Analysis of Operation and Maintenance Procedures of Recirculating Aquaculture System for Tropical Shark Tank

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Preface

This bachelor thesis is written at the Department of Mechanical and Marine Engineering at Western University of Applied Sciences (WNUAS), in the study called Manufacturing Engineering. We would like to thank Professor Maneesh Singh who supervised and helped us with relevant information and analysis to this thesis. We would also like to thank "Akvariet i Bergen" for their cooperation and for giving us this opportunity. Special thanks to Aslak Sverdrup, Espen Hansen, Even Bjørgo Skåtøy and Natalie Stenfeldt for taking their time to guide us, answering questions and provide us relevant information.

Abstract

This bachelor thesis will analyse the operation and maintenance procedures of the recirculating aquaculture system (RAS) for the tropical shark tank at "Akvariet i Bergen".

The current maintenance procedures consist of a simple inspection and maintenance routine, mostly based on corrective maintenance. This way of performing maintenance is not necessarily wrong, however "Akvariet i Bergen" should consider implementing structured methods for determining their maintenance routines.

This report will use reliability centered maintenance (RCM) as an analysis tool. It is a well-documented method, commonly used by companies all around the world. Performing RCM analysis on the RAS of the tropical shark tank has the potential to improve the maintenance procedures while reducing the maintenance cost. The analysis results in a maintenance program, including type of maintenance, maintenance intervals, and a recommendation to "Akvariet i Bergen" regarding possible improvements to their procedures.

The system is lacking documentation. There is no piping and instrumentation diagram (P&ID) and some of the components are not adequately marked, making it difficult to obtain an overview of the system. Therefore, the first part of the report will focus on acquiring a sufficient understanding of the system in order to make a P&ID.

Industry 4.0 is the future of industry. The concept is still in the early stages, meaning that there are great opportunities for improving it and making it easier for companies to implement in the future. Through research and analysis conducted in this report, applying Industry 4.0 at "Akvariet i Bergen" appears not to be justifiable in terms of resources today. However, this could change in the matter of a few years as the concept is further developed and improved.

"Akvariet i Bergen" will build a completely new aquarium with advanced technology in a few years. This report recommends "Akvariet i Bergen" to implement a rule-based approach of predictive maintenance to the new aquarium in order to obtain a cost-effective maintenance solution for the next century.

Keywords: operation and maintenance, P&ID, RCM analysis, corrective maintenance, preventive maintenance, predictive maintenance, RAS, aquarium, Industry 4.0, data logging

Sammendrag

Denne bacheloroppgaven vil analysere drifts- og vedlikeholdsprosedyrer for det resirkulerende akvakultursystemet (RAS) for den tropiske haitanken hos Akvariet i Bergen.

Nåværende vedlikeholdsprosedyrer består av en enkel inspeksjons- og vedlikeholdsrutine, hovedsakelig basert på korrigerende vedlikehold. Denne måten å utføre vedlikehold på er ikke nødvendigvis feil, men Akvariet i Bergen bør vurdere å iverksette strukturerte metoder for å bestemme sine vedlikeholdsrutiner.

Denne rapporten vil bruke reliability centered maintenance (RCM) for analyse. Det er en godt dokumentert metode og brukes av selskaper over hele verden. Å utføre RCM-analyse på RAS for den tropiske haitetanken har potensial til å forbedre vedlikeholdsprosedyrene samtidig som vedlikeholdskostnadene reduseres. Analysen resulterer i et vedlikeholdsprogram som inkluderer type vedlikehold, vedlikeholdsintervaller og en anbefaling til "Akvariet i Bergen" om mulige forbedringer av prosedyrene deres.

Systemet mangler dokumentasjon. Det er ingen rør- og instrument diagram (P&ID), og noen av komponentene er ikke tilstrekkelig merket, noe som gjør det vanskelig å få oversikt over systemet. Derfor vil den første delen av rapporten fokusere på å tilegne seg en tilstrekkelig forståelse av systemet for å lage et P&ID.

Industri 4.0 er fremtiden for industrien. Konseptet er fremdeles på et tidlig stadium, noe som betyr at det er store muligheter for å forbedre det og gjøre det lettere for selskapene å iverksette i fremtiden. Gjennom forskning og analyse utført i denne rapporten, kan anvendelse av Industry 4.0 på Akvariet i Bergen se ut til ikke å være forsvarlig med tanke på ressurser i dag. Dette kan imidlertid endre seg i løpet av noen få år etter hvert som konseptet videreutvikles og forbedres.

Akvariet i Bergen vil bygge et helt nytt akvarium med avansert teknologi om noen år. Denne rapporten anbefaler Akvariet i Bergen å implementere en regelbasert tilnærming av prediktivt vedlikehold for å oppnå en kostnadseffektiv vedlikeholds løsning for det neste århundre.

Stikkord: drift og vedlikehold, P&ID, RCM-analyse, korrigerende vedlikehold, forebyggende vedlikehold, prediktivt vedlikehold, RAS, akvarium, Industri 4.0, datalogging

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1. Introduction

1.1 Background

1.1.1 Akvariet i Bergen

The aquarium was founded as a foundation in 1960. “Akvariet i Bergen” is Norway’s largest aquarium and is one of Bergen’s biggest tourist attraction. Besides being a tourist attraction, the aquarium focuses on increasing young people's interest in the ocean and animals. [2]

AKVARIET
I BERGEN

Statsbygg is the foundation which owns the land and buildings of the aquarium. While statsbygg is the owner, “Akvariet i Bergen” is the foundation that has the responsibility for the operational activities.

In june 2019 the city council of Bergen decided that Statsbygg will be granted the right to purchase land on Dokken. “Akvariet i Bergen” will be co-located on this land with the Institute of Marine Research and the Directorate of Fisheries. The foundation’s statement for the movement to dokken is: “We want to move the ocean inside of Bergen” [3].

There has been done feasibility studies in september 2019 to look at the possibilities for the aquarium to move from Nordnes to the shipping area of Bergen city as part of an urbanisation. This study concluded positively for both the aquarium and the community of Bergen. [4]

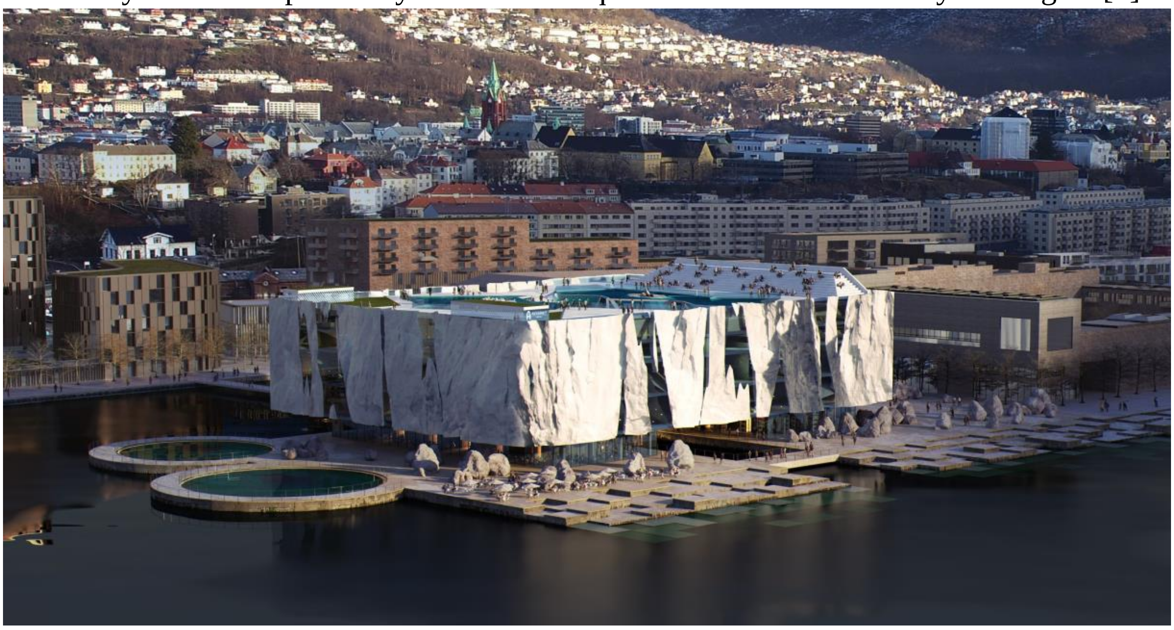

Figure 1: Draft of new aquarium [45]

1.1.2 Need for the project

“Akvariet i Bergen” is an old facility, so are the systems and the operation and maintenance procedures. Their current maintenance procedures consists of a basic inspection and maintenance routine, which is mostly corrective maintenance. There is no doubt that they could need someone to look into their maintenance procedures, and with using RCM you end up with only those maintenance task that are applicable and cost-effective. To be able to effectively use RCM analysis, tag numbers will be assigned to the components in the system. Proper documentation and drawings such as P&ID’s of the different subsystems are also lacking, which is critical to properly understand the system.

