FINAL REPORT

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TABLE OF CONTENTS

1.0 EXECUTIVE SUMMARY

Real time monitoring and control is becoming increasingly important for all manner of industrial applications. New advances in sensor technology have made real-time monitoring of biological processes significantly more reliable. The wastewater treatment industry is transitioning to increased use of remote SCADA (supervisory control and data acquisition) systems to replace manual testing and adjustment.

The use of remote monitoring and control in the meat processing industry is not widespread. From our industry experience, less than 10% of meat processing plants employ sensor technology for daily monitoring and optimisation of the wastewater treatment process. This means the industry spends a large amount on excess aeration and chemicals for nutrient removal, and the lack of monitoring prevents evaluation of the performance of anaerobic and aeration systems.

Many abattoirs currently do not consider sensor technology a worthy investment. What has been lacking is reliable industry experience and demonstrated case studies in the use of sensor technology. This research project was designed to assist abattoirs in evaluating the tangible and intangible benefits to their wastewater treatment by utilising a real time data monitoring and control system provided by good quality sensors. The deliverable being a comprehensive industry referral document for abattoirs regarding the implementation of sensor technologies and control systems - basic and advanced- for the wastewater treatment process.

The research was conducted in two phases, a desktop phase and a field demonstration phase. The objective of the desktop phase was to:

- Review the current waste stream sensor platforms and associated control systems
- Identify the key parameters for optimisation of the operation of the treatment process
- Determine the typical operating and capital costs for different tiers of sensor configuration
- Review the reported benefits and challenges of relevant case studies for sensor implementation in wastewater treatment both locally and internationally
- Analyse the business case for application of sensor technologies to better manage waste streams in abattoirs

The desktop phase has found that there are a range of technologies available to measure important wastewater parameters for regulatory and operational purposes. The reviewed case studies have shown that sensors enable optimisation of biological wastewater treatment processes leading to improved reactor performance, reduced energy and chemical requirements, and lower rates of impact of mechanical breakdowns on environmental outcomes.

Following the success of the desktop study, a field demonstration was undertaken to evaluate the benefits of sensor implementation for the optimisation of a local abattoir's anammox nitrogen removal process. The results from the field study were consistent with the benefits reported in the case studies. The cost of chemical inputs was reduced by 100% and energy use was reduced by 40% following optimisation of the process through active monitoring.

The results corresponded to a payback period of less than one year for the sensors in this application. In addition to the financial benefit, the sensor technologies enabled the abattoir to consistently meet regulatory requirements.

2.0 INTRODUCTION

The wastewater treatment process in abattoirs has become increasingly challenging for a number of reasons. These include stricter environmental discharge regulations, new opportunities for harnessing energy from anaerobic processes, and greater demand for process optimisation in order to minimise energy consumption and chemical dosing. There are also more advanced options in treatment technologies such as the advanced anammox process for nitrogen removal that can save substantial operating costs. Other developments that are in the research phase include producing fertilizer from wastewater and separating streams by contamination level for optimal processing. All of these innovations require high quality data collection and control systems at various stages of the wastewater treatment process.

Over the past few years, sensors have undergone considerable advancement. New sensors that require less frequent or no calibration, easier maintenance, relatively low cost and high accuracy have been developed. These advanced systems include ion selective electrodes and optical sensors. A variety of parameters can be monitored simultaneously using these advanced sensors, including COD, TSS, TOC, BOD, pH, DO, ORP, NO and VFA contents. Such sensors can be used to monitor the condition of the influent, anaerobic reactor/lagoon, aeration basin and treated effluent. It is equally important to consider the online probes or sensors for evaluating the fat, oil and grease contents of wastewater from abattoirs in order to evaluate the efficiency of pre-treatment systems and to avoid operational problems downstream. The data collected by these sensors can be used for preventing discharge permit violations, controlling the operation of the process, regular monitoring and optimising energy and chemical consumption.

The objective of this project was to perform a state-of-the-art review of current waste stream sensor platforms and associated control systems. This comprised identification of key parameters for the optimisation of the treatment process operations, techno-economic evaluation of sensor technologies, review of case studies and field validation of a selected sensor system and optimisation of processes at an abattoir.

3.0 PROJECT OBJECTIVES

The overall objective of the project was to develop an industry referral document for abattoirs regarding the implementation of sensor technologies and control systems - basic and advanced- for the wastewater treatment process.

The specific objectives of Phase I included:

1. A state-of-the-art review of current waste stream sensor platforms and associated control systems as well as software for determining characteristics of abattoir wastewater including fat, oil and grease (FOG) and operation of treatment units including dissolved air flotation system (DAF), anaerobic and aeration, and solid separation processes. This review would investigate different levels of systems (simple, medium and advanced) vis-a-vis the complexity of the operations and available capital.

2. Identification of key parameters for optimisation of the operation of the treatment process - including performance of the anaerobic system, biogas generation and nutrient removal with minimal or no supplementary chemical addition (such as anammox process, and biological phosphorus removal).

3. Techno-economic evaluation of suitable sensor technologies and associated systems as well as cost to set up and operate for determination of various characteristics of abattoir wastewater including FOG in different treatment units.

4. Cost benefit analysis and return on investment of implementing sensor technologies for abattoirs - economic, environmental and organisational such as nutrient reduction, saving of technician's time and preventive maintenance.

5. Review of case studies where available, including benefits of implementing sensor technologies for the wastewater treatment process - international and Australian, both in the red meat processing industry and other industries.

6. Investigate the business case for application of sensor technologies to better manage waste streams in abattoirs. If the outcomes of Phase 1 (particularly objective 6) were positive, then the project would proceed to Phase 2. Phase 2 was the field validation of a selected sensor system and optimisation of processes at an abattoir.

4.0 METHODOLOGY

To construct the industry referral document for sensors in abattoir wastewater treatment, both literature and field data were collected and analysed to ensure relevance to the local industry. The first phase was a desktop study, literature review, and industry consultation to evaluate the various technologies and sensors available for abattoir wastewater treatment applications nationally and internationally. This included:

- Identification and reporting of key parameters for treatment plant performance and regulatory compliance
- Review of sensor technology available, and how it operates as part of a SCADA (supervisory control and data acquisition) system
- Categorisation of available sensors (designated by tiers) depending on wastewater treatment plant application and technology
- Capital and operating cost estimates for the different tiers of sensor systems using data from suppliers that service Australian businesses
- Review of compliance and operational benefits of sensor and control implementation reported in the literature

These activities were completed utilising a wide variety of resources. These included articles published in reputed journals, reference textbooks and other research material obtained from access to online libraries and databases provided by universities and internally at EEI. The reviews also drew from EEI’s detailed knowledge of wastewater treatment engineering, and our extensive experience creating practical solutions in the wastewater field. Vendors and specialists in the industry were consulted to ensure the validity of the information provided.

The second phase tested the performance, operational and compliance benefits of sensor and control implementation reported in the literature in the field. EEI monitored the operation of an abattoir WWTP treatment system running the $\text{ANRUP}_{\text{anammox}}$ process for nitrogen removal.

The monitoring and control were conducted remotely in real time using a newly installed sensor and control system that measured nitrogen species, dissolved oxygen, pH, chemical oxygen demand (COD) and temperature parameters. The plant’s operation and performance data were collected at 10-

minute intervals. This enabled the operator to evaluate the performance of the WWTP and make any changes to the operation of the system in real time.

In addition to the performance data, EEI compiled historical and recorded present data related to:

- Energy use of the anammox WWTP
- Chemical dosage for the anammox WWTP
- Site labour costs
- Reported maintenance and compliance issues

This enabled the operational savings of advanced sensor and control use to be evaluated. From the data, the Payback Period, Net Present Value (NPV), and qualitative analysis of operating and reliability benefits could be established. EEI conducted internal laboratory tests and engaged external NATA approved laboratories to verify the accuracy of the data output.

5.0 PROJECT OUTCOMES – DESKTOP STUDY

5.1 Summary of Important Water Quality Parameters for the Meat Industry

Wastewater generated from the meat processing industry is considered ‘high strength wastewater’ due to its high content of organics and nutrients. Although the quality of wastewater varies throughout the meat processing industry, it generally has a high concentration of total organic carbon (TOC), chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), total phosphorus (TP), and total nitrogen (TN) (Kurup 2008). In order to minimise environmental impact, regulations have been established to ensure that wastewater generated from abattoirs is adequately treated prior to disposal. Therefore, the wastewater treatment plant (WWTP) has become an important facility in any meat processing establishment.

One of the consequences of requiring a WWTP is the cost associated with the operation of the system. An inefficient treatment system increases operating cost and it can cause frequent discharge violations. Although optimisation of abattoir WWTP systems is desirable, it is often difficult to achieve due to a lack of information on the variability of wastewater quality, details of monitoring, and availability of control systems. Many abattoir WWTPs have not been designed to provide a dynamic response to variabilities in flow, wastewater characteristics and treatment performances. In addition, most abattoirs do not have engineers or technical support specialised in WWTPs operations.

The major WWTP processes in the meat process industry can generally be divided into two groups, anaerobic and aerobic systems. Anaerobic systems utilise bacteria that break down organics in the absence of oxygen. These systems are often installed post-physical treatment such as dissolved air flotation system (DAF) and prior to the aeration system. Given the high organic content in abattoir wastewater streams, the anaerobic process is traditionally considered an essential unit process of the treatment plants.

Aerobic systems utilise aerobic bacteria to break down organics with oxygen input. For nitrogen removal, both conventional nitrification-denitrification and anammox require varying degrees of aerobic and anaerobic stages in a single treatment unit such as an aeration basin or reactor. Typically, the secondary wastewater treatment processes (anaerobic and aerobic) are dependent on microbial organisms. Therefore, it is crucial to provide the environmental conditions needed to sustain the required biological activity for the organisms.

Constant monitoring of the water quality parameters may be required for regulatory or process optimisation purposes. In general, the water quality parameters that are monitored in an WWTP are temperature, pH, dissolved oxygen (DO), conductivity, turbidity, salinity, TSS, BOD, COD, TOC, ammonia (NH_4-N), nitrate (NO_3-N), and nitrite (NO_2-N). Due to the characteristics of the wastewater, the meat processing industry also has a high interest in the monitoring of the fat, oil and grease (FOG) content, as well as the depth of crust formed on top of the system. Table 1 sorts these parameters based on operational or regulatory application.

Table 1: Important parameters for meat industry wastewater

Operational	Regulatory
Temperature	BOD
pH	Total Phosphorus
Dissolved oxygen	Total Nitrogen
COD/TOC	pH
Total suspended solids (TSS)	Total suspended solids
Fat, oil and grease	Salinity*
Conductivity*	Fat, oil and grease
Salinity*	Conductivity*
Ammonia	
Nitrite	
Nitrate	
Ortho-phosphate	

(* not typically required, only where hide processing effluent is discharged to the WWTP)

Traditionally, monitoring of the water quality parameters has been done manually. This task is labour intensive and requires skilled labour to perform, resulting in a high cost. This type of monitoring can only provide a “snapshot” of the system rather than real-time continuous information. Due to the limitations of conventional monitoring activity, the industry has gained significant interest in sensor technology being used as the primary method of monitoring the condition of the WWTP. Included in this report is an overview of the sensor technologies that are available to monitor the required water quality parameters.

5.2 Applicable Sensor Technology

5.2.1 Temperature Sensor

There are seven basic types of temperature sensor available, but there are two types of sensors which are suitable for monitoring the wastewater from the meat processing industry. These are thermocouples and resistive temperature devices (RTDs) based sensors. Thermocouples are voltage devices that determine temperature by measuring a change in voltage (OMEGA Engineering 2010). RTDs measure the resistance of the material to determine the temperature. Both sensors are suitable for continuous monitoring of the temperature of wastewater due to the electrical nature of the operation.

5.2.2 pH Sensors

A pH sensor operates by comparing the difference between the electrical potential produced by a glass membrane electrode and the reference electrode. **Figure 1** shows a typical pH sensor arrangement [Figure adapted from (Skrentner 1988)].

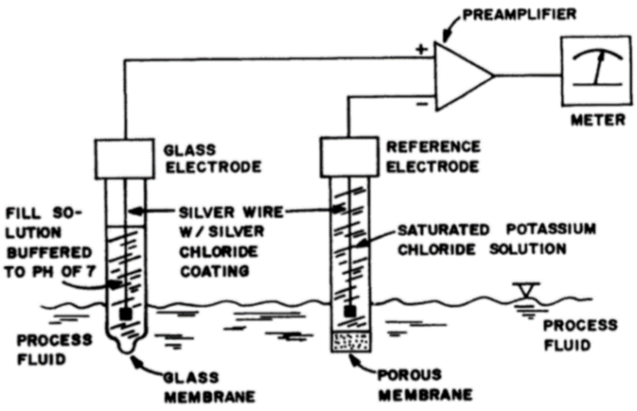


Figure 1: *Schematic of a pH Sensor (Skrentner 1988)*

The glass electrode is the most important part of the whole sensor setup as it is the device that produces the electrical potential that varies depending on the pH of the fluid. This sensor is known to be accurate and reliable with sufficient maintenance. General maintenance of the sensor includes cleaning of the glass membrane and calibration of the pH meter with the suitable buffer solutions.

5.2.3 Dissolved Oxygen Sensors

Dissolved oxygen (DO) sensors are used to provide information on how much oxygen is available in the water column. DO sensors consist of an electrochemical cell, the probe and a signal conditioner or transmitter (Skrentner 1988). In the electrochemical cell, dissolved oxygen from the water is reduced at the cathode, following the half-cell reduction reaction of:

$$O_2 + 2H_2O + 4\ electrons \rightarrow 4\ OH^-$$

At the anode, the target metal is oxidised. The effect of the reaction is a flow of electrons from the cathode to the anode proportional to the dissolved oxygen in the water. The movement of the electrons causes an electricity flow which can be detected and translated by the sensor into a DO measurement. There are several factors that can affect the accuracy of the DO sensors. These include temperature, suspended and dissolved solids, fouling of the membrane, and interference from other dissolved gases. General maintenance for the DO sensors includes cleaning and replacing the membrane, changing the electrolyte, and calibration of the sensor.

