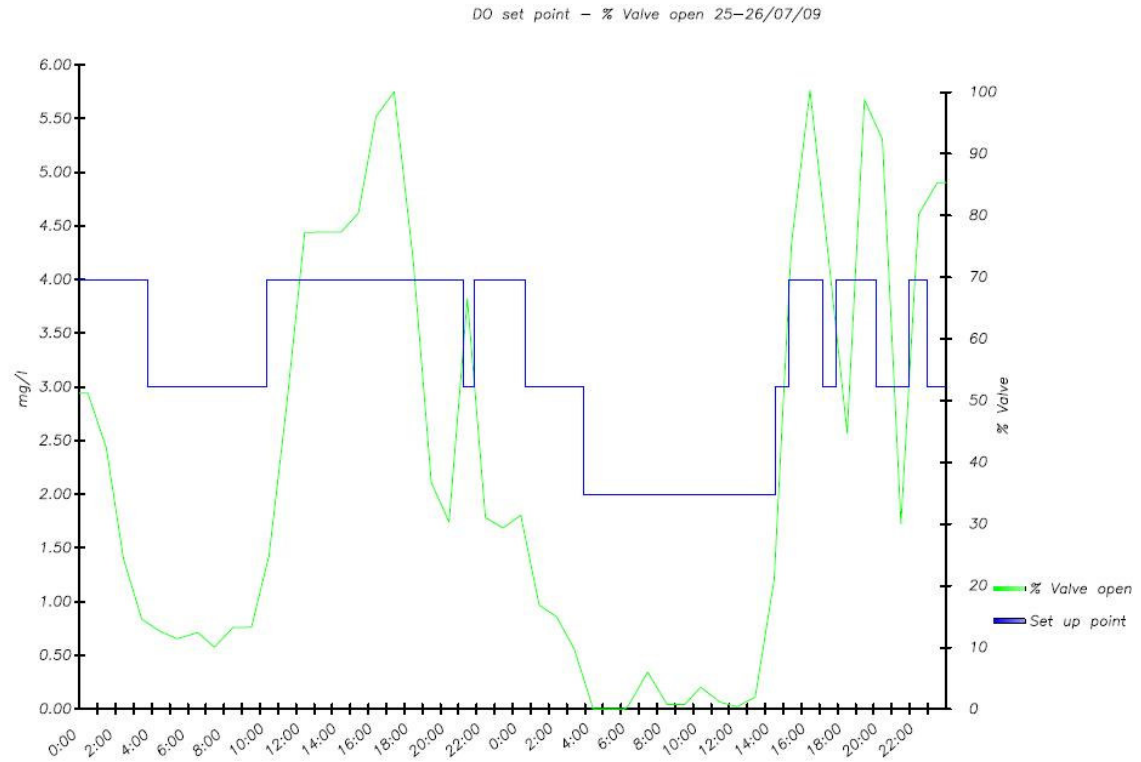
Percentage valve of air flow open in tank and DO set point from 19th till 20th July



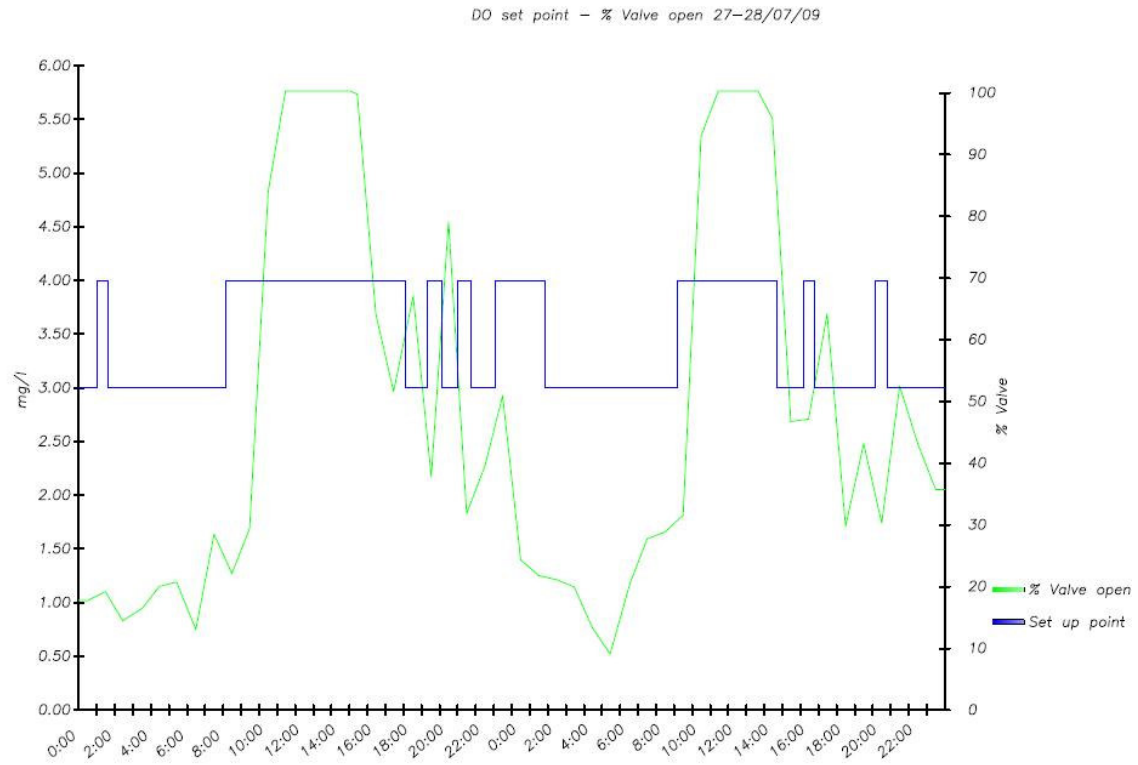
Percentage valve of air flow open in tank and DO set point from 21st till 22nd July