1.2 Research question

How can the current operation and maintenance procedures for the recirculating aquaculture system (RAS) of the tropical shark tank be improved by the use of analysis tools and theory?

1.3 Aim of project

The aim of this project is to analyse the operation and maintenance procedures of the recirculating aquaculture system (RAS) for the tropical shark tank at “Akvariet i Bergen” in order to identify possible improvements to these procedures.

1.4 Scope of work

This report will begin with a description of the methods of data collection utilised in the project. Then, the various analysis tools, standards and methods will be presented.

In the next part of the report, the focus will be on understanding how the system works; why each component is there, how the different components are connected, and so on. This knowledge will be useful when conducting different types of analysis of the system.

Further on the results from the analysis will be presented and discussed.

Finally, this report will reach an overall conclusion, including a final recommendation to "Akvariet i Bergen" regarding improvements to the maintenance and operation procedures of the recirculating aquaculture system (RAS) for the tropical shark tank.

1.5 Limitations, simplifications and assumptions

Limitations and simplifications

1. The documents/data on the system and its components are old and unclear.
2. Due to inadequate access to historical data on the system regarding maintenance, the analysis was conducted based on the students own experience and the experiences of the internal and external supervisor.
3. The RAS of the shark tunnel has an ozone generator installed. This is supposed to feed the protein skimmer with ozone. However, the ozone generator is no longer in use, so it will be neglected from the analysis in this bachelor thesis.
4. The analysis is limited to the parts of the system specifically related to the cleaning of water, meaning that the shark tank, the drainpipes, the two circulation pumps and the system supplying cold water are not analysed.

Assumptions

1. The information regarding degradation of components gathered from the OREDA Database is assumed to be applicable for the RAS of the tropical shark tank as information on the exact water conditions of the shark tank (temperature and chemical structure) does not exist.

1.6 Structure of report

The report will be divided into chapters containing the following:

Chapter 1: Introduction to the project

Chapter 2: Relevant theory will be presented and explained.

Chapter 3: Description of the methods of collecting data, including description of analysis tools, and methods used.

Chapter 4: Description of the system.

Chapter 5: Presentation of the results from the analysis.

Chapter 6: A discussion of the results.

Chapter 7: Conclusion with a final recommendation.

1.7 Abbreviations

AFM: Activated filter media

AI: Artificial Intelligence

EPI: Electrical Power Indicator

ERP: Enterprise Resource Planning

FFA: Functional Failure Analysis

FI: Flow Indicator

FMECA: Failure Mode, Effects and Criticality Analysis

FSI: Functional Significant Items

HAZOP: Hazard and Operability Analysis

IoT: Internet of Things

LI: Level Indicator

MCSI: Maintenance Cost Significant Items

MES: Manufacturing Execution System

MSI: Maintenance Significant Items

MTTF: Mean Time To Failure

MTTR: Mean Time To Repair

PdM: Predictive Maintenance

PI: Pressure Indicator

P&ID: Piping & Instrumentation Diagram

PM: Preventive Maintenance

RAS: Recirculating Aquaculture System

RCM: Reliability Centred Maintenance

TC: Temperature Control

TE: Temperature Element

TI: Temperature Indicator

TIC: Temperature Indicator Controller

TT: Temperature Transmitter

2. Theory

2.1 Maintenance

According to "BS EN 13306:2010 Maintenance - Maintenance terminology" maintenance is defined as a "combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function" [25, p. 5]. When maintenance was introduced to industry, it was only seen as a background activity of minor importance. Maintenance was only used in case of breakdown. Today, maintenance is regarded as a vital part of industry.

There are many different ways of performing maintenance. It is common to distinguish between three main types of maintenance. These three types are corrective, preventive and predictive maintenance, and they will be explained in the following subsections.

2.1.1 Corrective Maintenance

Corrective maintenance is defined by the British standard 13306:2010 as "maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function" [9, p. 13]. This is the simplest type of maintenance. When an item is broken, you simply replace it with a new item. In cases where failure of an item isn't critical, the item is cheap or doing other types of maintenance is difficult, this is the preferred type of maintenance.

2.1.2 Preventive Maintenance

Preventive maintenance (PM) is defined by the British standard 13306:2010 as "maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item" [25, p. 12]. This type of maintenance is more advanced than corrective maintenance. The objective is to prolong the lifetime of an item. This type of maintenance is preferred over corrective maintenance in cases where failure of an item is critical, or the item is expensive.

2.1.3 Predictive Maintenance

Predictive maintenance is defined by the British standard 13306:2010 as "condition based maintenance carried out following a forecast derived from repeated analysis or known characteristics and evaluation of the significant parameters of the degradation of the item" [25, p. 12]. This type of maintenance is the most advanced form of maintenance. It is a modern way of doing maintenance that requires substantial amounts of data and resources to process this information. To collect this information, you need sensors placed in appropriate locations in the system. When predictive maintenance is properly executed it results in maximising the service life and minimising the downtime of components in the system without increasing the risk of failure. [29, p. 263-264]

Figure 2: Predictive maintenance [43]

2.2 Industry 4.0

This subchapter will start by introducing the concept of Industry 4.0. Further on, the implementation of this concept to the new aquarium at Dokken will be discussed. Both advantages and disadvantages will be presented, culminating in a recommendation to “Akvariet i Bergen” regarding the implementation of predictive maintenance and Industry 4.0.

2.2.1 Background

Figure 3 shows the four stages of industrial revolution. The first industrial revolution took place in the late 1700s and was mainly about the transformation from manual work to taking advantage of steam-powered machines in production. [5, p. 2]

The second industrial revolution began in the 1850’s and is known for introducing the term “mass production”. Mass production became available because of the invention of several new technologies and is therefore called the technology revolution. This revolution consisted of new ways to produce steel for both products and production equipment. [5, p. 2]

The third industrial revolution began around the 1970's and is known as the digital revolution. This revolution revolved around automated production lines and processing industries controlled primarily by digital technology. [5, p. 2]

These revolutions were identified long after their impact and influence on the industry and the society. The vision for the fourth industrial revolution was presented in 2013 and named "Industry 4.0". This revolution revolves around the transformation to a so-called "smart industry", which is dependent on the concept "Internet of Things" (IoT). [5, p. 3]

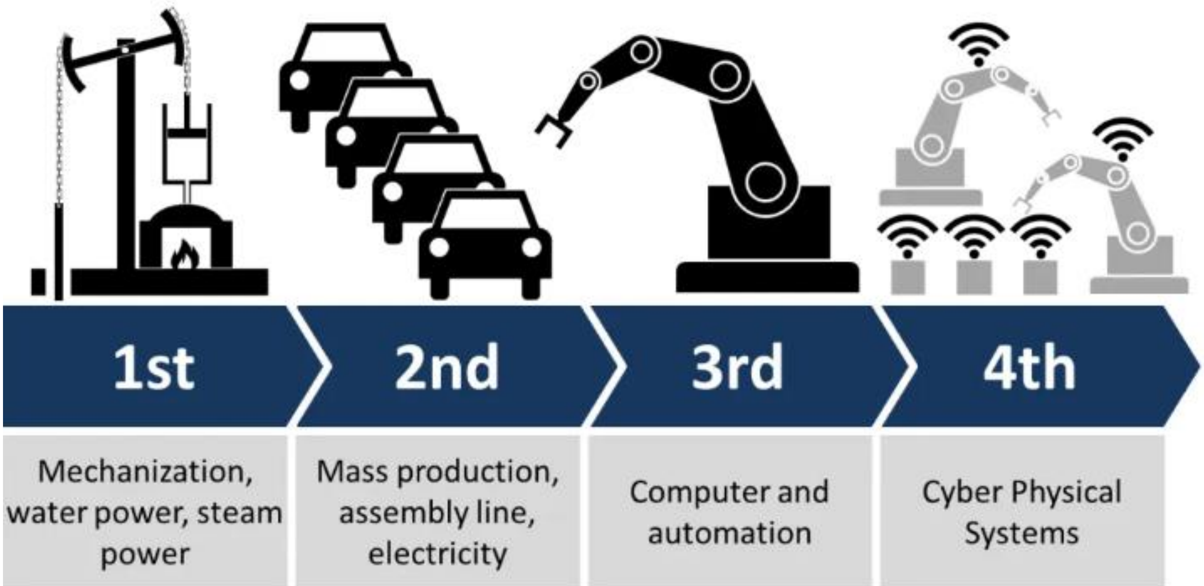

Figure 3: Four stages of industrial revolution [20]

2.2.2 What is Industry 4.0?

Industry 4.0 is a vision for the future which started in Germany. Over the last couple of years several other countries have gotten involved as well. Germany has been a leading country within industrial production for a long time. They were quick to capture the global trend regarding digitalisation and created the idea which today is called Industry 4.0. [22]