5.2.4 Conductivity and Salinity Sensors

Conductivity and salinity sensors can be classified into two different groups, sensors that require direct contact with the water and sensors that do not. The suitability of the sensor group depends on the amount of conductivity, the corrosiveness of the fluid, and the amount of suspended solids (Rosemount Analytical 2010).

Contacting Conductivity Sensor

Most contacting conductivity sensors consist of two metal electrodes that are in contact with the liquid. The conductivity of the liquid is analysed by applying an alternating voltage to the electrodes. The alternating electricity causes the ions in the fluid to move back and forth, producing a current. The generated current by the ion movement is measured by the analyser and used to calculate the resistance of the fluid by applying Ohm's Law (Rosemount Analytical 2010). The resistance of the fluid can be correlated to the conductivity of the liquid. To increase the range of the detectable conductivity, additional electrodes are used to form the sensor. **Figure 2** outlines the general mechanism of this sensor.

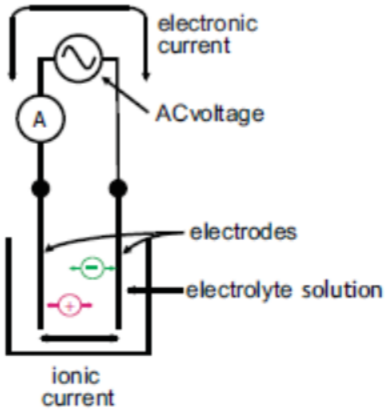


Figure 2: *Mechanism of the contacting conductivity sensor (Rosemount Analytical 2010)*

Inductive Conductivity Sensor

An inductive conductivity sensor, also known as a toroidal or electrodeless conductivity sensor, is a conductivity sensor where the analyser is not in contact with the liquid. This sensor consists of two wire-wound metal toroids encased in a corrosion-resistant plastic body (Rosemount Analytical 2010). One of the toroids acts as the drive coil, while the other acts as the receive coil. Similar to the contacting sensor, the analyser applies an alternating voltage to the drive coil. This alternating voltage induces a current in the surrounding liquid. The produced current then induces an electrical current in the receive coil, which is measured by the analyser. The induced current measured in the receive coil is proportional to the conductivity of the liquid.

Figure **3** outlines the general mechanism of this sensor.

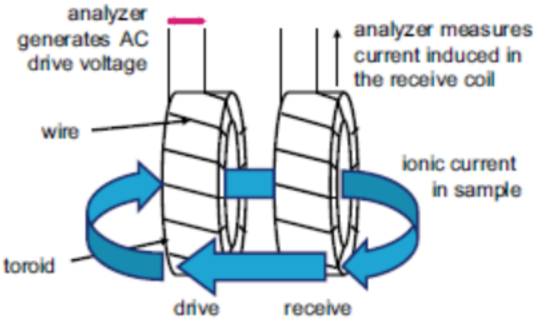


***Figure 3:** Inductive Conductivity Sensor (Rosemount Analytical 2010)*

Due to the availability of protective material in the sensor, this type of conductivity sensor is suitable to monitor the conductivity of the wastewater produced by the meat processing industry.

To determine the salinity of the water, a correlation is made with the measured conductivity. This is possible as a higher salinity means that more ions are available, hence increasing the conductivity of the water.

5.2.5 COD_{total}, $COD_{soluble}$ and TOC Sensors

There are several types of chemical oxygen demand (COD) and Total Organic Carbon (TOC) sensors that are currently available. These include optical methods (such as UV-visible spectroscopy and fluorescence) and electrochemical method sensors.

Optical Methods

The optical sensors operate by detecting the absorbance of light by organic matter in the water at a specific wavelength. Due to the presence of aromatic substances and double bonds on the molecular structure of organic matter, most have absorption peaks in the UV region with an absorbance wavelength of 254-280 nm (Dobbs, Wise & Dean 1972). By detecting the absorbance at those wavelengths at various COD/TOC values, a linear correlation can be established between the absorbance and the actual value.

However, turbidity and suspended solids within the water have been found to interfere with the transmitted optical signals. To minimise this interference, multiple light sources with different wavelengths are used. With a wider range of wavelengths, a wider range of COD/TOC reading can be monitored.

A study by Zhao et al. (2011) using multiple light sources with wavelengths ranging from 200 to 720 nm has successfully created a COD sensor with the range of 30 to 1,000 mg/L. With the advancement of fibre optic technologies, this method is becoming more reliable, accurate and viable for continuous monitoring. The BOD values are generally determined as a correlation between the $COD_{soluble}$ values and the actual BOD tested at a laboratory to obtain an indirect measurement of BOD.

Electrochemical Method

The principle behind the electrochemical method for measuring COD/TOC is based on exhaustive electrolysis. Organic matter within the water is hydrolysed by the electrode which creates electrical flow depending on the number of electrons consumed during the process (Lee et al. 1999; Liao et al. 2016). Similar to the optical method, a correlation between the electrical voltage and actual measurement is created to easily translate the electrical voltage into an estimated COD/TOC measurement. Despite the good accuracy of the system, the complexity and the size of the sensor is a disadvantage when compared with the optical sensor. However, a sensor such as that described by Liao et al. (2016) could be commercially available in the near future. This could provide the industry with a COD sensor that is sensitive, highly accurate and has a small footprint.

5.2.6 Phosphate Sensors

There are several methods that can be used to detect and quantify phosphate concentration in the water. These include potentiometric techniques, indirect voltammetric detection based on the reaction of phosphate with other substances, and through detection of enzymatic reactions (Villalba et al. 2004). This report will review only the most applicable method, which are the potentiometric method, biosensors and the automated conventional spectrophotometry method.

Potentiometric Method

The potentiometric method is the most widely used technology for phosphate sensors due to the inexpensive production cost and high portability. This operates by utilising phosphate sensitive materials as the electrodes. The change in electrical potential due to the concentration of phosphate present is converted into a phosphate measurement (Korostynska, Mason & Al-Shamma'a 2013).

Early phosphate sensors of this type were unreliable due to the interference of other substances. However, with the application of selective membranes, this interference has been significantly reduced (Villalba et al. 2004). This type of phosphate sensor is known to the industry as an Ion Selective Electrode (ISE) sensor.
***Figure* 4** outlines the general schematic of the phosphate ISE sensor.

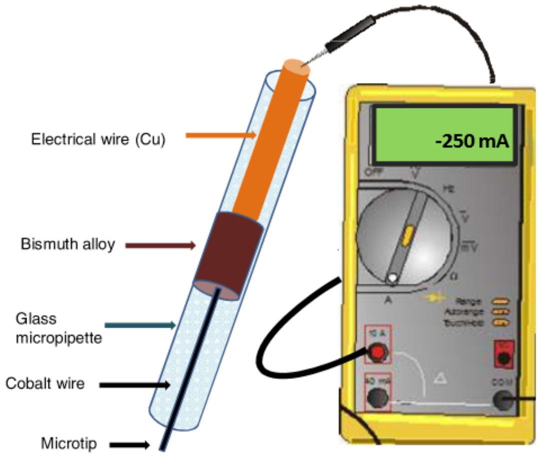


Figure 4: *Key components of an ISE sensor (Korostynska, Mason & Al-Shamma'a 2013)*

Phosphate Biosensors

Instead of directly measuring the concentration of phosphate, biosensors measure the product of the reaction between enzymes and phosphate. The measured quantity of the product is correlated with the actual phosphate concentration produced from laboratory testing.

Figure 5 outlines the general flow process of a biosensor.

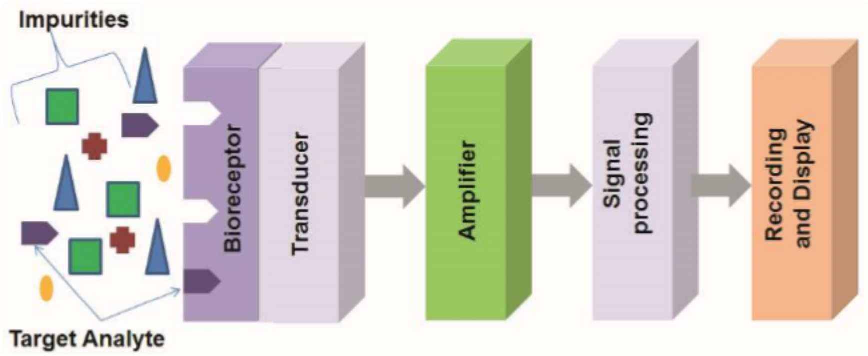


***Figure 5:** Processes in a biosensor (Korostynska, Mason & Al-Shamma'a 2013)*

The major advantage of the biosensor is the higher accuracy when compared with other methods. The utilisation of enzymes minimises the interference from other substances due to the superior selective mechanism. However, the complexity of the system has resulted in the system being unavailable to the market. In the future if this technology was readily available it would lead to a more reliable and accurate phosphate sensor.

Automated Conventional Method

This method utilises the conventional phosphate laboratory testing procedure. The phosphate is measured using the blue ammonium molybdate method. This method utilises pumps and motors to perform the sampling and testing of the target liquid. This method is normally known as an Auto-Analyser in the industry. Samples from the liquid are pumped automatically to the testing equipment, where chemical reagents are added similar to the laboratory method. After the reactions are finished, the sample is analysed for the product of the reaction by spectrophotometric methods. The sample is disposed of after the testing is completed. The advantage of this method is the high accuracy as it directly measures the phosphate concentration in the sample. The disadvantages of this system are its inability to provide real-time continuous data and the high cost associated with the equipment.

5.2.7 Ammonia, Nitrate and Nitrite Sensors

Detection of ammonia, nitrate and nitrite follow similar methods as the one used to detect the other parameters. In general, the types of sensor can be classified into:

1. Optical method
2. Potentiometric method

3. Biosensors
4. Automated conventional method

The process of detection using the methods mentioned above is similar to the process described for the COD/TOC and phosphate sensors. What differentiates the ammonia, nitrate and nitrite sensors to the other sensors that utilise similar technology is the detailed specification of the sensor. For example, the optical method sensor for ammonia, nitrate and nitrite utilise wavelengths of less than 220 nm (USGS 2014; Drolc & Vrtovsek 2010) which is shorter than the COD/TOC sensor that utilises a wavelength of 254 nm. Sensors which share the same methodology have similar advantages, disadvantages, and maintenance requirements.

At present, the ammonia and nitrate sensors available in the market are typically based on ISE sensor technology. There are also nitrate and nitrite sensors available using UV optical methods.

5.2.8 Fat, Oil & Grease Sensors

Currently fat, oil and grease (FOG) sensors are used in a wide range of industries such as food processing, water utilities, pharmaceuticals and abattoirs. However, minimal publications have been made publicly available. Most of the information has been kept by the commercial entity that develops the system. Based on the limited information available on the manufacturers' fact sheets, it has been found that the sensor utilises a high-frequency signal. This signal travels differently depending on the substance. By detecting the difference in travel speed of the signal, the depth of the FOG layer can be deduced.

Figure 6 illustrates the mounting of a FOG sensor. In the diagram, 'A' represents the air, 'B' the FOG and 'C' the water. The numbers 1 and 2 show the sensor and transmission cable protected by shrink tubing respectively (Pepperl+Fuchs 2014).

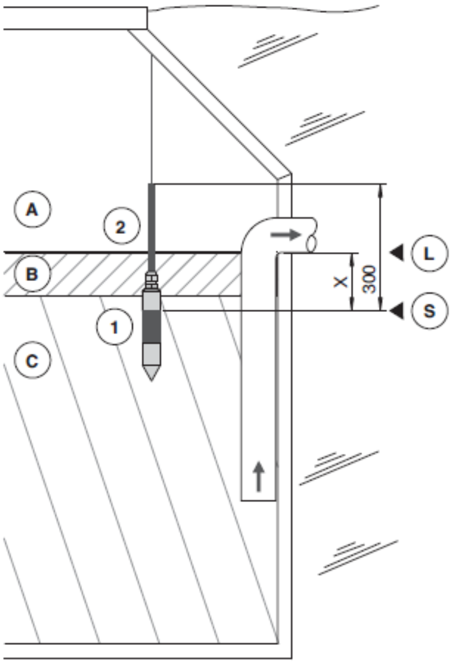


__Figure 6:__ Mounting of a FOG Sensor (Pepperl+Fuchs 2014)

5.2.9 Total Suspended Solids Sensors

Total suspended solids (TSS) sensors utilise an optical sensor to detect the residual light from a light source after it has been in contact with the suspended solids within the water. The technology that is currently utilised in TSS sensors is nephelometry. Nephelometry is the configuration of the sensor where the light source and the photodetector (optical sensor) are set at a 90-degree angle from each other (Figure 7). The sensor will calculate the turbidity (murkiness) of the water and the turbidity will be used to calculate the corresponding TSS value.

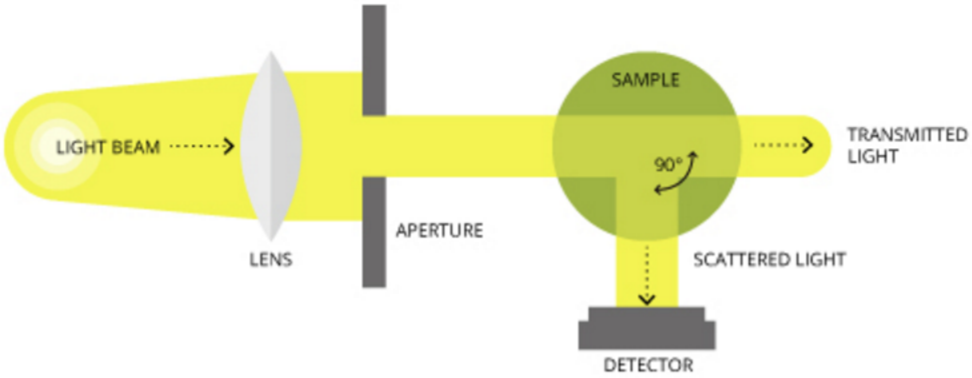


Figure 7: *Nephelometry configuration for a TSS sensor (Fondriest n.d.)*

This type of sensor can be ISO 7027 compliant if a suitable light source is used (US EPA 1999). However, the simplest nephelometry configuration has a limited detection range of up to 40 NTU (Nephelometric Turbidity Units). If the expected turbidity is higher than 40, a variation of the sensor can be used, where multiple photodetectors are used at various angles (Figure 8).