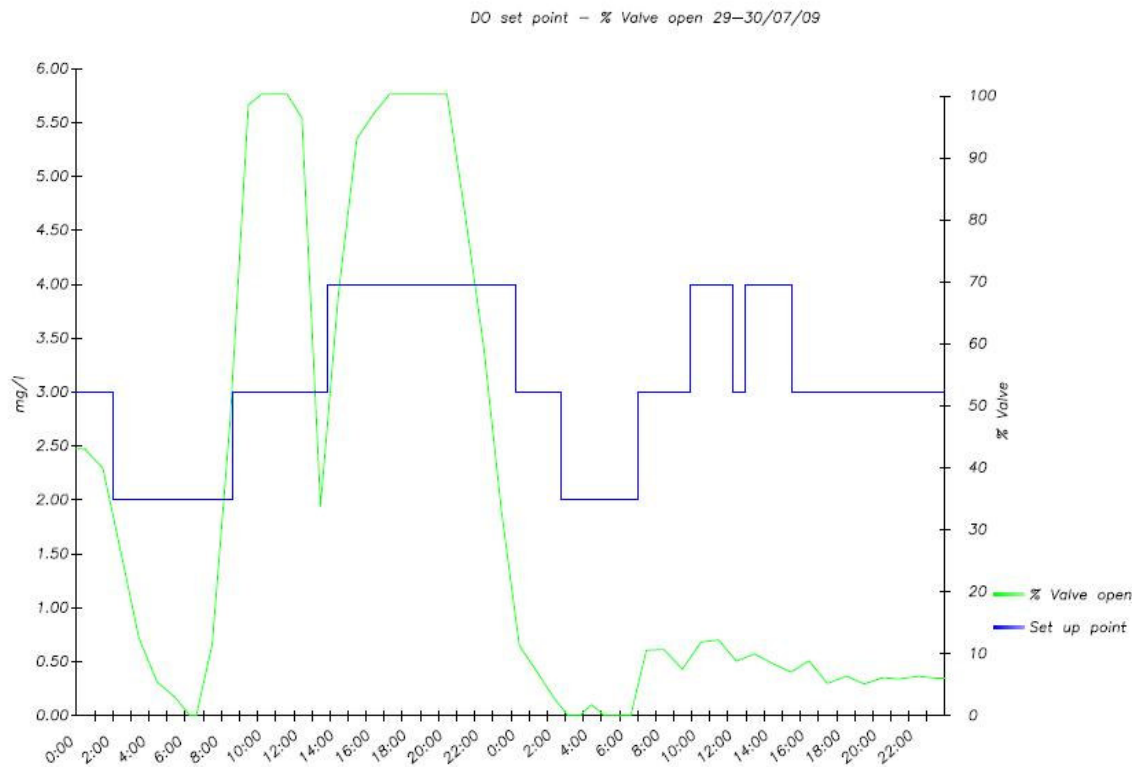
Percentage valve of air flow open in tank and DO set point from 23rd till 24th July



Percentage valve of air flow open in tank and DO set point from 25th till 26th July