The German government gathered a workgroup with the goal of formulating the next steps toward the future of factory automation. The result was Industry 4.0, which describes the transition to a "smart industry". The implementation of Industry 4.0 is dependent on various main concepts to be operating. Among these is “Internet of Things” (IoT). The goal with Industry 4.0 is to be able to control and access the entire supply chain through the internet. [5, p. 4]

If this principle is transferred to industrial production, machines will no longer only process products, but the products themselves will communicate with machines and give them instructions. In this way, the machines of the future will organise themselves, supply chains will assemble themselves and customer orders will be directly converted to manufacturing instructions. Factories or production facilities of the future will be so flexible that each product can be tailored after the customers’ needs, without it being more expensive than mass production. [22]

Industry 4.0 will demand new types of cooperation between humans and machines, which again will increase technological and organisational complexity. Employees of the future will need a broader spectre of knowledge on work processes before and after production. [22]

2.2.3 Internet of Things

Internet of things (IoT) is often referred to as the communication between objects. These objects are able to “talk” with each other, and this connection makes up the internet of things. By combining devices like sensors, phones and wearables together as an automated system, you can receive information, analyse it and use it to execute an action. [21]

If you translate this principle to industrial production, it leads to machines doing more than just producing a product. By communicating with the product itself, the product can give instructions on how it is supposed to be processed to achieve its end goal. This makes the orders from customers more direct to the fabrication, thereby making the industry more flexible. Because of this, machines can organise the production processes themselves, which increases the production efficiency. [22]

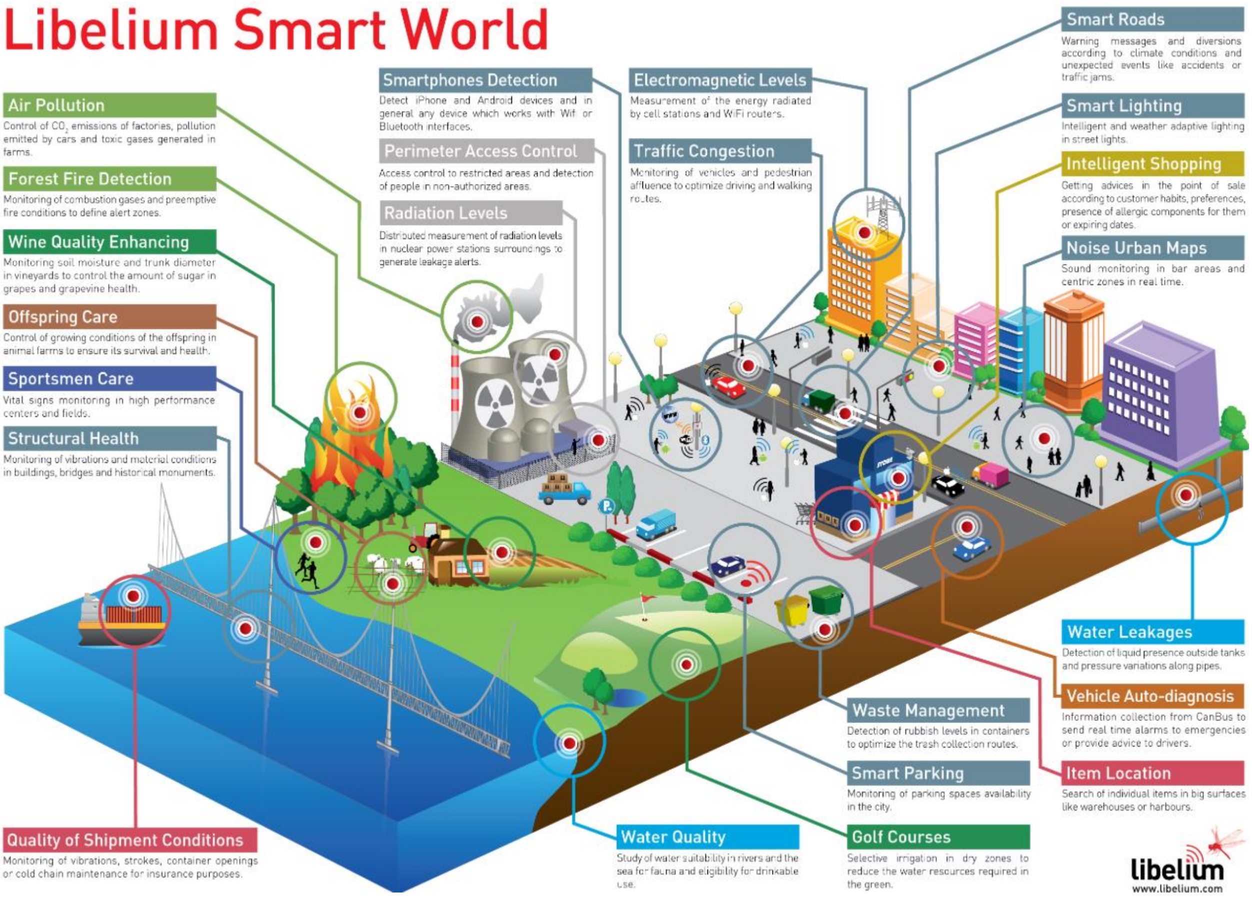

Figure 4: Libelium smart world [40]

2.2.4 Using Industry 4.0 for Predictive Maintenance

Internet of things (IoT) is a crucial factor in enabling predictive maintenance. By using IoT-sensors and -machines together to communicate with each other, you can make smart factories that come to life. These systems can act automatically when needed. [24]

Sensors measure different kind of parameters to identify what is happening inside various types of machines. The traditional way of doing inspection has involved taking machines apart to properly inspect them. This is necessary because most wear and tear happens on the inside of the machines, which makes this inspection method complicated and time consuming. By using sensors, companies can save a lot of time and costs, by not having to take machines apart to inspect them. Sensors measure most commonly parameters like vibration, noise, temperature, pressure and oil level. The use of sensors is therefore critical to be able to perform continuous condition monitoring of equipment, which is called predictive maintenance. [31]

Predictive maintenance is dependent on a set of base components. These are sensors, central data store, predictive analytics algorithms and root cause analysis, which is used by maintenance engineers to investigate and determine the corrective action to be performed. [33]

The figure below (figure 5) shows how these different base components collaborate. Described in a simplified way, production asset data is streamed from sensors to the data store which uses business data from ERP (enterprise resource planning) and MES (manufacturing execution system) systems together with process flows to give context to the production asset data. Then, predictive analytics algorithms are used to provide information on how to reduce downtime, which is further investigated using root cause analysis software. [33]

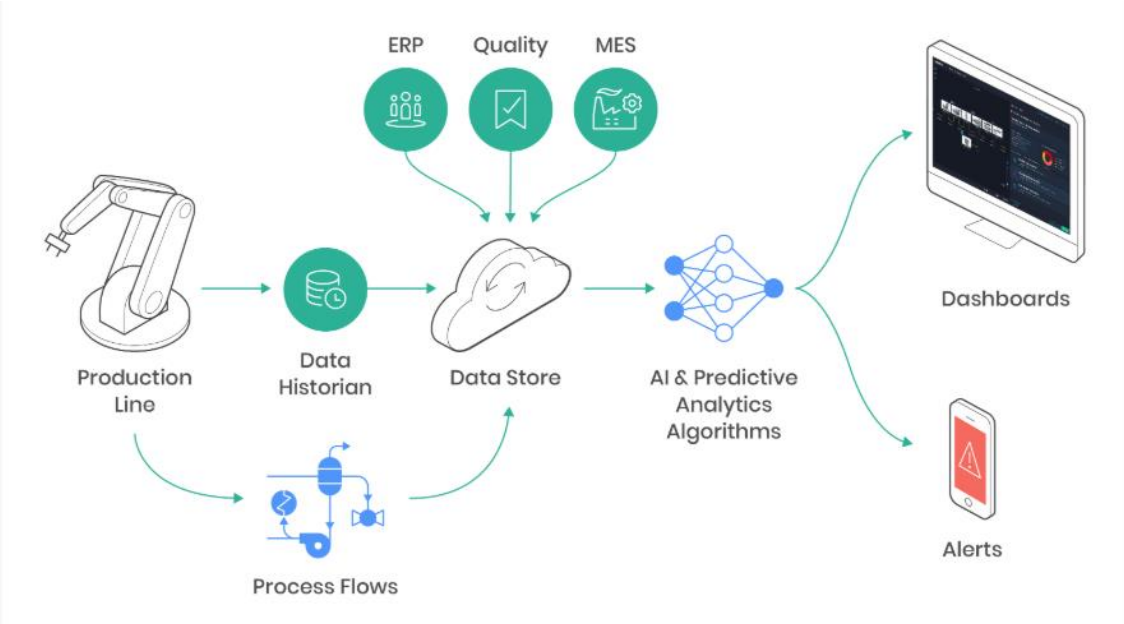

Figure 5: Collaboration of base components [33]

Predictive maintenance also requires a set of tools. Internet of things, which was discussed in the previous subchapter, is one of these tools. According to "Predictive Maintenance for Industry 4.0 | Complete Guide" [33] IoT can be described in the following way: “Predictive maintenance tools include an industrial IoT platform to model, simulate, test and deploy the predictive maintenance solution”.