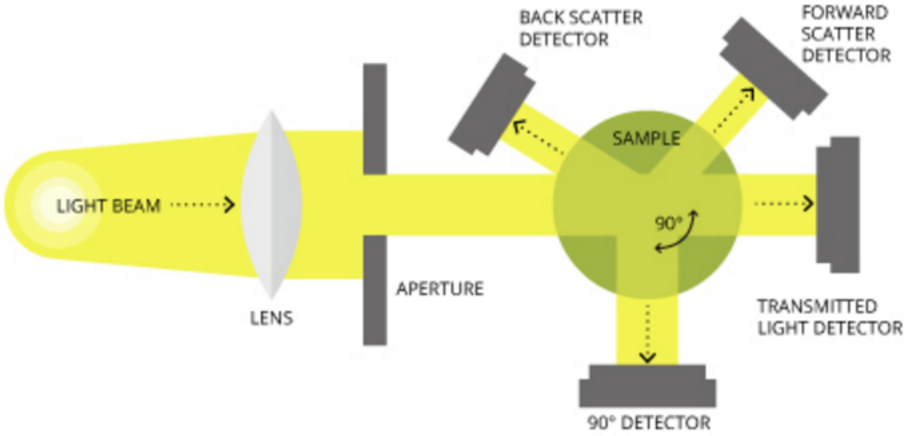


Figure 8: *Variation of the nephelometry configuration for high turbidity (Fondriest n.d.)*

This configuration is known as a Ratio Design. Through the utilisation of multiple photodetectors, the detection limit of the turbidity can be increased to 10,000 NTU (Fondriest n.d.). The ratio design is suitable to be used for monitoring wastewater produced by the meat processing industry due to the expected high TSS content. Multiple equipment providers have implemented this technology into their sensors.

5.2.10 Summary of Sensors Technologies

In summary, there are several viable methods for monitoring water quality parameters that are useful in providing data for optimisation of the treatment system and to ensure compliance with the discharge permit. **Table 2** summarises the available technologies that are used to monitor water quality parameters.

Table 2: Available monitoring technology for various parameters

Water Quality Parameter	Available Technology
Temperature	• Thermocouples • RTD
pH	• Electrochemical
Dissolved Oxygen	• Electrochemical method
Conductivity & Salinity	• Contacting sensor • Inductive sensor
TSS	• Nephelometry • Ratio design
COD& TOC	• Optical sensor • Electrochemical method
Phosphate	• Optical method • Potentiometric method • Biosensors • Automated conventional method
Ammonia, Nitrate & Nitrite	• Optical method • Potentiometric method • Biosensors • Automated conventional method
Fat, Oil & Grease	• HF sensor

5.3 Implementing Sensors into a SCADA System

Sensors alone cannot monitor or control a process, they need to be implemented as part of a SCADA (supervisory control and data acquisition) system. There are many types of SCADA systems available, but they all typically consist of four main components. These are data acquisition, data transfer, remote data conversion and control, and central control. These components work together to monitor and control a process. A range of hardware and software products are available to fit the needs of each component (Bailey 2003); this overview will focus on the applicable information for the meat industry. Before SCADA is explained in detail, each component will be introduced.

5.3.1 Data Acquisition

Data acquisition refers to the raw data input measured by sensors, instruments, meters and other field devices for use by the SCADA system. These devices measure the important parameters used to control the process. Some examples of these parameters include pressure, volume, flow rate, DO and pH. The applicable sensor technology section has detailed some examples of common industry sensors and how they function.

Generally, when sensors measure these parameters the data is transmitted in the form of analogue (smooth and continuous current or voltage) signals. These analogue signals need to be interpreted by other parts of the SCADA system in order to display and read the data. The sensors may be located within the same plant or be spread large distances away. For example, a treatment pond may be located far away from the rest of the plant facilities, but it can still be easily monitored as part of a SCADA system.

5.3.2 Data Communication

The data communication component is the link between all components of the SCADA system. It enables the other components to communicate with each other. This link could be wired or through radio, microwaves, satellite, the Internet or other wireless technologies.

Analogue Signals

Sensors commonly transmit analogue signals, information about the process is contained in a signal with varying amounts of current or voltage. The industry standard for this transmission is through 4-20 mA cable (Paonessa & McDuffy, 2016). For example, a level detector measuring the height of water in a tank will transmit a 4 mA signal when the tank is empty and a 20 mA signal when the tank is full. This signal is transferred through the cable to the applicable remote data conversion device downstream.

Modbus® and Digital Signals

To enable all the components of the SCADA system to communicate with one another, a communication protocol has to be implemented. This is important for the parts of the system that display data and control the operation. The communication protocol is the ‘language’ these devices use to communicate with each other. For example, this is how the instructions from an operator at the central computer are communicated to a PLC (Programmable Logic Controller) to open or close a valve.

Modbus® is an example of an industry open standard communication protocol commonly used in SCADA systems. Modbus® is a type of digital signal. Digital signals are discrete and stepping and are used by the majority of microprocessors and computers. A Modbus® signal defines a message that a controller can interpret. The protocol tells the controller how to request communication with another device on the network and what to do when a request is made (MODICON, 1996).

5.3.3 Remote Data Conversion and Control

At its simplest the remote data conversion and control component of the SCADA system converts the incoming analogue data signals from the sensors into a digital signal. The digital signal is then transmitted to where it is needed by the relevant data communication component. These devices are generally located at the process site, hence the ‘remote’ in the title. They receive data from the sensors, and also send and receive data and instructions from the central command computer. Some examples of these devices include remote terminal units (RTUs), intelligent electronic devices (IEDs) and programmable logic controllers (PLCs). As technology has developed, the sophistication of these devices has increased. Aside from data conversion, process control is now also commonly handled by these devices.

RTUs and PLCs

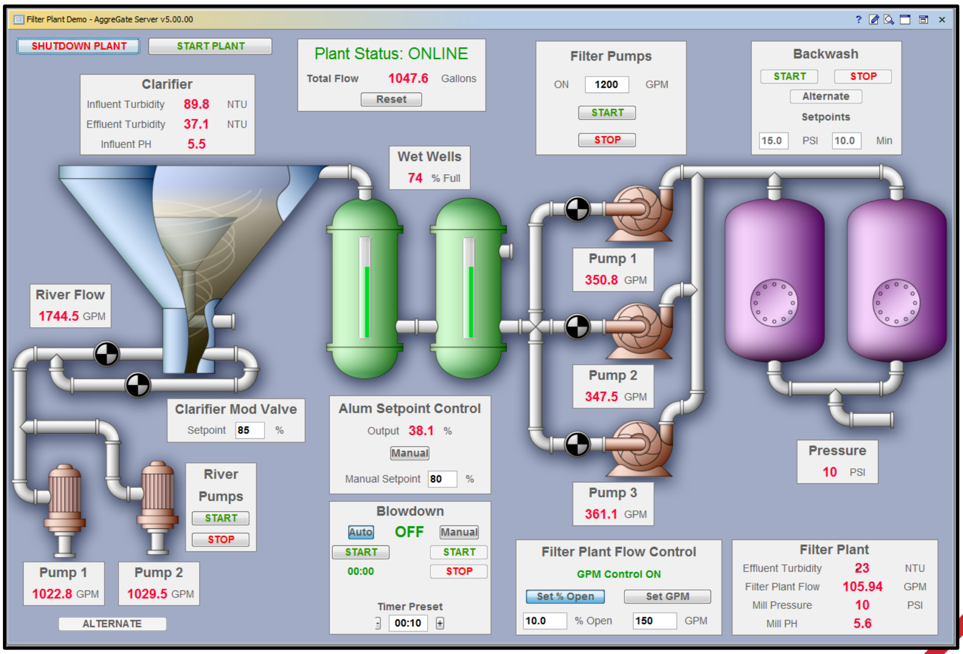
RTUs are microprocessor-based devices that can be programmed to control mechanical processes like pumps and valves in response to direction from the central command computer. PLCs are a more versatile computer based solid state device that can control industrial equipment (Bailey 2003). Early PLCs utilised a simple computing language called a ladder program to manage control operations in response to analogue data input (Bolton 2002). Modern PLCs can even be compared to desktop PCs in terms of their processing capabilities. The expanded software capability of PLCs allows them to perform many different functions that can be readily updated or altered.

Graphical User Interface Devices

Graphical User Interface (GUI) devices provide an immediate visual display of the incoming sensor data. The Hach sc100 TM Controller for example can display the data measured by multiple sensors. This is important in providing a check to ensure the information reaching the PLC is realistic, otherwise the PLC will not meet the desired output specifications on account of the incorrect data input.

5.3.4 Central Control

The central control component of the SCADA system is otherwise known as the central computer or master terminal unit (MTU). An operator can directly control the various operational processes from the MTU via software called the human machine interface (HMI). The HMI displays all the real-time information collected throughout the process and is the means of direct control. Figure 9 is an example of an HMI where the operator sees all the relevant plant process information and can directly adjust the flow rates, pressures and timing of the unit operations.


Filter Plant Demo - AggreGate Server v5.00.00

Plant Status: ONLINE
Total Flow 1047.6 Gallons

Clarifier
Influent Turbidity 89.8 NTU
Effluent Turbidity 37.1 NTU
Influent PH 5.5

Filter Pumps
ON 1200 GPM

Backwash
Setpoints
15.0 PSI 10.0 Min

Wet Wells
74 % Full

River Flow
1744.5 GPM

Pump 1
350.8 GPM

Pump 2
347.5 GPM

Pump 3
361.1 GPM

Clarifier Mod Valve
Setpoint 85 %

Alum Setpoint Control
Output 38.1 %
Manual Setpoint 80 %

Blowdown
OFF
00:00
Timer Preset 00:10

Pressure
10 PSI

River Pumps
Pump 1
1022.8 GPM
Pump 2
1029.5 GPM

Filter Plant Flow Control
GPM Control ON
10.0 % Open
150 GPM

Filter Plant
Effluent Turbidity 23 NTU
Filter Plant Flow 105.94 GPM
Mill Pressure 10 PSI
Mill PH 5.6

Figure 9: *Example of HMI Software (TibboSystems 2016)*

Additional security and safety features such as alarms, cameras and motion sensors also display and communicate with the operator via the HMI. The status of all the equipment is displayed at the HMI so the operator can easily see what maintenance is required. The data presented will also indicate if there is an issue with the performance of any component, allowing for quick rectification of the problem.

5.3.5 Control Loops

Closed loop control ensures the process meets the desired specifications by accounting for changing environmental conditions and real-world variance. In closed loop control the input conditions of a process are controlled based on the desired output.

A simple block diagram for a closed loop control system is shown in Figure 10 below. In this block diagram the ‘plant’ refers to any system or process to be controlled, ‘measurement’ refers to data acquired by sensors or other instruments, and the ‘controller’ can adjust the relevant operating conditions of the plant. The controller may be a PLC or RTU and can also receive instructions from the central computer. Any difference between the measured output and the programmed desired output generates an error value interpreted by the controller. The controller will then attempt to change the plant in order to drive the error term to ‘0’.

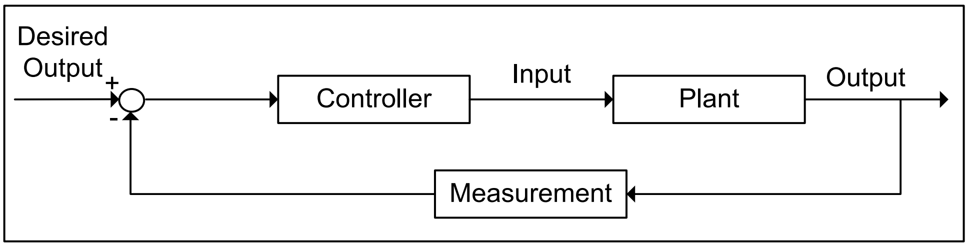


Figure 10: *Block Diagram of a Closed Loop Control System*

These control loops are the basis of the SCADA system. For example, consider a dissolved oxygen (DO) dosing system for a wastewater treatment plant. The sensor continuously measures the DO concentration and sends the information to a PLC. When the concentration falls below the programmed desired value the PLC will turn on an air pump until the desired output is reached. An operator can change the PLC’s target oxygen value at any time and monitor the process via the HMI.

5.3.6 Supervisory Control and Data Acquisition Overview

SCADA (supervisory control and data acquisition) systems have been in operation since control systems were first introduced to manage and optimise industrial processes. Fundamentally, SCADA systems enable the measurement and control of important process parameters from a program or operator based at a central command computer(s) (Frank R. Spellman 2013). The central computer oversees all the control loops throughout the plant and can actively adjust plant operating conditions as required. This allows processes to be monitored without needing staff to physically visit the equipment at that location.

The term SCADA implies remote operation of the control system (Bailey 2003). The distance between the controlling and controlled location may be further than a direct wired connection will practically allow. Systems may instead communicate through radio, microwaves, satellite, the Internet or other wireless technologies.

Figure 11 illustrates how the components of a SCADA system can interact with each other. The data acquisition, data transfer, remote data conversion and control, and central control components are shown communicating in this particular example wirelessly.