Percentage valve of air flow open in tank and DO set point from 27th till 28th July



Percentage valve of air flow open in tank and DO set point from 29th till 30th July

Appendix D: Total and average of power consumption per m3 of wastewater arriving at the IFAS and AS process



Total and average of power consumption per kg of AOR arriving at the IFAS and AS process

Appendix E: Theoretical air flow, real air flow, power consumption, AOR load and m3 wastewater arriving at the IFAS and AS process

IFAS process									AS process						
Data	Load BOD5 (Kg/d)	Load NH4 (Kg/d)	AOR (kg/h)	Air flow (m3 air/h)	Theoretical Air flow (m3 air/h)	Consump kWh/m3air	Consump. kWh/m3WW	Consump. kWh/kg AOR	Load BOD5 (Kg/d)	Load NH4 (Kg/d)	AOR (kg/h)	Air flow (m3 air/h)	Consump kWh/m3air	Consump. kWh/m3WW	Consump. kWh/kg AOR
8-jun	2296.76	463.95	202.77	8,806.59	7,811	0.016977	0.24	0.74	2931.40	592.14	258.46	5,431	0.021314	0.15	0.45
9-jun	2246.96	537.50	213.87	8,222.24	8,409	0.016977	0.23	0.65	2783.78	665.91	265.32	5,265	0.021314	0.15	0.42
11-jun	2779.66	770.95	284.59	4,760.56	10,919	0.016977	0.12	0.28	3282.40	910.39	321.71	4,861	0.021314	0.13	0.32
15-jun	4044.63	705.35	337.23	3,960.23	11,865	0.016977	0.10	0.20	4858.22	847.24	387.20	5,532	0.021314	0.15	0.30
16-jun	2864.64	536.68	244.06	5,282.13	8,972	0.016977	0.13	0.37	2072.68	388.31	151.30	5,348	0.021314	0.23	0.75
18-jun	3050.27	657.35	261.24	8,632.88	10,196	0.016977	0.24	0.56	1783.08	384.26	158.66	5,846	0.021314	0.35	0.79
22-jun	2707.12	524.72	200.40	9,057.79	8,722	0.016977	0.29	0.77	2264.78	438.98	196.15	4,898	0.021314	0.23	0.53
23-jun	2892.42	597.90	239.60	9,150.00	9,535	0.016977	0.26	0.65	2113.24	436.83	188.79	5,607	0.021314	0.28	0.63
25-jun	2106.98	409.00	174.47	7,263.93	7,167	0.016977	0.33	0.71	2931.17	568.99	254.14	4,802	0.021314	0.21	0.40
29-jun	2328.42	470.18	205.25	7,312.30	7,907	0.016977	0.24	0.60	2379.80	480.55	209.61	5,460	0.021314	0.22	0.56
30-jun	2144.85	511.91	203.92	7,728.58	8,089	0.016977	0.25	0.64	2061.06	491.91	197.25	5,808	0.021314	0.25	0.63
2-jul	2300.94	603.28	225.14	7,073.83	9,033	0.016977	0.23	0.53	2315.31	607.05	231.92	5,886	0.021314	0.24	0.54
6-jul	2721.71	607.18	250.25	6,988.38	9,457	0.016977	0.22	0.47	2359.49	526.38	218.99	5,286	0.021314	0.24	0.51
7-jul	2787.45	669.56	266.83	7,302.79	9,996	0.016977	0.22	0.46	2849.88	684.56	273.96	5,907	0.021314	0.22	0.46
9-jul	2268.32	581.71	222.81	5,488.34	8,812	0.016977	0.17	0.42	2149.09	551.13	213.25	5,006	0.021314	0.20	0.50
13-jul	2697.49	467.70	221.94	4,445.03	8,218	0.016977	0.14	0.34	2647.36	459.01	220.55	5,012	0.021314	0.20	0.48
14-jul	3970.83	566.46	301.00	7,979.34	10,255	0.016977	0.23	0.45	4032.37	568.59	310.65	5,216	0.021314	0.19	0.36
16-jul	3538.86	423.28	255.90	8,294.04	8,613	0.016977	0.36	0.55	3865.66	462.37	281.29	5,856	0.021314	0.29	0.44
17-jul	5344.64	627.27	376.60	8,268.33	12,057	0.016977	0.22	0.37	4410.32	517.61	310.23	5,769	0.021314	0.23	0.40
Avera	2899.63	564.84	246.73	7,158.81	9,264.89	0.017	0.222	0.515	2846.90	556.96	244.71	5,410.32		0.219	0.499

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