One can implement predictive maintenance using the principles of Industry 4.0 in a lot of different ways. For machine and parts manufacturers, it is common to use it for monitoring and analysing the condition of an equipment to get alerts about its productivity levels, power consumption, health status and internal wear. Another common area of utilisation for predictive maintenance is minimising production defects and reducing waste. This is often referred to as Quality 4.0 and can predict when the number of defective products is likely to exceed a set limit and provides the root causes for the expected failure. Predictive maintenance is also used for Factory 4.0, or a so-called connected factory. Here, sensors are installed in machines, workstations and other relevant sites to predict issues across the factory floor. It is therefore reasonable to believe that predictive maintenance with the use of Industry 4.0 can be beneficial to implement to the new aquarium, even though the greatest benefits are achieved in other user areas. [33]

There are two approaches to predictive maintenance that are most commonly used. These are rule-based and machine learning-based. The rule-based approach is also referred to as condition monitoring. This relies on sensors to collect data about assets and sends alerts according to predefined rules. For example, if temperature or vibration is reaching a level that is higher than the predefined limit, an alert is sent to an operator dashboard, to address the issue ahead of failure. This approach creates a level of an automated system, but is still dependent on skilled personnel who knows which parts require measuring. These operator dashboards can be integrated with the use of machine learning to create a visually understandable map of all the assets conditions in real time. [33]

The other approach to predictive maintenance is the machine learning-based, which is an application of artificial intelligence (AI). The difference between artificial intelligence and machine learning is according to Marr [34]

> "Artificial Intelligence is the broader concept of machines being able to carry out tasks in a way that we would consider "smart". Machine Learning is a current application of AI based around the idea that we should really just be able to give machines access to data and let them learn for themselves". [34]

Artificial intelligence can be applied for predictive maintenance. We are in the early stages of exploiting this technology, but there are already many companies benefitting from this approach. A machine learning-based approach uses large sets of historical or test data combined with tailored machine learning to predict what will go wrong and when. [33]

3. Method

3.1 Theoretical approach

3.1.1 Qualitative/quantitative method

Quantitative methods are used to collect data in the manner of measurable units, and the qualitative methods are used to capture feelings, opinions and experiences. This makes the qualitative method more subjective, as the analysts themselves will most likely have an impact on the subject, collection and the interpretation of the data. On the other hand, with a quantitative method the analysts have minimal to no influence on the output data, which makes them more objective than the qualitative methods. This report has used a combination of qualitative and quantitative methods in the analysis. Quantitative methods have been used when measurable units have been available. However, this has been difficult to find, so qualitative methods have often been the solution. [26, p. 51-62]

3.1.3 Field observations

When considering the conditions of the RAS of the tropical shark tank, field observations have been the most important source of information. The system is not equipped with sensors continuously monitoring the conditions, meaning that data regarding this is not available. Consequently, field observations were the most effective way of assessing the state of the system.

3.1.4 Supplier

The main supplier of the RAS is Erwin Sander. They have provided manuals for some of the main components, information about maintenance and safety and a folder containing construction propositions and tenders.

3.1.5 Professor in operation and maintenance

The supervisor for this Bachelor project, Maneesh Singh, is an expert in operation and maintenance. During the entirety of this project, he has provided input in terms of personal experience, professional articles, documents, databases, etc. This has played a significant role in the process of gathering data and in the decision-making processes.

3.1.6 Meetings with employees

A substantial amount of data for this report is collected through several meetings with workers that have years of experience with operating and maintaining the system.

3.2 Software

Two software programs are used for this thesis. These two programs are further explained here.

3.2.1 Excel

By using Excel, this thesis adopts an analytical tool to create tables and to express the authors' quantitative and qualitative results.

3.2.2 Edraw Max

With the use of Edraw Max, a P&ID will be developed of the applicable system. This software implements ISO standard symbols that are up to date and easy to use. These symbols will be used, but the ISO standard will not be followed 100% because of the simplicity of the P&ID.

3.3 Databases

In order to make the analysis in this report as accurate as possible, databases have been applied when possible. For this report, the only components analysed according to databases are the centrifugal pumps. They are described in the OREDA Database [8]. Information regarding maintainable items and probabilities of failure are collected from this database and used when conducting the RCM analysis in chapter 5.

3.3.1 OREDA

The OREDA (offshore and onshore reliability data) database comprises reliability data gathered from 278 installations. It contains over 39 000 failure and 73 000 maintenance records. [7]

"The data are recorded per owner and installation. Each individual item (e.g. a gas turbine) occu-pies a single inventory record in the data-base. This record contains a technical description (e.g. manufacturer information) plus operating and environmental conditions--. For each inventory, all failure events are stored. Each failure event is identified by item name, date of failure, failure impact, failure mode, failure cause etc. The maintenance records contain data on corrective maintenance linked to the corresponding failure record, and data on preventive maintenance linked to the corresponding inventory record" [7].

The OREDA database has been changed and improved regularly for over 30 years by the different companies who collaborated to create it [8]. It is a thorough and reliable source of information. This is the reason why it has been applied in this Bachelor thesis.

3.4 RCM

In this subchapter RCM will be explained. The different steps of an RCM analysis and the various analysing tools will be presented. This subchapter is be based on the book "Reliability centred maintenance" by Marvin Rausand [9] and PowerPoint slides related to the book "System Reliability theory: Models, statistical methods and applications" by Marvin Rausand and Arnljot Høyland [10].

RCM is a technique used for developing a preventive maintenance programme. RCM cannot improve the system, but it can provide information so one can know what kind of preventive maintenance is needed. Rausand and Høyland defines RCM as "a systematic consideration of system functions, and a priority-based consideration of safety and economics that identifies applicable and effective PM tasks" [10]. Further on they say that the objective for a RCM is to reduce the maintenance cost, by focusing on the most important functions of the system, and avoiding or removing maintenance actions that not are strictly necessary. [10]

The usage of preventive maintenance is often mistaken. It is often wrongly assumed that the more an item is routinely maintained, the more reliable it will be. The opposite often happens, which is due to maintenance-induced failures. RCM was designed to balance the costs and benefits, to obtain the most cost-effective PM program. In order to fulfil this desire, the system performance standards have to be specified. PM will not prevent all failures, so it is important to identify all the consequences of each failure and the likelihood of failure must be known. Applicability and effectiveness are by far the two most important criteria when using PM to address each failure. To be effective, PM must provide a reduced expected loss related to personnel, injuries, environmental damage, production loss, and/or material damage. It is important to remember that RCM never will be a substitute for poor design, inadequate build quality or bad maintenance practices. [10]

Experience has shown that approximately 30% of the efforts of an RCM analysis is involved in defining functions and performance standards which leads answering questions and so on. [9]

3.4.1 What is RCM?

According to Rausand [9, p. 122] an RCM analysis can be worked out as a sequence of the following 12 steps:

1. Study preparation
2. System selection and definitions
3. Functional failure analysis (FFA)
4. Critical item selection
5. Data collection and analysis
6. FMECA
7. Selections of maintenance actions
8. Determination of maintenance intervals
9. Preventive maintenance comparison analysis
10. Treatment of noncritical items
11. Implementation
12. In-service data collection and updating

In this report however, step 5 (Data collection and analysis) will be excluded from the analysis.

3.4.1.1 Study preparation

In the first step the project group is established. The group must define and clarify the objectives and the scope of the analysis. Further on the group needs to define the issue and the aim of project. It is important to clarify the limitations, simplifications, scope of work, assumptions and acceptable criteria for the project. Before further work, process diagrams, P&ID's, overall drawings and other relevant documents should be made available. It is important to have a clear and good communication with the client, so all confusions can be clarified quickly. [9, p. 122-123]

3.4.1.2 System selection and definitions

Before taking the decision if an RCM analysis should be performed on a plant, two questions should be considered. 1) To which systems are an RCM analysis superior compared to more traditional maintenance planning? 2) At what level of assembly (plant, system, subsystem …) should the analysis be done? Generally, all systems would benefit from an RCM analysis. However, with limited resources, priorities must be made, especially when introducing RCM in a new plant. The group should clearly identify the selected system and break it down into functions and sub functions. It is also important to establish the system hierarchy levels, which makes it easier to point out all the functions in the system and show the connection. [9, p. 123]

3.4.1.3 Functional failure analysis (FFA)

This step can be broken down into three tasks. The first task is to identify and describe the systems required functions and performance criteria. To complete this you need to have a complete understanding of how the system operates. Without this understanding you will not be able to analyse and classify the different functions. Some helpful tools to complete this task would be using predetermined checklists or classification schemes. [9, p. 123-125]

The next task is to describe the input interfaces required for the system to operate. This can be illustrated with functional block diagrams, reliability block diagrams or fault trees.
The final task is to start the functional failure analysis (FFA). Functional failures should be listed in a FFA worksheet, where their criticality is ranked from low to high in four consequence classes. These are safety of personnel, environmental impact, production availability and cost of material loss. [9, p. 123-125]

3.4.1.4 Critical item selection

Critical item selection is performed with the purpose of identifying the analysis items that are potentially critical in regard to the functional failures identified in the FFA. These analysis items are denoted functional significant items (FSI). At this stage of the analysis, some of the functional failures are considered less critical and will not be taken into account. [9, p. 125]

Identifying the FSI can be done in different ways, depending on the system in consideration. When dealing with complex systems, a formal approach applying techniques like fault tree analysis, reliability block diagrams, or Monte Carlo simulation may be used to identify the FSIs.