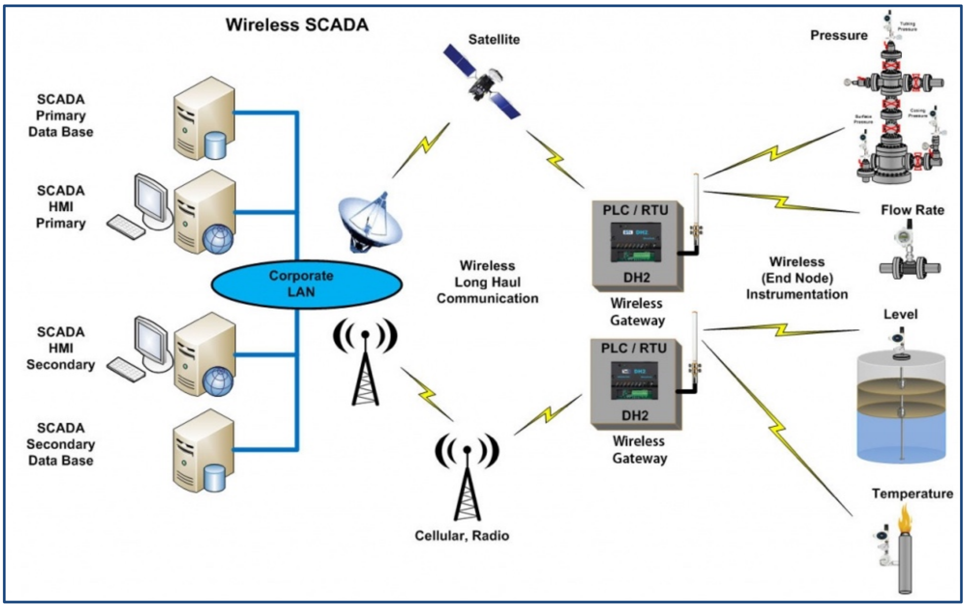


***Figure 11:** Example of a wireless SCADA system setup, courtesy OleumTech (OleumTech, n.d.)*

There are many theoretical benefits to implementing a SCADA system, these include (Bailey 2003):

1. Improved operation of the process due to quicker response times and more efficient use of material and energy resources
2. Increased productivity of personnel, and lower risk of errors associated with human fatigue or error
3. Improved process safety due to readily available data and continuous monitoring and adjustment of unit operations
4. Inbuilt safeguards to protect plant equipment and the environment in case of process failure
5. Improved data acquisition and storage to allow for optimisation of the process and aiding decision making.

5.3.7 Maintenance and Calibration

A SCADA system can only function properly if the data it is receiving is accurate. The control mechanisms in place cannot deliver the desired output of a process if it’s controlling from inaccurate information. That is why sensors require initial calibration, and to be checked periodically to ensure they are providing an accurate response. For example, it’s recommended to clean and calibrate Hach ISE ammonia and nitrate probes on a monthly basis (Hach 2013).

Analogue sensors in particular need to be calibrated in the system circuit to avoid interference that will affect the transmitted current (Earl 2015). It's also important to consider the precision and resolution of a sensor. Precision refers to the repeatability of the measurement, and resolution the small interval changes that can be detected. A reliable, well calibrated sensor should be accurate, precise and offer a high resolution.

Different calibration techniques are required depending on the sensor to be calibrated. A reference solution or physical standard (like the triple point of water) is used as a known measure to compare the actual sensor output (Earl 2015). Readings are then taken to define the 'characteristic curve' of the sensor. The characteristic curve defines the sensors output for a given testing input. The number of values in the range required to accurately define the curve is based on how linear the relationship between the sensor output and the measured parameter is (Earl 2015).

Sensors which operate over a small range and have a strong linear relationship generally only require a one-point calibration. Here the sensor output is compared to a single reference point in the operating range to confirm accuracy. One-point calibration can only correct an offset or 'drift' from the expected value, it cannot correct the slope of the characteristic curve. Two-point calibrations can correct the slope and drift of the curve, these involve reference comparisons at the high and low ends of the measuring range. If the sensor relationship is highly non-linear more reference measurements are needed in order to create an accurate calibration curve.

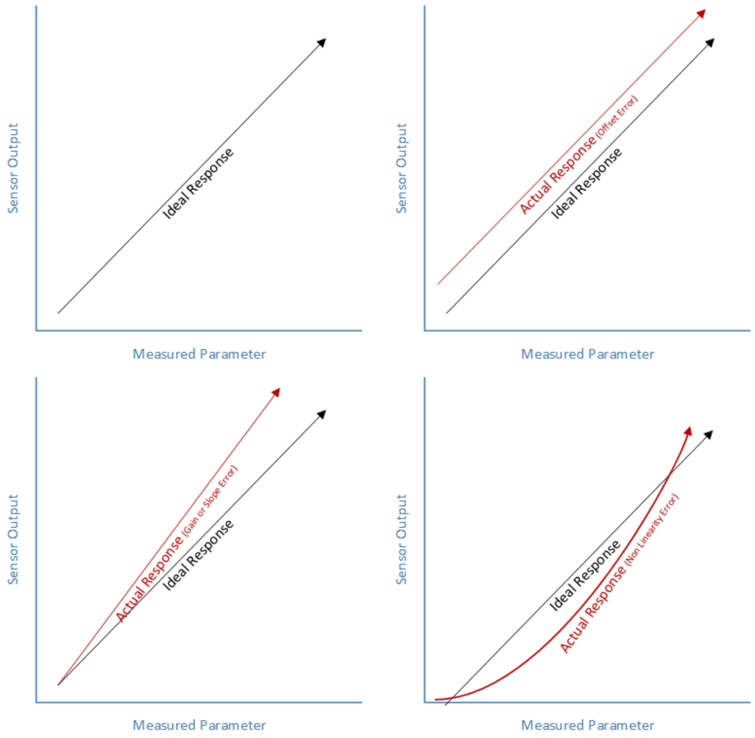


Figure 12: *Illustration of sensor responses that can be corrected through calibration (Earl 2015).*

5.4 Characterisation of Sensor System Configurations

This report characterises four different tiers of monitoring system configurations. The tiers are differentiated based on the benefits/outputs gained through the implementation of the monitoring system. Tier 1 is the least expensive option, but it only monitors a limited number of parameters, thus resulting in the least potential benefits gained. The Tier 4 system is the most expensive, where a variety of parameters are continuously monitored.

5.4.1 Tier 1

The Tier 1 system monitors basic physical parameters. The physical parameters monitored are temperature, dissolved oxygen, pH, and conductivity. Monitoring of the pH at various sections of the treatment process can identify whether the pH is in the optimum range or if it has reached a critical level. A critical pH can inhibit or kill the bacterial consortium responsible for the treatment processes, leading to process failure.

If an aerobic system is used as part of the treatment process, the monitoring of dissolved oxygen at the aerobic section is beneficial. This allows the operator to deduct whether enough oxygen is being provided to the system, or whether there is an overload of organic or ammonia inputs. An aerator breakdown or malfunctioning can easily be detected by a low dissolved oxygen concentration within the aerobic section of the treatment process. This can be picked up early, without relying on a physical or visual inspection.

Conductivity should be measured if saline water is discharged to the WWTP, from hide processing wastewater for example. Conductivity is directly related to the salinity of the wastewater. High salinity is harmful to the bacteria which could result in the failure of the treatment system.

The main purpose of the Tier 1 monitoring system is to provide elementary optimisation of the treatment process and provide a basic failure detection system. This type of system is suitable for small size facilities that use a basic wastewater treatment process.

5.4.2 Tier 2

The Tier 2 monitoring system configuration analyses basic nutrient and physical parameters. In addition to the parameters monitored by the Tier 1 system, the Tier 2 system monitors ammonia (NH_4-N) and nitrate (NO_3-N). The inclusion of the ammonia and nitrate is beneficial to optimise a nitrogen removal system using the conventional nitrification-denitrification pathway.

Additional sensors can also be added to the system configuration if required. For example, sensors that do not significantly increase the overall cost of the system include redox potential (ORP), total suspended solids (TSS) and fat, oil and grease (FOG). These parameters are not as crucial as the other parameters, but the availability of those parameters will allow further optimisation of the system and can also be used as an additional method of detection to identify malfunctioning of the system.

The main focus of the Tier 2 system configuration is to optimise and ensure that all of the treatment processes of a conventional wastewater treatment plant are operating as they should be, rather than for regulatory purposes. By ensuring that all processes are happening as intended, it is assumed that the system will perform close to the designed capabilities, which should allow the quality of the treated effluent to reach the discharge permit.

5.4.3 Tier 3

The Tier 3 system configuration is recommended for state-of-the-art wastewater treatment systems where the main objective of the system is to achieve high treatment capability while minimising the operating cost of the system. The availability of continuous data from a wide range of water quality and operating parameters allows implementation of treatment technologies that require a precise control system to operate.

Tier 3 systems monitor the concentration of nitrite and organic content (BOD/COD) in addition to the previous parameters from Tier 1 and 2. The availability of data for all of the nitrogen species enables the implementation and optimisation of the anammox technology for nitrogen removal. The benefit and cost savings resulted from the implementation of the anammox process is reviewed in Section 7.

The availability of the continuous organic concentration data can be beneficial in a number of ways. Most fundamentally it will act as an indicator of the performance of the organic removal process. A measured sudden increase in BOD/COD concentration indicates a catastrophic event has occurred that has ceased all biological activities and potentially killed the bacteria within the system. While a steady rise of the organic constituent means that the system is not performing adequately and requires optimisation or troubleshooting. Through continuous monitoring of BOD/COD, an early indicator of non-compliance can be quickly identified and resolved to ensure compliance with the discharge permit during the sampling period.

Digital flow meters can be connected to the control system so that the quantity of flows to each section (anaerobic, recycling, sludge returns in any) can be monitored and utilised for the optimisation of the operation of the plant.

5.4.4 Tier 4

The Tier 4 system adds continuous phosphorus concentration monitoring. This can help reduce the chemical dosing for phosphorus removal and be a performance indicator of the biological phosphorus removal processes within the treatment plant (if applicable).

The purpose of the Tier 4 system configuration is to serve both operational and regulatory objectives to fully ensure continuous optimisation and compliance with the discharge permit. This configuration is recommended for firms which have the strictest discharge permit regulation.

5.5 Capital Cost Analysis

As described in the previous section, a monitoring system generally consists of the sensors/probes, cables (data and power), controller, analogue to digital signal converter, and an adapter to translate the digital signal to the computer language so a control/operating system can interpret the meaning of the signal.

Table 3 presents the estimated capital cost requirement for the different control system tiers. Please note that the costs presented for the equipment are indicative only, and some manufacturers may add additional installation and delivery costs. For each system configuration, only one sensor per parameter is included. Depending on the complexity and the outcome desired by the user, additional sensors may be required to be installed at various stages of the treatment system. The installation costs also vary for different abattoirs, as some have their own technical support team who can carry out either the whole or part of the installation.

The Tier 1 system consists of a temperature sensor, dissolved oxygen sensor, pH sensor, conductivity sensor, cables to connect the sensors to the controller, a controller, an analogue to digital signal converter, and a digital signal interpreter. The average capital cost requirements to assemble the Tier 1 system is approximately $17,000. In Australia, the technology providers that can supply the system include Hach, Krohne, Semrad, and Xylem (in alphabetical order).

The Tier 2 system adds the nitrate and ammonia sensor. On average, the total system will cost approximately $32,000. In Australia, the technology vendors that can supply the nitrate and ammonia sensor include Hach and Xylem.

The Tier 3 system includes the grease detector, nitrite, organic content (BOD/COD), and total suspended solids sensors (TSS) in addition to the previous sensors. At the time of writing this report, the market price to assemble the Tier 3 system is about $80,000. In Australia, the sensors can be sourced from a variety of technology providers, including Hach, Krohne, Semrad, and Xylem.

The Tier 4 system consists of all of the sensors from the Tier 3 system and adds the phosphorus (ortho-P) auto-analyser. Currently, an auto-analyser is the only technology available to the market that continuously monitors the phosphorus concentration. The addition of the auto-analyser has resulted in an increase in the capital cost to approximately $130,000. The technology providers that can supply the auto-analysers includes Hach and Seal Analytical.

Table 3 summarises the estimated capital cost requirements for each tier of the system.

Table 3: Estimated capital cost requirement

Tier	Estimated Capital Cost Requirement
1	$17,000
2	$32,000
3	$80,000
4	$130,000

5.6 Operating Cost Analysis

The operating cost associated with the monitoring system consists of maintenance cost, consumable cost, and electricity cost. However, the electricity consumption of running the monitoring system is small and can be neglected in the analysis. The maintenance cost of the system varies for each tier due to the inclusion of different sensors. Some sensors only require monthly visual inspection and cleaning, whereas other sensors require the replacement of caps and electrodes which is a significant contributor to the operating cost of the system. Labour cost is not included as it varies from site to site. However, based on industry observation, the labour cost to perform the general maintenance is low as the time required to carry out regular maintenance is not exhaustive, not more than 3 to 4 hours per month for the all the probes.

On average, the Tier 1 system has a yearly operating cost of $600. The average yearly operating cost is calculated by determining the overall operating cost of running the system for 10 years and dividing it by the number of operating years. The operating cost of the Tier 1 system consists of replacing the caps and electrodes for the pH and dissolved oxygen sensor.

The Tier 2 system has a higher operating cost of approximately $3,000 per year. This is due to the inclusion of the nitrate and ammonia sensor, where the electrode requires replacement every 18 months. The Tier 3 system has the same operating cost as the Tier 2 system. This is due to the technology utilised by the additional sensors. The additional sensors use the optical method, which only requires a visual inspection for maintenance.

The Tier 4 system has an average yearly operating cost of approximately $6,200. This is due to the yearly maintenance requirement of the auto-analyser. Since an auto-analyser relies on pumps and a spectrophotometer to automate the analysis of phosphorus, routine maintenance is required to ensure that all of the mechanical components of the system are operating precisely to ensure accurate measurement.

Table 4 summarises the estimated operating cost of each tier of the monitoring system.

Table 4: Estimate average yearly operating cost

Tier	Estimated Average Operating Cost
1	$600
2	$3,000
3	$3,000
4	$6,200

5.7 Recommended Sensor Placement

The typical unit operations of a conventional abattoir WWTP consist of pre-treatment, dissolved air flotation, anaerobic unit, aerobic unit, clarifier, and a holding pond.

Figure 13: Process flow diagram of conventional abattoir wastewater treatment

As previously mentioned, different sensors have different recommended placement in relation to the stages of the treatment system. **Table 5** shows the recommended installation location for the sensors.

Table 5: Recommended Installation Location by Sensor Type

Sensor Type	Recommended Installation Location
Temperature	• Anaerobic • Aerobic
pH	• Anaerobic • Aerobic
Dissolved Oxygen	• Aerobic • Outlet
Total suspended solids (TSS)	• Aerobic • Outlet
Conductivity	• Anaerobic • Aerobic
Salinity	• Anaerobic • Aerobic
Fat, oil and grease	• Anaerobic • Outlet
BOD/COD/TOC	• Anaerobic • Aerobic • Outlet
Ammonia	• Aerobic • Outlet
Nitrate	• Aerobic • Outlet
Ortho-phosphate	• Phosphorus removal section • Outlet

Sensors which are installed on the Outlet are primarily used to monitor the quality of the treated wastewater to ensure that it does not exceed the discharge permit. The other installation locations are primarily used to enable optimisation and to detect malfunctioning of the processes.

5.8 Cost Benefit Analysis from Theory

The benefits gained from the implementation of the monitoring system varies depending on which tier of system configuration is used, and the processes and technology adopted in the treatment plant. However, it is observed that the rule of economy of scale is applicable for quantifying the benefits gained through the implementation of the monitoring system. This means that larger facilities with higher throughput will have a higher benefit-to-cost ratio when compared with a smaller facility.

Despite this trend, the implementation of a monitoring system can still be beneficial to a smaller facility, where the benefits outweigh the initial capital requirement.

5.8.1 Tier 1

The component in a wastewater treatment system that contributes the most to the operating cost of running the system is typically the electricity/energy cost. Most of the electricity is used to power aerators that supply oxygen to the reactor/treatment pond for an aerobic system. For a wastewater treatment plant with no monitoring of dissolved oxygen, the aerators tend to run continuously. This method of operation is not optimised, with most of the electricity wasted as the dissolved oxygen concentration is not the limiting factor for the improvement of the treatment process. In addition, this kind of practice will also result in the high consumption of electricity during peak hour which causes unnecessary costs to the operation of the overall facility.

Through the monitoring of the dissolved oxygen concentration, a control system that automatically operates the aerators can be implemented. The oxygen threshold values can be set which allows the aerator to automatically turn on when the supplementation of oxygen is necessary. This method of operation is similar to the Just-in-Time (JIT) practice which has a proven track record and has been widely adopted in the supply chain field.

Another example that follows this principle is the economic benefit generated through the monitoring of pH. At various sections of the treatment process, chemicals are often added to adjust the pH of the water. In a system where pH is monitored, pumps can be operated by a control system to automatically add the chemical until the pH reaches the desired level. This practice minimises the chemical usage which ultimately results in a lower operating cost for the treatment plant.

Due to the continuous nature of the monitoring system, operators can also easily detect an early indicator of a failing or malfunctioning system. The necessary actions can then be taken before the problem becomes catastrophic. This would result in less downtime for the treatment plant, which ensures the primary activities performed by the facility are not impacted. In addition, resolving the problem early is considerably less expensive than resolving the problem later on.

From a regulatory perspective, monitoring of the basic physical parameters can help the operator determine whether the quality of the treated effluent is within the discharge permit limits, albeit only partially. By maintaining compliance with the discharge permit, it will avoid unnecessary consequences and fines.

Through the optimisation of the system and compliance with the environmental regulations, the facility that implemented the system can demonstrate its environmental commitment. Customers are now more aware of a product’s environmental impact and this can influence purchasing decisions. Proactive steps which demonstrate the firm’s commitment to the environment creates a win-win situation, where the sales of the product are improved, and the facility’s environmental impact is minimised.

5.8.2 Tier 2

The Tier 2 monitoring system allows for better and more precise optimisation of the conventional nitrification-denitrification treatment process. In general, the two main contributors to the cost of operating a conventional nitrogen removal system are the energy/electricity cost to run the aerators and the addition of a carbon source (for example methanol). In conjunction with the monitoring data from the Tier 1 system, the operating cost can be reduced through precise control of the aerators and the addition of methanol. Through the optimisation of the process, the supplementation of both oxygen and the carbon source can be carried out at the correct phase/time and dosage, resulting in maximisation of the treatment plant treatment capacity.

5.8.3 Tier 3

To gain most of the benefits associated with the implementation of the Tier 3 system configuration, an anammox based nitrogen removal system is required. Compared with the conventional nitrification-denitrification pathway, anammox only requires 38% of the oxygen compared to the conventional pathway and does not require any carbon source (Kurup 2017). This significantly reduces the cost of nitrogen removal. The availability of all of the nitrogen species monitoring data, especially nitrite, is crucial in maintaining the anammox process.

The monitoring of organic content (BOD/COD) and TSS ensures compliance with the discharge permit as well as maximisation of the production of process by-products with economic value. An example of by-products which have some economic value are biogas and dewatered sludge. Biogas can be used to power electrical generators to produce electricity and heat that can be directly used by the facility or sold into the electricity grid. Good quality dewatered sludge can be sold directly to a composting facility or if desired, processed internally.

Assessing the benefits from an environmental impact perspective, Tier 3 systems enable implementation of the anammox process which significantly reduces the carbon footprint of the treatment system.

5.8.4 Tier 4

When comparing the benefits gained from the Tier 3 and 4 system configurations, there is no additional significant benefit that can be gained from the Tier 4 system. The purpose of a Tier 4 system would be the continuous monitoring of phosphorus as part of the granted discharge permit requirements. This will ensure that the treated effluent complies with the regulation at all times and eliminates the risk of ceasing operation due to non-compliance with environmental regulations. This kind of benefit is beneficial to a larger facility where any disruption to the operation will result in significant loss of revenue.

5.9 Recommendation for System Configuration

Based on the characteristics of the current product available from various technology providers/vendors, several recommendations are given to help users to design their monitoring system.

Before committing to a certain technology provider, decide on what level/tier of the monitoring system is required. The decision on the type of monitoring system required depends on the size/ capacity of the facility, processes adopted in the wastewater treatment plant, budget availability, risks associated with the failure of the operation of the treatment plant, and the desired outcome from the implementation of the monitoring system (for example for compliance assurance, optimisation, maximisation of resources recovery, etc.).

By considering these aspects, the suitable parameters to be monitored can be identified. If required, this process can be undertaken by a qualified third-party consultant. The identification of the parameters will allow users to determine the number of sensors required for the monitoring system. Often technology providers have sensors that monitor several parameters which will reduce the overall cost of the system. In addition, it is recommended that a single technology provider is used to supply all the parts of the monitoring system. Each technology provider often uses proprietary cables and controllers, and the use of sensors from multiple technology providers will result in the installation of additional controllers. This creates unnecessary cost and operational and maintenance difficulty.

5.10 Instrumentation, Control and Automation

Since the 1970s, sensors and control systems have been identified as an important part of wastewater treatment. The field that studies and implements this technology is called instrumentation, control and automation (ICA). Despite acknowledgement of the benefits that can be gained from ICA, adoption has not been wide spread until recently. There are two main drivers that have accelerated the adoption of ICA in the wastewater treatment industry. These are stricter environmental regulations and the increased availability of sensors to monitor the required parameters.

ICA in the wastewater treatment industry is based on a PID (proportional – integral – derivative) controller. **Error! Reference source not found.** outlines the basic schematic of a PID controller.

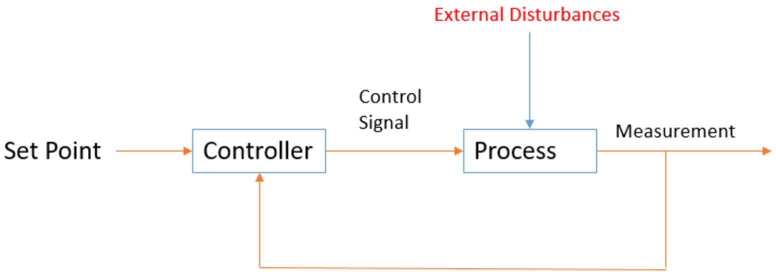


Figure 14: *Basic schematic of a PID Controller*

This control scheme can be applied to a range of parameters in wastewater treatment, including aeration systems. The aeration system is the main component of a wastewater treatment system where performance can be significantly improved through the implementation of a control system.

A PID controller can monitor and regulate the concentration of dissolved oxygen in the aerobic section of the process. Reviewing Error! Reference source not found. in this context, the 'measurement' component represents a dissolved oxygen sensor continuously monitoring the concentration of dissolved oxygen in the water. A controller compares the measured value from the sensor with the dissolved oxygen concentration desired set value. The controller's programmed logical instruction will determine the necessary action to be taken to resolve any discrepancies between the measured and desired values.

The most basic program is an on/off logical gateway where the aeration system would be turned on or off depending on whether the dissolved oxygen concentration is below or above the set point. Based on the logical decision, the controller will then send a control signal to the actuator (in this case aerator unit) to turn on or off. The control cycle continues with the reading of the new dissolved oxygen concentration.

The more advanced version of the basic control system is called the cascade control system. The cascade control system consists of multiple control loops, where one control loop controls the other loops. **Figure 15** outlines the conventional cascade control system used in an aeration system.

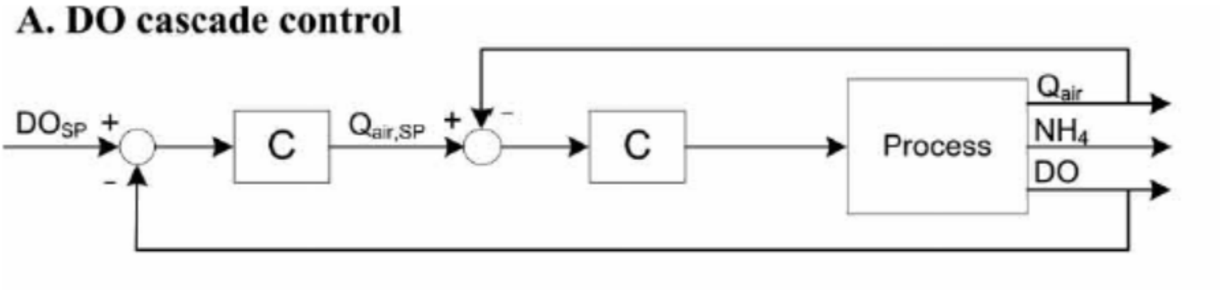


***Figure 15**: Cascade controller used in aeration systems (Amand, Olsson & Carlsson 2013)*

For this example, the dissolved oxygen control loop controls the action of the airflow (aerators) control loop (Q_{air}). Like the basic control system, the dissolved oxygen concentration is monitored by a sensor and compared to the set value. However, instead of sending an on/off signal to the aerator, a set value for the airflow is sent to the airflow controller. The airflow controller then monitors the airflow through the aerator and adjusts the valve when necessary.

5.11 Benefits Associated with Sensor Implementation from the Literature

The benefits of implementing sensors and control in wastewater treatment operations can only be realised through optimisation and automation. This process requires combining the knowledge of control system engineering and wastewater treatment engineering.

To demonstrate, consider the automation of aerators once again. In an aeration unit, the oxygen requirement is often not homogeneous. The oxygen requirement tends to be higher near the input point and gradually decreases as it nears the output point of the unit. This phenomenon is often observed in a plug-flow system or when there is insufficient mixing within the unit. By having multiple dissolved oxygen sensors, many locations in the unit can be monitored and aerators can be turned on or off depending on the dissolved oxygen concentration.

Employing a variable speed drive can further improve the efficiency of the system. A variable speed drive can adjust the output of the compressor so sufficient air can be provided depending on the condition. For example, if the dissolved oxygen concentration is close to the set value the compressor does not need to work at maximum capacity. On the other hand, if there is a large discrepancy from the set value, the aeration system will work at a higher capacity. By delivering the oxygen at the correct location and at a suitable rate, less air will be wasted, and the energy required for the operation of the aerator can be minimised.

Another example of pairing wastewater treatment engineering to the control system is controlling aeration through the monitoring of the ammonia concentration within the water. If optimisation of nitrogen removal is the goal, it is beneficial to monitor the ammonia concentration to ensure that sufficient oxygen is provided to ensure that most of the ammonia is converted into nitrite (in the case of anammox process) or nitrate in a conventional nitrification-denitrification system. It has been found that ammonia monitoring has allowed the wastewater treatment system to extend the duration of the anoxic phase, which generated a higher rate of nitrogen removal.

In general, the benefits of the implementation of a control system can be categorised into three groups. These are economic, regulatory/ compliances, and operational benefits.

5.11.1 Economic Benefits

The economic benefits are the key driver that encourage wastewater plants to implement a control system for process optimisation. Optimisation significantly reduces operating costs through the minimisation of energy and chemical usage. In addition to operating cost, optimisation will also increase the efficiency and capacity of the existing infrastructure. This extends the lifespan of the infrastructure and delays the need for an upgrade. Maintenance and troubleshooting costs will also decrease as the running time of the unit, such as aerators, is minimised.

5.11.1.1 Energy Reduction

According to Ingildsen (2002), the aeration system uses up 60% of the energy required to run a conventional wastewater treatment plant. In addition, the operator tends to operate the aeration system in excess to ensure that the biological processes continue. This practice leads to an unnecessary increase in electricity consumption that ultimately increases the operating cost of the treatment system. The most common optimisation practice adopted by the wastewater industry is the reduction of energy required for the aeration system. This is due to the small investment required and high value for capital invested. The aeration is normally targeted to reduce the operating cost of organic (COD/BOD) and nitrogen removal. There are various case studies that explore the energy reduction through the implementation of a control system, these are presented in *Table 6*.

Table 6: Case Studies of Energy Reduction through Control Systems

Reference	**Flow (m^3)**	**Population Equivalent**	**Energy Reduction (%)**	**Savings (AUD$/ year)** **1 USD = 1.34 AUD** **1EUR = 1.45 AUD**
Rieger, Takacs and Siegrist (2012)	205,000	550,000	25	$569,500
Rieger, Takacs and Siegrist (2012)	31,000	83,000	20	$34,840
Rieger, Takacs and Siegrist (2012)	40,000	130,000	16.5	$160,800
Lynggard-Jensen (2011)	n/a	200,000	n/a	$105,850
Lynggard-Jensen (2011)	n/a	120,000	n/a	$44,950
Lynggard-Jensen (2011)	n/a	83,000	n/a	$58,000
Lynggard-Jensen (2011)	n/a	84,000	n/a	$191,400
Sunner, Thornton and Haeck (2012)	n/a	50,000 – 250,000	20%	n/a
Poole et al. (2012)	n/a	n/a	17%	n/a

Faxa et al. (n.d.)	n/a	27,000	317,000 kWh/year	n/a
Husmann et al. (1998)		60,000	16%	
Silva (n.d.)	n/a	n/a	n/a	$26,000
Frank R Spellman (2013)	85,000	200,000	20%	$36,180

Based on the collection of case studies, it has been observed that the implementation of a dissolved oxygen control system can reduce the energy consumption of the treatment system by approximately 20%. As for the actual monetary value resulted from the energy reduction, it is incredibly dependent on the scale (population equivalent) of the treatment system and the unit cost of electricity.