Simpler systems may only need logical thinking in the identification process because it is obvious which analysis items that influence the system functions. [9, p. 125]

Another important part of the critical item selection is to identify analysis items denoted maintenance cost significant items (MCSI). These are items with high repair costs, high failure rate, long lead time for spare parts, low maintainability, or items requiring external maintenance personnel. [9, p. 125]

After identifying the FSIs and the MCSIs, these are combined to give a more complete picture of the criticality of the items. This combination is denoted maintenance significant items (MSI). Whether this screening of critical items should be done or not, depends on the situation. In some cases, it may be beneficial to only consider critical items, in other cases all items should be analysed. [9, p. 125]

3.4.1.5 Data collection and analysis

The different steps of the RCM analysis require a variety of input data, like design data, operational data and reliability data. Reliability data is necessary to decide the criticality, to mathematically describe the failure process and to optimise the time between PM tasks. According to Rausand [9, p. 125] reliability data include:

- Mean time to failure (MTTF)
- Mean time to repair (MTTR)
- Failure rate function z(t)

The failure rate can be an increasing (most common) or decreasing function of time, or a combination of both.

Several life models are available and may be used for detailed modelling of specific failure mechanisms. However, in most cases the Weibull distribution is the preferred distribution.
The operational and reliability data are collected from available operating experience and from external files where reliability information comes from similar systems. This information should be considered carefully before it is used, because such information is generally available at a rather coarse level. [9, p. 125-126]

When developing a maintenance program for new systems, you can experience situations where there is complete lack of reliability data. Helpful sources of information may be experience data from similar equipment, directions from manufactures, and results from testing. The RCM method will even in this situation provide useful information. [9, p. 125-126]

3.4.1.6 Failure mode, Effects and criticality analysis (FMECA)

The objective of this step is to identify the most dominant failure modes listed in step 4 Critical item selection. You can use a various amount of different FMECA worksheets to carry out this analysis. The worksheet can contain unit, MSI, functions, failure mode, likelihood of failure, effect of failure, failure mechanism, failure characteristic, maintenance action and maintenance interval. [9, p. 126-127]

3.4.1.7 Selection of maintenance actions

The main idea of selection of maintenance actions is to decide for each dominant failure mode whether preventive maintenance is relevant and efficient, or if the be solution is to let the item run to failure, and afterwards carry out corrective maintenance. You must know clearly what the objective is. If it is to prevent a failure or discover a hidden failure, the recommended option is to carry out preventive maintenance. PM will clearly not prevent all failures to happen, so you should carefully compare costs versus effort to see if it is beneficial to carry out preventive maintenance or let the item run to failure and then carry out corrective maintenance. [9, p. 127-128]

3.4.1.8 Determination of maintenance intervals

There are several problems with many common PM models. Often, they are focused on maintaining a single unit, but in practice it is more common to run maintenance on several different systems at the same time, or in a specific sequence. Some are also based on data that is not available or is difficult to collect and use. This causes practitioners to often abandon models in favour of the manufacturers recommendations and personal experience, resulting in too frequent maintenance. If this is the case, you can later revise your maintenance policy in order to reduce excessive costs. [9, p. 128-129]

3.4.1.9 Preventive maintenance comparison analysis

Two superior criteria for selecting maintenance tasks are used in in RCM. According to Rausand [9, p. 129] the selected task must meet two requirements:

- It must be applicable
- It must be effective

Applicability means that preventive maintenance actually reduces the likelihood or consequence of failure for the item. If not, it is not point in carrying out PM. The PM task need to maintain or increase the reliability of the item in order to be applicable. Cost-effectiveness means that the PM does not cost more than letting the item run to failure. A smart way of evaluating cost effectiveness is by listing possible costs with PM and by letting the item go to failure and comparing them. [9, p. 129]

3.4.1.10 Treatment of non-critical items

In the critical item selection, MSIs were selected for further analysis, whereas non-critical items were dropped. This raises the question of what to do with the items which are not analysed. For plants with an existing maintenance program, it is recommended to carry out a brief cost evaluation. If the existing maintenance cost related to the non-critical items is insignificant, it is sensible to continue this program. [9, p. 129]

3.4.1.11 Implementation

A required basis for implementing the results of the RCM analysis is that the organisational and technical maintenance support functions are available. Experience reveals that many accidents occur either during maintenance or because of inadequate maintenance. When implementing a maintenance program, it is crucial to consider the risk associated with the different maintenance tasks. For complex maintenance operations, like for example offshore well workovers, a task analysis combined with for example a Human HAZOP may be performed to unveil possible hazards and human errors related to the maintenance task. [9, p. 129-130]

3.4.1.12 In-service data collection and updating

One of the core advantages of using RCM is the ability to feed data collected during operation, back into the analysis. When a significant failure occurs, it should be compared to the classification in the FMECA, and if it was not accurate, it should be revised. [9, p. 130]

Short term updates to the analysis should consist of updated failure information, reliability estimates and interval adjustments. Medium term updates could review the basis for maintenance actions compared to maintenance experience. A long-term update should review the entire RCM analysis, including external variables like regulations and standards. [9, p. 130]

3.4.2 RCM Tools

In this subchapter the different tools used in the RCM analysis will be presented. This report has used Rausand [9] as inspiration for making the FFA and FMECA sheets.

3.4.2.1 FFA Sheet

An FFA sheet is used when doing a functional failure analysis. The sheet is used to organise the results of the analysis in a clearly defined way. An example of a FFA sheet is shown below which is based on Rausand [9, p. 125].

Tag-nr	Sub units	Maintenable Item	Main Function	Main Function Failure	Secondary Function	Secondary Function Failure	Consequence for System

Tabell 1: FFA sheet

3.4.2.2 FMECA sheet

The FMECA sheet is a tool used for Failure Mode, Effects and Criticality Analysis. The sheet is used to organise the results of the analysis. An example of a FMECA sheet is shown below which is based on Rausand [9, p. 126]

					Effect of failure											
					Consequence Class				Risk class							
Unit	MSI	Functions	Failure mode	Likelihood of Failure	S	E	A	C	S	E	A	C	Failure mechanism	Failure characteristic	Maintenance action	Maintenance interval

Tabell 2: FMECA sheet

3.4.3 Classification of likelihood-, consequence- and risk class

When doing an FFA and FMECA analysis, it is important to clearly decide in what way likelihood, consequences and risks should be determined. In this report a qualitative approach will be made when selecting and describing the different classes.

The consequences will be classified as shown below:

	Safety	Environmental	Availability	Material loss (cost)
L	None/minor cuts, bruises, wounds with short healing time	None/minor spillage, but noe effect to local ecosystem	No stop or reduced production capasity/rate	No replacement or no expensive parts in need of replacement
M	Severe injuries without fatal outcome, but longer healing time	Harm to environment which can be fixed over time	Stop in production with short recovery time	One or a few expensive parts in need of replacement
H	Death or permanent severe injuries	Permanent harm to environment without any forseable solution for fixing	Full stop in production with long recovery time	Many and/or very expensive parts in need of replacement

Tabell 3: Classification of risk class

The likelihood will be defined as shown below:

Likelyhood	Description
N	No occurences of failure are expected
L	Some failures may occur during the life of the installation for a system compromising a small number of components
M	Several failures may occur during the life of the installation for a system compromising a small number of components
H	In a large population, one or more failures can be expected anually
E	In a small population, one or more failures can be expected anually

Tabell 4: Classification of likelihood

When combining consequence and likelihood, the following risk matrix will be used as shown below:

Likelihood		Level of risk	
E	High	High	High
High	Medium	High	High
Medium	Low	Medium	High
Low	Low	low	Medium
N	Low	Low	Low

Tabell 5: Risk matrix [36]

4. The system

The tropical shark tunnel was introduced to “Akvariet i Bergen” as an attraction in the spring of 2010. In other words, the recirculating aquaculture system (RAS) that is analysed in this report is approximately 10 years old.