The wastewater produced by the meat industry, generally requires a high population equivalent treatment system. Wastewater from the meat industry contains high organic and nitrogen concentrations which require a significant amount of oxygen for treatment. Considering this, a significant reduction of the energy cost can be expected through the implementation of a control system. Depending on the design of the system, an automated control system can allow the treatment system to be operated during off-peak period. Through this operation, the energy cost can be reduced as the unit cost of electricity will be lower when compared with the peak period.

5.11.1.2 Improvement in Performance and Efficiency

In Australia, effluent discharge to the environment is regulated by discharge permit. In general, the discharge permit regulates the load and concentration of organic constituents (BOD), nitrogen, phosphorus, pathogens and other contaminants. Evaluation of the compliance to the discharge permit is assessed through execution of the monitoring program that is agreed to by the producer (meat processing facility) and the regulator. If during the monitoring period the effluent was found to exceed the conditions stated in the permit, a fine and possibly a shutdown notice will be given to the meat processing facility. This would cause significant economic loss to the facility.

An improvement in the performance of the wastewater treatment through a control regime can also result in a reduction of the sewerage cost when the effluent is discharged to the sewer network. Usually water utilities charge the sewerage cost based on flow and constituent loading. There are various constituents that are charged by the utilities, but the major contributors are BOD, nitrogen and phosphorus. Significant reduction of the loadings of these constituents will reduce the sewerage cost that needs to be paid by the facility.

In many countries, effluent discharge is governed by a “discharge tax” where facilities are charged depending on the loading of the constituent and the location of the effluent discharge. The tax increases with additional constituent loading or if the effluent is discharged at an environmentally sensitive location where many stakeholders will be affected if contamination occurs. The introduction of discharge taxes has become the main economic driver of the implementation of control systems for wastewater treatment plants internationally.

Rieger, Takacs and Siegrist (2012) have studied the implementation of a control system to improve the performance and capacity of the nitrogen removal by wastewater treatment plants. Three plants from Switzerland were chosen with the population equivalent ranging from 35,000 to 600,000 population equivalent. Based on the study, it was found that the implementation of a basic aeration control system allowed an increase of approximately 40% in terms of nitrogen removal. As a discharge tax was applicable in this scenario, the economic benefits resulting from the improvement in the nitrogen removal ranged from approximately $67,000 to $300,000 per year. The improvement was due to the reduction in aeration period that resulted in an increase in the anoxic period, allowing longer time for denitrification. In addition to the direct saving, an improvement in the performance of nitrogen removal will also result in an increase in the treatment capacity, extending the lifespan of the plant and delaying the need for an upgrade. A study by Husmann et al. (1998) showed improved nitrogen removal was observed in the treatment system where the control system was implemented, especially in winter.

5.11.1.3 Chemical Cost Reduction

ICA can reduce the chemical costs of a wastewater treatment plant. This is achieved through monitoring the concentration of a constituent and adjusting the dosage of the required treatment chemicals based on the monitoring result. In a conventional wastewater treatment system, the chemicals that are targeted for this reduction are the carbon source (such as methanol) for denitrification and chemicals for phosphorus reduction, as well as acid/alkali in some cases where the pH is to be managed.

In a conventional treatment system, a carbon source, usually in the form of methanol, is added to complete the process of denitrification. The need for a carbon source is even higher in a scenario where the nitrogen concentration is high and there is not enough residual carbon to complete denitrification. When there is no control system available, dosing of carbon sources is done in excess, resulting in methanol wastage. Through the monitoring of the concentration of nitrate and organics (BOD/COD), dosing of methanol can be optimised. A study by Sunner, Thornton and Haeck (2012) has shown that the control of methanol dosing in activated sludge plants in the United Kingdom has resulted in a 50% reduction of methanol usage. Another study by Tong et al. (2006) has shown that automation for external carbon dosing could reduce the flow up to 24.2%.

To reduce the chemical usage for phosphorus reduction, orthophosphate is monitored at either the discharge point or the last unit prior to effluent discharge. The reading of orthophosphate concentration is compared against the discharge permit. The difference between the values will result in an adjustment to the dosage rate. A study by Dabkowski et al. (2012) measured the concentration of orthophosphate of water before entering the final clarifiers. This information was used to control the ferric chloride flow. After 160 days of operation, it was observed that the control system reduced the ferric chloride feed by 56%. The chemical reduction savings resulted in a 7-month payback period for the control system. Another example was the case study by YSI (2016) that showed a 14% reduction of aluminium sulphate (alum) dosing after the implementation of a control system.

5.11.2 Compliance and Operational Benefits

Besides economic benefits, ICA improves the reliability and consistency of the treatment system. Unlike a chemical based reaction, a biological system is more sensitive to changes in operating conditions. Extreme changes in pH, temperature, and other operating conditions may result in the death of the bacteria responsible for treatment. Unbalanced nutrient concentrations can result in the dominance of a single bacteria species or the bulcking of sludge which results in incomplete treatment or the washout of biomass.

Recovery from such an event often takes days or even months, resulting in high risk of non-compliance during the recovery period. In addition, a significant amount of resources and attention needs to be invested to troubleshoot and fix the problems. To recover the initial performance, it is often that a deep understanding of wastewater treatment engineering is required. Through the implementation of ICA, the operating conditions of the treatment system are monitored and maintained. This ensures that the plant is operated at maximum capacity and risks of a biological process failure is minimised.

Several case studies have demonstrated the ability of ICA to improve the reliability of the operation of the biological process in a treatment system and to provide early indications of process failure. A case study by Carrasco et al. (2004) showed that the implementation of ICA in an anaerobic treatment system has allowed users to understand the current state of the system and detect early anomalies, such as organic overloading. This quick identification ensured critical operational changes were made promptly. (Faxa et al. n.d.) also showed that the implementation of ICA allows minimisation of the impact of external disturbances. The application of a control system was proven to improve the reliability of the system as shown by Poole et al. (2012).

6.0 PROJECT OUTCOMES – FIELD DEMONSTRATION STUDY

The scope of the field study was to evaluate the performance, reliability and benefits of selected sensor systems in managing and controlling a WWTP. The results could be compared with the desktop study to bring an Australian meat industry context. EEI continuously monitored an abattoir anammox WWTP over a nine-month period. The collected set of data was utilised to make active operation decisions and ensure compliance with the participant’s environmental discharge regulations.

6.1 Field Study Site Background

The field study was completed at a multi-species abattoir in Western Australia. The abattoir produces approximately 0.5 ML of wastewater per day that has high biochemical oxygen demand (BOD), total suspended solids (TSS), total phosphorus (TP), and total nitrogen (TN) in the form of ammonia. The wastewater must be treated prior to onsite irrigation and disposal to ensure the local environment is protected.

The original wastewater treatment system constructed in 2011 consisted of an anaerobic reactor, and an aerated pond to treat an influent BOD of 2,000 – 3,000 mg/L and a total nitrogen (TN) of 350 to 450 mg/L. The EEI-ANRUP system that was in operation at the WWTP employed a conventional nitrification/denitrification process and had effectively removed total nitrogen to less than 45mg/L without any external carbon addition for over three years.

The plant was forced to consider altering the WWTP nitrogen removal processes in 2015 after changes in abattoir operations resulted in a lower influent BOD of 900 – 1,200mg/L, affecting the BOD:TN ratio. The lower influent carbon meant that denitrification in the plant was restricted. To compensate, methanol was added during the denitrification stage at a significant cost.

To address these operational changes, EEI assessed the nitrogen treatment options with respect to economic, reliability, ease of maintenance, health and safety, and environmental factors. Following the assessment, EEI advised the abattoir to implement the anaerobic ammonium oxidation (anammox) process for nitrogen removal, despite it being a novel process in Australia in 2014.

EEI completed the implementation of the anammox process at the abattoir WWTP in 2015. EEI was able to reuse the existing treatment pond infrastructure available. The most significant addition was the installation of additional sensor equipment. The sensors available included DO, ammonia, nitrate (using ion-selective electrode technology), and pH. However, EEI recognised that the process could be improved further with a more advanced monitoring and control system.

Figure 16: *Aerial shot of the WWTP*

6.2 The Anammox Process

The anammox process is the most cost-effective solution for high nitrogen, low bio-available carbon streams. Anammox bacteria provide an alternative pathway to remove nitrogen in wastewater. **Figure 17** and **Figure 18** provide an overview of the conventional nitrification/denitrification and anammox removal pathways.

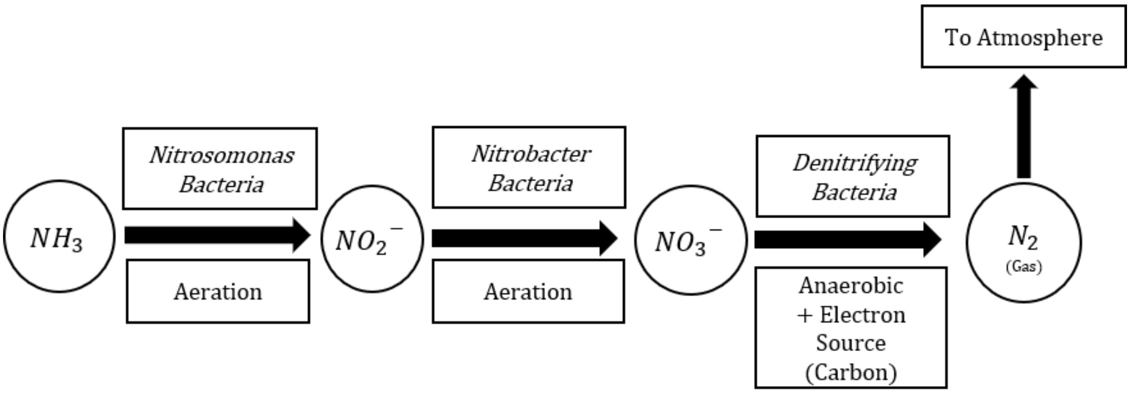


Figure 17: *Conventional Nitrification/Denitrification Nitrogen Removal Process*

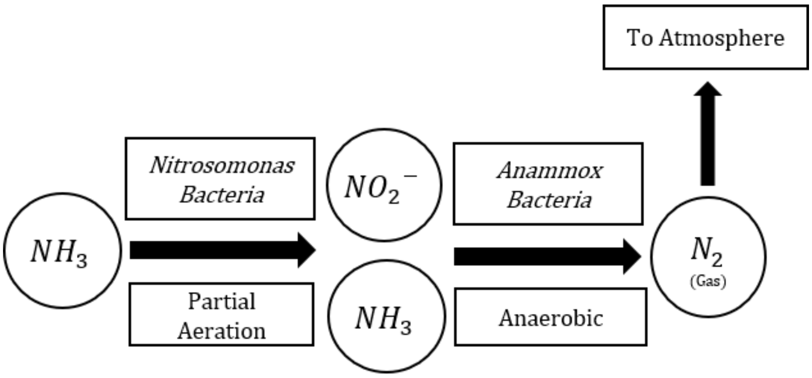


Figure 18: *Anammox Nitrogen Removal Process*

Anammox has many benefits when compared with the conventional process (nitrification-denitrification). Predominantly these are the reduced energy and chemical dosing requirements, in addition to low sludge production. As can be seen in **Figure 18**, anammox only requires a partial aeration stage (partial nitrification) until approximately half the ammonia (NH_3) has been biologically converted to nitrite (NO_2^-). The anammox bacteria can then foster a direct reaction between the ammonia and nitrite to form nitrogen gas (N_2) under anaerobic conditions that requires no carbon addition.

By comparison, the conventional process requires complete aeration until all ammonia is converted to nitrite and then nitrate (NO_3^-). Denitrifying bacteria can then reduce the nitrate to nitrogen gas using an electron source under anaerobic conditions. **Table 7** summarises the differences in the chemical and oxygen requirements of the two processes.

Table 7: Key Parameters of Anammox Performance

	Nitrification - Denitrification	**Partial Nitrification - Anammox**
Carbon Requirements	2.6 kg BOD/kg of N removed	No carbon source required
Oxygen Requirements	4.6 kg O_2/kg of N removed	1.9 kg O_2/kg of N (59% less)
Sludge Produced	1 kg VSS/kg of N removed	0.08 kg VSS/kg of N removed

6.2.1 Controlling the Anammox Process

Controlling the anammox process requires more sets of data and attention than the conventional nitrification/denitrification process. For example, it's very important to prevent nitrite being further oxidised to nitrate during the partial nitrification stage. This requires monitoring of the dissolved oxygen (DO) and nitrite with control of the aeration, influent and recycle streams. In addition, monitoring of the pH, total suspended solids (TSS), COD, ammonia, nitrate, TN, and temperature is central to ensuring the conditions are suitable for the biological reaction processes and that all equipment is functioning correctly.

While the anammox process is desired, other nitrification/denitrification processes will still compete with the anammox bacteria unless the conditions are adequately controlled.

6.3 The Sensor and Control System Field Trial

The goal of the field trial was to evaluate the economic and process benefits of advanced sensor implementation at an abattoir WWTP. This abattoir provided an excellent opportunity to compare the performance of the original anammox control system installed in 2014 and a more advanced system for the field trial in 2017.

As described previously in this report, EEI has characterised typical set-ups for different tiers of monitoring systems. Tier 1 is the least expensive option, but it only monitors a limited number of parameters (temperature, DO, conductivity and pH). Whereas Tier 4 is state of the art and can fulfil both operational and regulatory objectives to fully ensure continuous optimisation of complex processes and compliance with the discharge permit.

The original control system for the anammox system is a Tier 2 designation and was installed in 2015. It consisted of ammonia, nitrate, temperature, DO, conductivity and pH sensors. The system installed at the WWTP for this field trial was a Tier 3 designation. The Tier 3 system actively measures COD, ammonia, nitrite, nitrate, DO, TSS, pH, temperature and conductivity through different sensor technologies. The data was collected at 10-minute intervals and was regularly monitored by EEI engineers through a human machine interface (HMI).

Sensor technology for water applications has continued to advance (WWAP 2017) and the field trial system was expected to require less maintenance and calibration than the original system. The additional parameter data (nitrite, COD, and TSS) was also expected to aid in optimisation of the anammox processes at the WWTP.

The sensor system was installed in the WWTP anammox treatment pond. The pond is operated as a sequencing batch reactor (SBR) with an overflow clarification at one of the corners. EEI used the real time data to control aeration (including intensity and duration of aeration), and cycle residence time (flow of the influent, effluent and recycle streams) via the HMI.

Figure 19: *Monitoring System Components*

6.3.1 Monitoring Data Results

The following series of **Figures (Figure 20-Figure 25)** show samples of the monitoring data acquired during the field trial from November 2017 to June 2018. **Figure 20** demonstrates the difference in fidelity of the results between active monitoring (data collected every ten minutes) and a hypothetical sampling of the system every three days (the orange line).

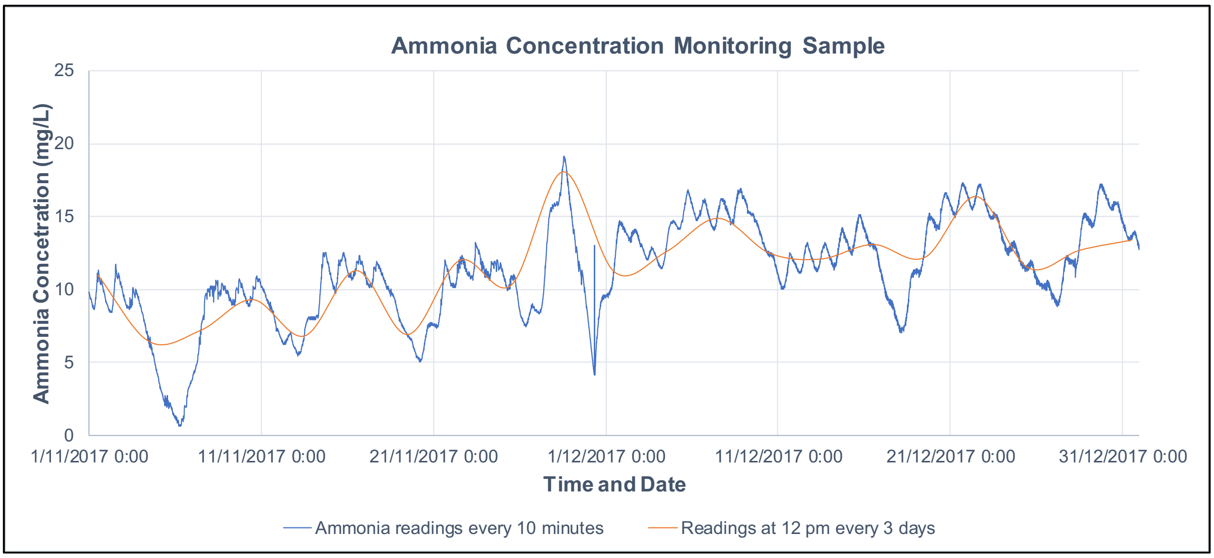


Figure 20: *Sample of the ammonia data acquired from monitoring the WWTP*

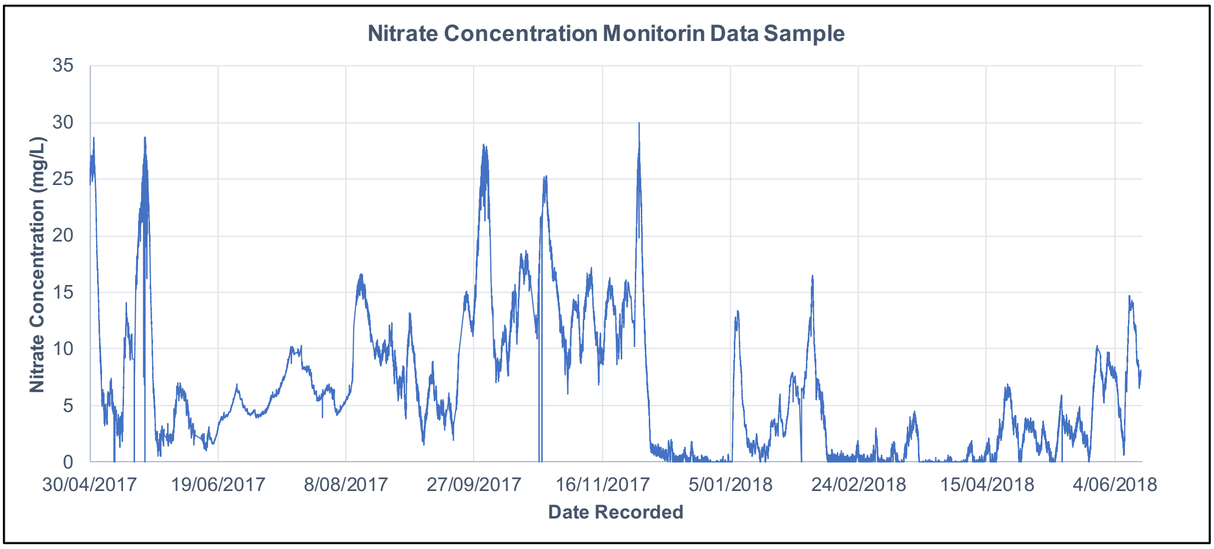


Figure 21: *Sample of the nitrate data acquired from monitoring the WWTP*

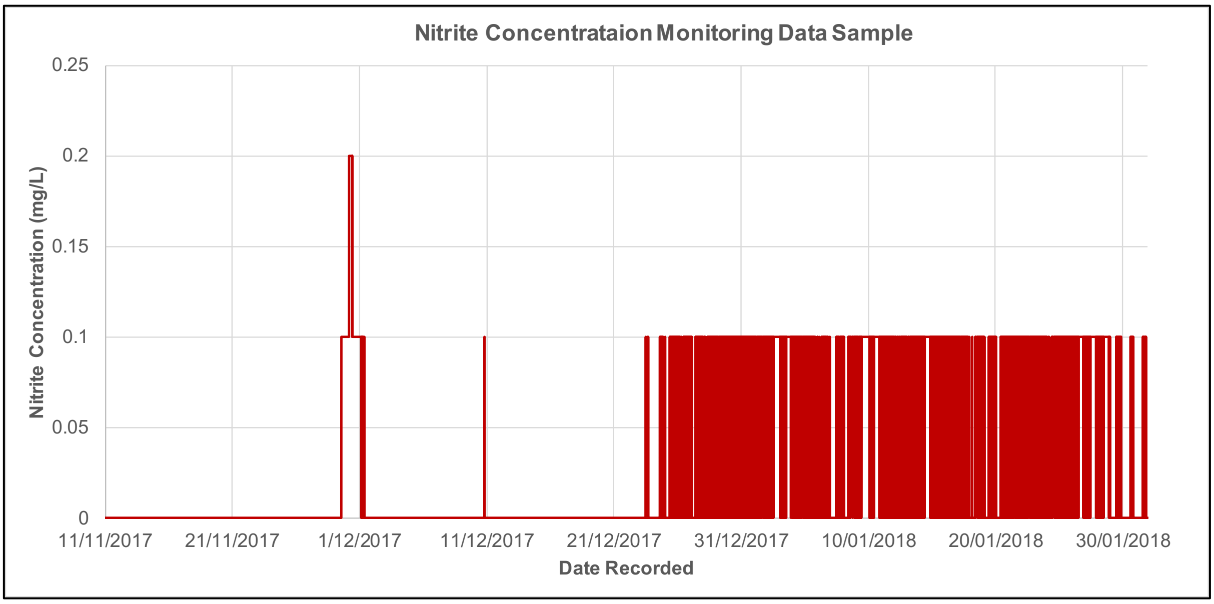


Figure 22: *Sample of the nitrite data acquired from monitoring the WWTP*

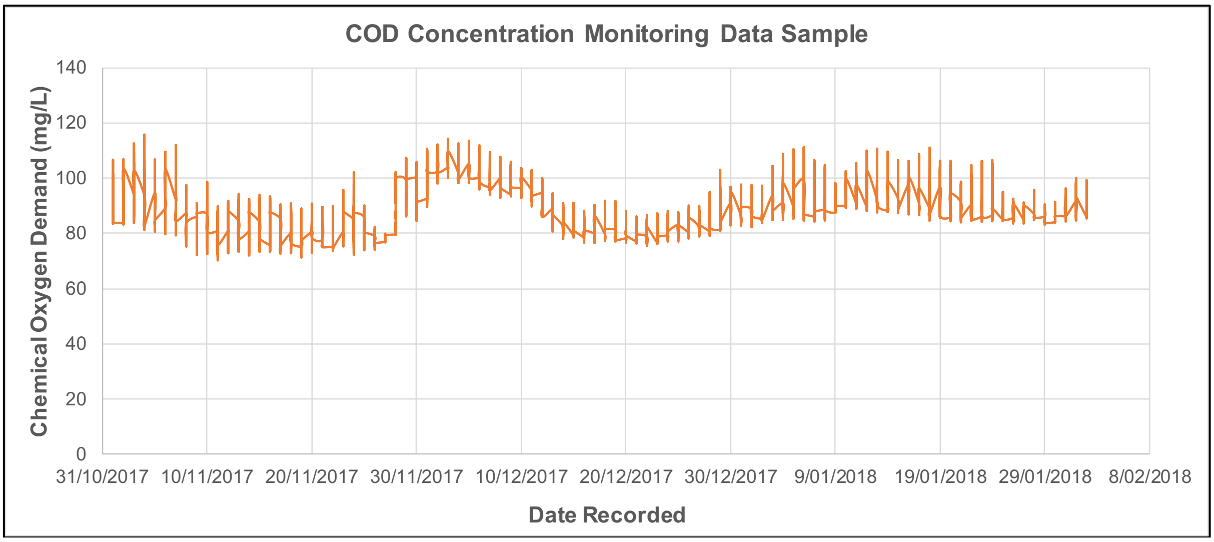


Figure 23: *Sample of the COD data acquired from monitoring the WWTP*

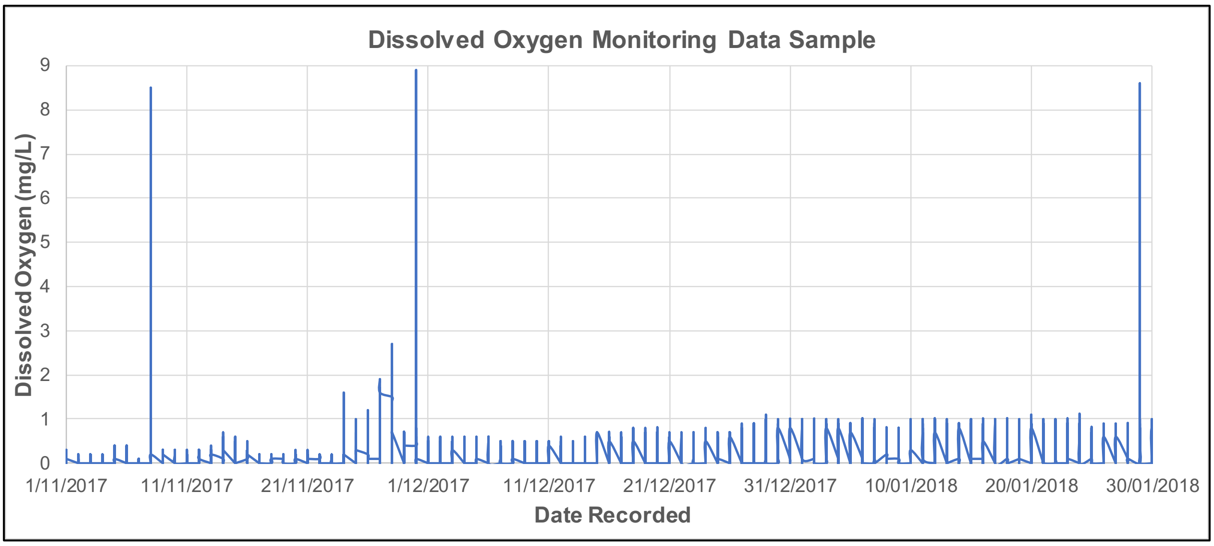


Figure 24: *Sample of the DO data acquired from monitoring the WWTP*

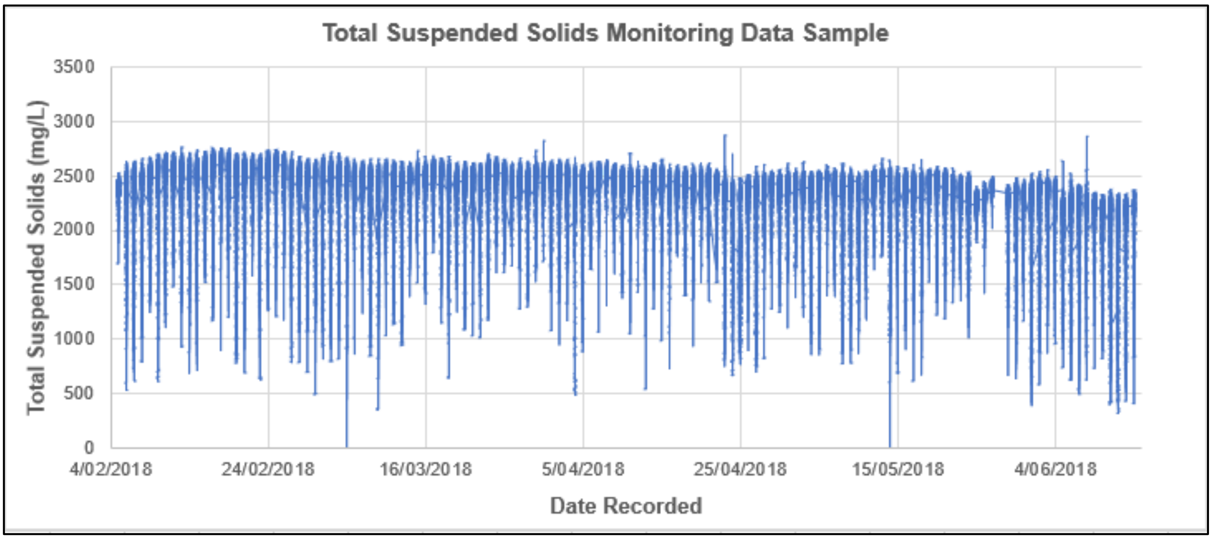


Figure 25: *Sample of the TSS data acquired from monitoring the WWTP*

6.3.2 Validation of the Monitoring Data

To ensure that the sensors were operating correctly, and that plant's discharge restrictions were complied with over the field trial EEI wanted to verify the data collected. EEI used external NATA approved laboratories to test collected samples that were compared with the relevant sensor data. EEI also conducted laboratory testing on-site and at our inhouse laboratory. The results showed consistent agreement between the chemical testing methods and the sensor technology for ammonia, nitrite, nitrate, COD, DO, and pH.