4.1 General description

Figure 6: Inside of the shark tunnel [44]

This is an introduction to the RAS of the tropical shark tank in “Akvariet i Bergen”. Components of the system will be described in detail later in subchapters 4.1.1-7. As shown below in the P&ID (figure 7), the shark tank is connected to a sump tank via an overflow. The sump tank contains bio blocks that works as a biofilter. From the sump tank there is one filtration loop which uses sand filters and a protein skimmer. The protein skimmer loop contains two parallel centrifugal pumps with accompanying sand filters. Last in the loop is a protein skimmer which uses air to filtrate animal waste and other unwanted substances. To return water from the sump tank to the shark tank, a centrifugal pump sends the processed water from the sump tank through a UV filter. Because the sump tank is both the start and the end of the filtration loop and always has a certain level in it, it works as a buffer tank.

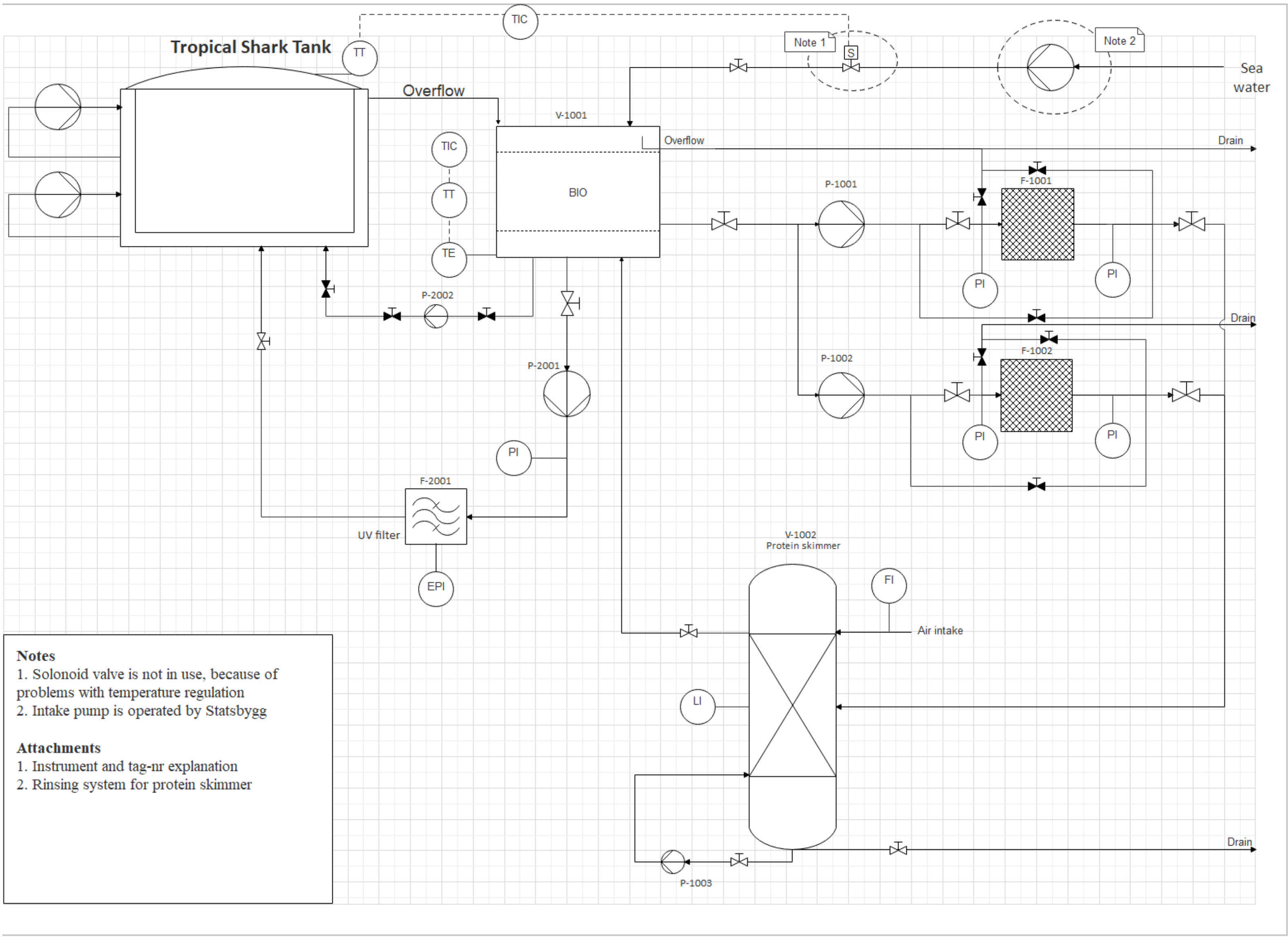

Figure 7: Piping & Instrumentation Diagram

If the level in the sump tank rises too high, water will overflow directly to the drain system. Water in the system is heated with heating elements inside the sump tank. Fresh seawater from “Byfjorden” is added to the shark tank with the use of a pump outside of the aquarium operated by Statsbygg. This seawater works as a cooling medium to regulate the temperature of the water. The water inside the shark tank is circulated by two circulating pumps.

As seen in the P&ID above (figure 7), tag numbers have been assigned to the appropriate components to make it easier to identify components. This helps with the conception of the operation and maintenance analysis and decreases the risk of future misunderstandings. The P&ID can also be found in a larger format in attachment 1. To describe tag numbers and abbreviations in the P&ID there is added a instrument and tag number explanation in attachment 2.

4.1.1 Biofilter

In the RAS of the shark tank bio blocks are placed inside a sump tank made of concrete. The saltwater from the shark tank goes through an overflow (made of plastic) and into the sump tank where it gets filtered by the bio blocks. In the bottom of the sump tank there are heating cables that heat the water to the desired temperature. There is also a manual valve set in a constant position leading a continuous flow of cold water at approximately 10 degrees Celsius from the ocean and into the sump tank. This cold water is used to refill or replace water in the system, as well as regulating the temperature of the process liquid. The heating is controlled by a temperature indicator controller (TIC) located at the heating elements.

An overflow from the sump tank leads excess water through to the drain system. When the biofiltration is done and the water is heated, it leaves the sump tank to undergo further filtration processes. The sump tank filled with bio blocks will be referred to as a biofilter in this report.

A biofilter is a living filter composed of a media upon which a film of bacteria grows. This film of bacteria is called a biological film or a biofilm. It has a slimy texture and is gradually developed with the progression of the filtration process on the surface of the filter media. Pollutants in the water are removed due to biological degradation. In an aquarium, the two primary water pollutants that need to be removed are fish waste excreted into the water and uneaten fish feed particles. Fish waste primarily refers to ammonia compounds, which is a waste product of fish metabolism. High concentrations of ammonia are toxic to most fish and it is therefore vital that it is removed to ensure a healthy environment for the fish. [11], [12]

4.1.2 Sand Filters

4.1.2.1 The Process

The way a sand filter works is that water is pumped into the valve head and down into the filter tank. The valve head is spraying the water out over the surface of the sand. The sand is only filled up to about half of the filter tank. Then the water runs through the sand, which captures the dirt, and are then collected at the bottom of the filter tank. The water is further on pumped back up

Figure 8: Sand Filter [17]

to the valve head and out to your system. Even though it is a simple process, it is often executed incorrectly. [19]

4.1.2.2 Operational Procedures

It is possible to use three different filter positions, which is the normal filter position, backwash position and rinse position. When the filter is in filter position, water is coming out from the top and down into the sand. The sand captures the dirt on the surface, which leads to all the dirt being captured at the highest sand layers. This dirt will pack the sand tight together in the highest layers of the sand. The pump is still pumping an equal amount of water, which leads to the sand getting tighter packed with dirt. This is causing pressure to build up on the top of tank and it can be applicable to perform maintenance in terms of backwashing. Most sand filters have a gauge which shows the pressure in the tank. This is used to consider when to backwash. [19]

4.1.2.3 Backwashing

To backwash the filter, you move the valves from the filter positions to the backwash positions. Now, water is coming out from underneath the tank, instead of from the top. This will stir around the sand and clean it. Dirty water is pumped out of another outlet and then you can move the valves to the rinse positions. The rinse positions are almost equal to the normal filtering positions. The water is coming from the top of the tank, but are flushed out of the same outlet as for the backwash. The purpose with these positions is to pack the sand together again, after being stirred around in the backwash positions. The reason why you do not go directly from the backwash positions to filter positions is because dirty water would then go right through the stirred sand and out to your system without being filtered by the sand. By using the rinse positions for a short period of time, the dirty water would be flushed out the same outlet as for the backwash positions until the sand is packed again and you can switch to the filter positions. [19]

A common problem is that sand filters are being backwashed to often. This will lead to poor filtration and dirty water. This is due the fact that backwashing leads to looser structure of the packed sand, which means that the water is running through the sand without hardly any resistance. When the filter gets dirty, it packs the sand tighter and tighter which creates higher resistance for the water. This makes the sand filtrate finer and finer particles. In conclusion, sand filters filter best when they are dirty. [19]

For the sand filter in this report it is recommended to backwash at a pressure difference of 0,6 bar. This pressure difference is the difference between the pressure into the filter and out from the filter. The backwash is recommended to last for seven minutes, with a following rinse of three minutes. [1]