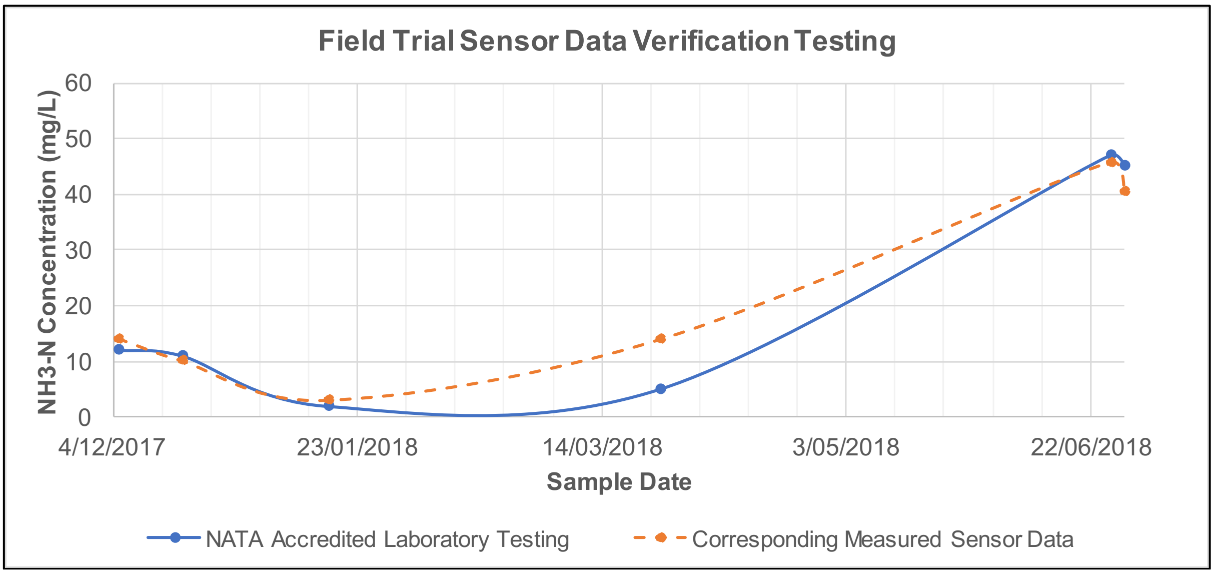


Figure 26: *NATA Laboratory Comparison with Sensor Data Collected*

7.0 DISCUSSION

7.1 Evaluation of Field Trial and Previous Sensor Performance

7.1.1 Direct Economic Benefits

7.1.1.1 Optimisation of the Anammox Nitrogen Removal Process

The original Tier 2 system installed in 2015 had already significantly optimised the energy and chemical inputs of the initial anammox process. Through the original monitoring, EEI could now easily control the SBR cycles (aeration or residence time) to limit the nitrite lost to nitrate and better promote the anammox mode over nitrification/ denitrification. This resulted in a much more efficient use of the aerators, and reduced nitrate accumulation.

The Tier 3 control system of the field study allowed further optimisation of the treatment process. The implementation of the nitrite sensor allowed further tightening of the aeration modes, reducing the energy for aeration further. The optimisation processes were completed while maintaining complete adherence to the abattoirs waste discharge permit regulations.

The value of data collection for process optimisation was demonstrated in both the real time availability and the ability for historical data storage and retrieval. By having historical data readily available, the controlling engineer could compare recent and seasonal performances to detect process inefficiencies and stress points.

7.1.1.2 Site Labour Requirements

The upgraded Tier 3 control system has reduced the daily labour requirements of operating the WWTP, particularly the anammox section. EEI has consulted with the abattoir and used our own recorded hours to estimate the changes in labour (including the external monitoring) budget with installation of the successive sensor systems.

The original anammox system required a technician to be onsite at the WWTP approximately three days a week with the support of a senior supervisor. The technician's duties would include manual sampling of the treatment for external TSS analysis, routine inspection and maintenance of equipment, supervision and manual control of some plant processes. In addition, due to the limited data available, the site visits from the plant consultant were more frequent to perform on-site testing (ammonia, nitrite, nitrate, COD etc.), and resolve any issues.

The installation of the Tier 2 system in 2015 streamlined many of the manual processes and eliminated several routine elements from the technician's duties. The technician now only had to be onsite 1 – 2 days per week. The sensors available in 2013 required frequent cleaning and recalibration, and this formed part of the onsite duty requirements. The increased data availability meant that the plant engineering consultant could perform many of the supervisor's duties remotely from their office, and fewer site visits were required to maintain optimal plant performance.

The Tier 3 field trial system demonstrated the benefits of modern sensor technology. The sensors required far less calibration and were more resilient to effects rendering maintenance/reset necessary. The technician was only required onsite for occasional calibration, sampling and maintenance. This equated to a couple of hours every 2-3 weeks. The availability of the additional parameters eliminated the need for any site testing and the engineering support team was not required to visit the site due to successful preventative maintenance alerted by the sensors.

The annualised operating cost results can be seen in **Table 8**. The table compares the ongoing costs of the original anammox system, the system after implementation of the Tier 2 control system in 2015, and the current field demonstration with the advanced sensor and monitoring equipment.

Table 8: Operating Cost Parameters Comparison of the Anammox WWTP Section

Operating Year	***Annual Direct Energy Cost***	***Annual Chemical Dosage Cost***	***Annualised Site Labour Costs (Including Sensor Monitoring)***	**Total**
2014	$71,120	$109,000	$193,120	$373,240
2015	$59,770	$55,000	$109,120	$223,890
2018*	$57,130	$0	$63,290	$120,420

* Annualised year to date

The study confirms the economic benefits of implementing sensor technology and the value of real-time and historical data availability for operators. The original Tier 2 system has already saved the abattoir significant chemical and aeration costs by optimising the treatment process. The more advanced Tier 3 system continued that improvement, while also enhancing the reliability and resilience of the sensor system.

7.1.1.3 The Payback Period and NPV

The payback period and the NPV of the investment for sensor technology system will not be the same for all abattoirs. It will vary depending upon the upgrade of the WWTP to realise the actual benefits that will be provided by the sensor technology. For example, the Tier 3 sensor technology provide an opportunity to fully incorporate an anammox system for nitrogen removal. If nitrogen removal is an essential requirement for an abattoir and if they currently employ an external carbon source, the benefit will be substantial to the extent that the payback period can be less than one year as demonstrated in our present case study.

Typically, a Tier 3 system costs about $100,000 to implement and the benefits that we have estimated for this project shows that the payback period of a Tier 1 system can be less than a year if the benefit is fully utilised. The benefit is considered the difference between savings of having no sensor technology versus a Tier 3 system, which would enable full level application of the energy efficient anammox process for nitrogen removal and reduction of energy costs and chemical costs.

Similarly, a Tier 2 system that would cost about $30,000 would also give a payback period of less than a year even with improvement in energy efficiency, lower operating, and chemical costs.

Assuming a discount rate of 10% (which is very high for the present day cost of capital), the cost of replacement required for sensor caps $10,000 for every 3rd year for the Tier 3 system and annual cost of $5000 for every year for the Tier 2 system; the net present value of the investment considering the life of the sensors of 5, 10 and 15 years are presented in **Table 9.**

Table 9: NPV of sensor systems

Sensor System type	**NPV**		
	5 year	10 year	15 year
Tier 2	$576,920	$1,006,318	$1,217,288
Tier 3	$945,961	$1,687,151	$2,050,512

7.1.1.4 Peak Load Control

The installation of the control system has allowed the plant to be operated optimally during peak load charge times. While outside the scope of the anammox section analysis presented in Table 8, it has been estimated that the savings have been in the order of $50,000 per year. The monitoring of various parameters enabled the reduction in use of the WWTP load demanding electrical equipment (aerators, pumps etc) during the peak load demand time.

7.1.2 Maintenance and Reliability Benefits

7.1.2.1 Reduced Aeration Load

As the abattoir is located in a regional area, maintenance and ease of operation were key factors for pursuing anammox. By reducing the load on the aeration systems with the optimised system, the maintenance required to keep the system running has also lessened. The aeration systems are typically some of the most prone equipment to failure, and the consequences can be severe if adequate redundancy is not in place. The majority of aeration optimisation occurred with the installation of the 2015 system, however small improvements were still made over the field trial.

7.1.2.2 Early Failure Detection and Preventative Maintenance

The field trial demonstrated the early detection benefits of the Tier 3 control system. The control and monitoring system has been able to quickly identify when transfer and aeration pumps failed during the study period. We could then direct the abattoir to send a maintenance technician to fix the problem. If the sensor system was not in place, the time to identification may have been days. This could have resulted in bacteria die off or discharge limit breaches. The availability of more parameters (COD, nitrite, and TSS) presented more opportunities for preventative maintenance that would have been missed in the 2015 system.

7.1.2.3 Consistent Plant Treatment Performance

The WWTP has consistently achieved full compliance with their environmental discharge permit for the duration of the field trial. The monitoring data has given the abattoir confidence in the operation of the system, and the consistent results have fostered a constructive relationship with the environmental regulatory authority.

Figure 27 provides a visual summary of the measured benefits of both the 2015 Tier 2 and the 2017 Tier 3 installed systems. Cost reduction comparisons are against the original anammox system prior to modern sensor installation (year 2014).

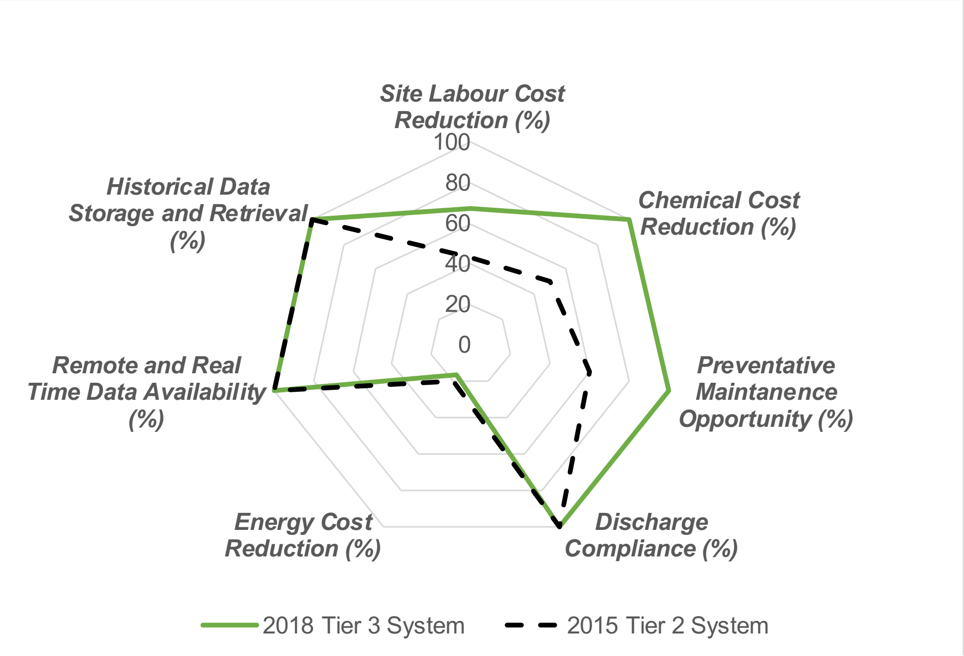


Figure 27: *Summary of Key Sensor Performance Indicators*

7.2 Field Study Limitations

It's important to note that these results were obtained from the optimisation of an anammox nitrogen removal process. Other wastewater treatment processes rely on different energy and chemical inputs to operate. Primary physical treatment methods such as dissolved air flotation systems (DAFs) have a different set of control challenges not assessed in this field trial. The economic benefit findings of the study are particularly relevant to the optimisation and maintenance of biological wastewater treatment systems (both aerobic and anaerobic).

8.0 CONCLUSIONS/RECOMMENDATIONS

The investigation into sensor technologies to manage waste streams and optimise the use of their by-products has demonstrated the technology available for the active monitoring of wastewater treatment parameters and the benefits of optimising the treatment process. This final report constitutes the industry referral document for abattoirs regarding the implementation of sensor technologies and control systems.

The research has highlighted:

- There are a range of technologies available to measure important wastewater parameters for regulatory and operational purposes
- Not every wastewater treatment plant has the same monitoring requirements, and different ‘Tiers’ of monitoring system are suitable depending on the process application
- Case studies in the literature have shown that sensors enable optimisation of biological wastewater treatment processes leading to improved reactor performance, reduced energy and chemical requirements, and lower rates of mechanical and environmental incidents
- Findings in the literature have been achieved in an Australian meat industry context through a field demonstration trial optimising the anammox process with the aid of active monitoring through sensors.

The field demonstration has demonstrated the operational benefits of modern sensor implementation for abattoir WWTPs. The trial compared the performance of the original anammox system, the system after installation of a Tier 2 control system, and the system during the field trial of a Tier 3 system.

Both the Tier 2 and Tier 3 system have shown that if benefits of the sensor technology have been fully utilised, the payback period can be less than one year for a typical abattoir. In addition to the financial benefit, the sensor technologies enable abattoirs to meet the regulatory requirements with much ease without violating emission permits.

The report recommends:

- Meat industry wastewater treatment plant operators review their current control systems with respect to their process needs
- Consideration of the potential benefits of a sensor and control system upgrade given the benefits, NPV and payback period reported from the literature and this field demonstration

Sensor technology is constantly improving, and the pace of change has been rapid this decade. The author recommends the state of sensor technology and its applicability to improve wastewater treatment processes in the meat industry be continuously reviewed.

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