4.1.2.4 Filter Media

Figure 9: Filter media sand & AFM [42]

The sand filter in this report is using glass as filter media instead of normal sand. “Akvariet i Bergen” used normal sand in the beginning, but changed to glass as filter media after a while. Glass, or activated filter media (AFM), has several advantages compared to normal sand when used a filter media in a sand filter. It has better filtration effect and eliminates the basis for bacteria growth. AFM is a direct replacement for normal filter sand, without a need for additional investments. It consists of broken glass, which is made from green and brown recirculated container glass. AFM is further on “activated” so the filter media receive certain characteristics which makes it outperform filter sand in every way, and it lasts longer. It has especially tree important characteristics. AFM has a self-sterilising surface, which makes it impossible for bacteria to stick and will therefore not develop biofilm, which filter sand does. It also has an activated surface which leads to electrostatic filtration. This type of filtration attracts particles as a magnet and increases the filtration rate compared to sand. The last important characteristic is the increased surface on AFM. AFM has a way bigger surface than filter sand and normal glass and has therefore superior mechanical filtration. AFM has a certified filtration degree down to one micron, and the hydrophobic activated surface captures 50 % more organic material than other filter medias. It is also the most sustainable filter media because it saves water and energy by more effective and slower backwashing. [18]

4.1.3 Protein Skimmer

Protein skimmers are commonly used in saltwater aquariums to remove organic compounds such as food and waste particles from the water. “Akvariet i Bergen” uses a Helgoland 1000 protein skimmer delivered by Sander in the RAS of the shark tunnel.

4.1.3.1 Working principle of Sander’s protein skimmers

Sander’s protein skimmers use fine air bubbles as an effective filtration element. On the bubble surface there is built up an active zone, to which protein compounds adhere easily due to their molecular structure. This results in a protein molecule with two molecular ends; a hydrophobic moiety which adhere to the bubble surface, and a hydrophilic moiety which points into the surrounding water. Various pollutants such as bacteria, viruses and other particles adhere to the hydrophilic end. [16]

As a result, a conglomerate is formed, consisting of air bubbles, protein molecules and pollutants, which floats to the water surface due to the buoyancy of the air bubbles. Because of the protein compounds’ surface activity, a firm foam structure builds up, enclosing the pollutants. By discharging this foam via the foam tube, the pollutants are removed not only from the aquarium, but completely from the water cycle. [16]

Another important function of a Sander protein skimmer is that it effectively enhances the cycle of gases in the water. The animals in the aquarium breathe in oxygen and exhale carbon dioxide. This reduces the water’s pH, which is not good for the marine life in the aquarium. To prevent this, carbon dioxide is vastly discharged, and oxygen is re-introduced inside the skimmer. The water from the outlet of the skimmer is constantly slightly oversaturated with oxygen. [16]

4.1.3.2 The Main Elements of the Skimmer

In this subchapter the main elements of the protein skimmer will be presented and explained. The two following figures (figure 10 and figure 11) will be referred to in order to give a better understanding.

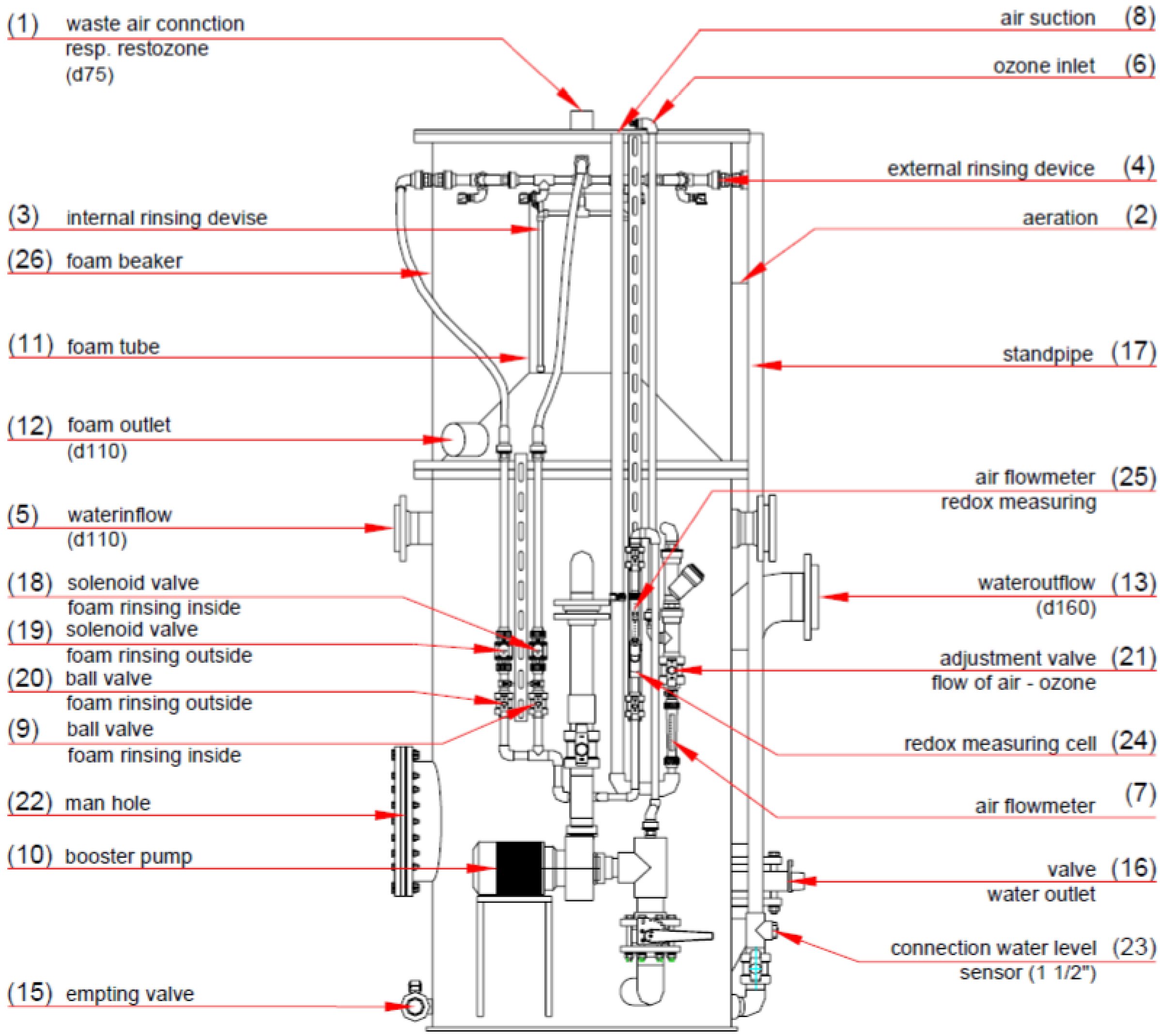

Figure 11: Protein skimmer overview [17]

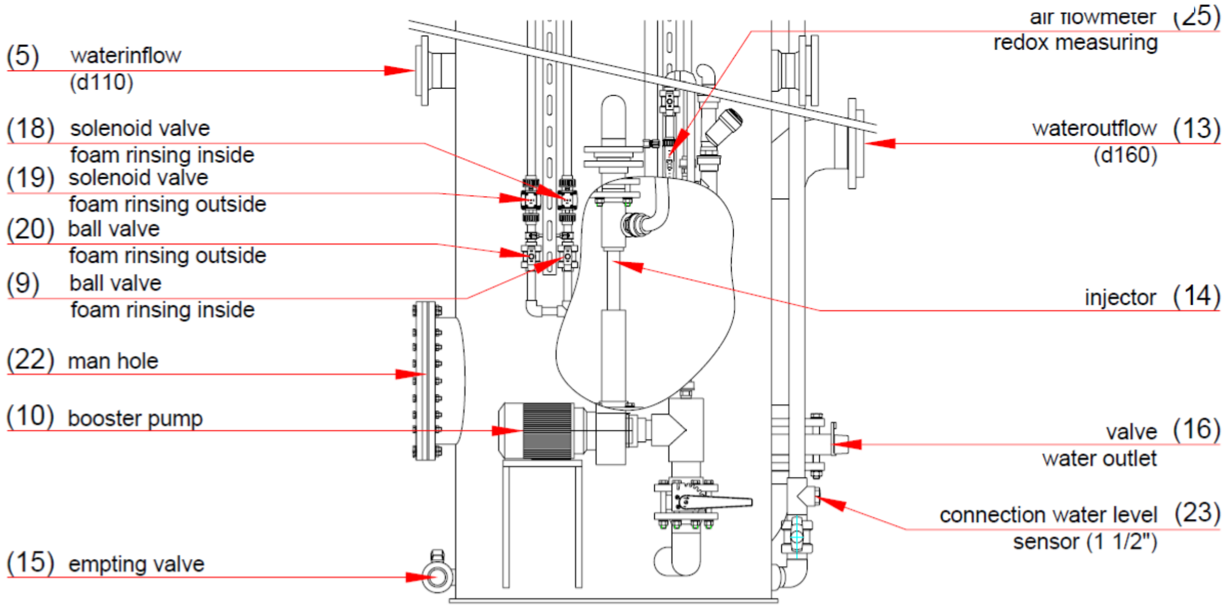

Figure 10: Protein skimmer details [17]

The Bubble Production System

The air bubbles used to filtrate the water in the protein skimmer are produced by the injection unit. It consists of a booster pump (10) and an injector (14). The booster pump (10) sucks water from the skimmer and discharge it through the injector (14), which is installed inside the reaction body. Due to a vacuum provided by the injector (14) air is sucked in and fine bubbles mix with the water. The injector (14) is designed to ensure a steady stream of fine air bubbles. These air bubbles are carried into the reaction chamber near the base of the protein skimmer. [16], [17]

The Water Inlet

The water inlet (5) is located at the upper end of the reaction tank. Water flows through the reaction tank from the top to the bottom in a counter flow to the air bubbles, providing optimal contact between the air bubbles and the unwanted particles in the water. [16], [17]

The Water Outlet

The water flows out of the reaction tank through a standpipe near the bottom of the tank. The outlet pipe (13) is aerated to ensure that the skimmer can never run dry. [16], [17]

The Foam Area

The top the reaction tank has a tapered end that passes over into the foam tube (11). For the skimmer to work efficiently the water level in the skimmer should be adjusted to the middle of the tapered end. Foam will develop above this water level. Slowly but continuously the foam will be carried off into the foam tube (11) by the ascending airflow. The foam gets dehydrated and therefore dryer and more concentrated as it rises through the foam tube (11). When the foam reaches the top of the foam tube (11) it drops into the foam beaker (26), while the waste air leaves the skimmer through a pipe length (1) in the lid plate. [17]

The External Rinsing Unit

The booster pump (10) provides water to the external rinsing unit (4). Water is spattered via nozzles into the foam beaker (26), cleaning both the inner wall of the foam beaker (26) and the external wall of the foam tube (11). The intervals and the periods of the rinsing process can be controlled by a timed solenoid valve (19) and should be adjusted according to the degree of soiling of the foam beaker (26). Finding an optimal interval is important. Then you can adjust the timer installed on the solenoid valve (19) to this optimal setting, e.g. using intervals of about one hour for a period of about 10 seconds. [17]

The Internal Rinsing Unit

The internal rinsing unit (3) works in the same way as the external rinsing unit (4), except from the fact that it rinses the inside of the foam tube (11). It gets water from the booster pump (10), then the water is spattered via nozzles into the foam tube (11). The intervals and the periods of the rinsing process can be adjusted on the timer installed on the solenoid valve (18), e.g. using intervals of about 15 minutes for a period of about 10 seconds. [17]

Due to the fact that the internal rinsing unit (3) and the external rinsing unit (4) are connected to the same booster pump (10), the two rinsing processes are not allowed to run simultaneously. [17]

A P&ID of the rinsing system for the protein skimmer can be found in attachment 3.

4.1.3.3 Maintenance Procedures

The automatic time-based internal and external rinsing will be considered as parts of the process in the protein skimmer in this report. This means that the rinsing processes are not maintenance actions, however the rinsing equipment itself will require maintenance. This includes the internal and external rinsing nozzles as well as the booster pump. Other parts of the protein skimmer, such as reaction tank, foam beaker, foam tube, etc., will also be analysed in terms of maintenance procedures in this report.

Functional test of the nozzles of the external rinsing system

Performing a functional test of the nozzles of the external rinsing system can be done by following the instructions given in the manual for the protein skimmer. This is shown below in figure 12. [17]

Loosen the screws and take off the lid.
Test the function of the nozzles of the external rinsing system (4) manually.
The nozzles should spray against the outside of the foam tube (11) and against the inside of the foam beaker (26)
The rinsing spray should not reach into the foam tube (11)!
For re-adjustment of the nozzles proceed like this:
- loosen the screws of the nozzles.
- readjust the angle of the nozzles.
- the rinsing spray should not reach into the foam tube (11)
- re-tighten the screws.

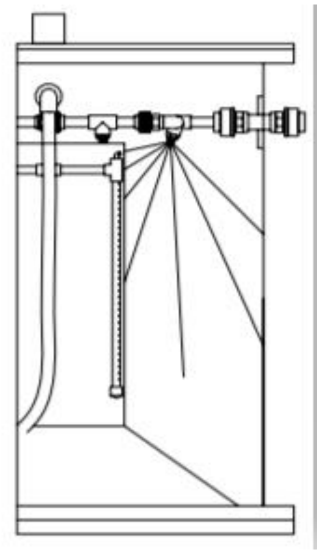

Figure 12: excerption from manual [17]

4.1.4 UV Filter

The UV filter used in the system is Wedeco AB 60. This filter has a flow rate of 56 m3/h and utilises UV light to kill bacteria in the water. The UV light comes from UV lamps which is protected by sleeves. All the components are covered by a chamber where flanges/gaskets and pipes are connected. UV filters uses the electromagnetic energy of the light to attack the genetic core of the harmful substances in the water. The UV energy destroys unwanted microorganisms by changing their DNA and making it impossible for them to reproduce. UV filters are typically used with other filters as well because UV filters do not eliminate all the unwanted content. A benefit with using UV filter is that it uses little energy and the bulbs last for a solid amount of time.[6]

UV light is found on the electromagnetic spectrum between x-ray and visible light. Of all the different spectres of Ultraviolet light, it is the UV-C with a wavelength of 256 nanometre that disinfects bacteria. UV light must strike the cell to sterilise it. It does not remove any particles from the water, it simply prevents cells from reproducing. The UV lamps in a UV water filtration system never make contact with the water. The lamps analysed in this report are housed in a sleeve inside the water chamber. The flow rate of the water is an important factor. If it is too high the UV lamps will not be able to work sufficiently, and a flow rate that is too low can lead to much heat building up and hurting the UV lamps. It is therefore critical to manipulate the flow rate to the most appropriate pace. [6]

If maintenance on the UV filter is due, the associated pump will be stopped, and another pump will be started. This pump sends water from the sump tank directly to the shark tank without using the UV filter and is called the bypass pump.

A yearly overhaul is carried out by an external company to maintain sufficient performance. A yearly report can be found in attachment 4.

4.1.5 Centrifugal Pumps

The main function of a centrifugal pump is to increase flow rate and/or pressure in a system. With the help of a motor transferring mechanical power to impellers, which accelerate the liquid to the output side of the pump. The input side of the pump will therefore work as the suction side and the output side will work as the pressure side. [13]

There are four centrifugal pumps in the purifying system. It is one pump for each sand filter, one that acts like a booster pump for the protein skimmer, and one before the intake side of the UV filter which also works as the return pump from the biofilter to the aquarium tank. These four pumps have vital roles in the system. Because there are two pumps working in parallel with the sand filters, these are not looked upon as critical as the two other ones. This is because if one of them fail, there will still be flow through the system and water will still be purified.

In order to provide some circulation to the water in the shark tank there are two submerged centrifugal pumps. However, these pumps will be neglected from the analysis in this report.

4.1.6 Miscellaneous

Pipes

All the pipes are made of plastic. This is advantageous because plastic is not susceptible to corrosion. In addition, the system pressure i relatively low, meaning that plastic pipes will be sufficient in terms of strength as well. Plastic pipes also have insulating properties, which reduces heat loss through the pipes. As the temperature of the process liquid (25 degrees Celsius) is higher than the temperature of the air surrounding the pipes (16-17 degrees Celsius) this is energy saving. Other advantages of plastic pipes are the fact that they are lighter and generally cheaper than metal pipes. [37]

Valves

All valves used in the system are manually operated gate valves. These valves will be excluded from the RCM because maintenance is expected to not be applicable in the lifetime of the system. Factors in the system like low pressures, saltwater as process liquid and mainly materials in plastics make maintenance on the valves redundant.

Sensors and Indicators

There are various sensors placed at different locations in the system. Sensors in the form of pressure, level and flow indicators are located throughout the system. These sensors are analogue and only designed for manual inspection of the parameters in the system. Three digital sensors are also present and assures more accurate readings. These are located in the UV filter, sump tank and the aquarium tank. The UV filter sensor reads power outage per square meter, while the sensors in the sump and aquarium tank reads temperature. Temperature is crucial for the life inside the tank to thrive.

4.1.7 Process Liquid

The process liquid of the RAS is saltwater at approximately 25 degrees Celsius. Pressures in the system are relatively low, about 1 bar. The water flowing from the shark tank and into the RAS contains unwanted sea/fish particles and other pollutants. By sending the water through the RAS these contaminants are removed and the water can be used again. Keeping the water around 25 degrees is important in order to give the fish and sharks a healthy environment. As mentioned earlier, this temperature is regulated by heating cables in the sump tank and a constant stream of seawater at 10 degrees celsius into the sump tank.

4.2 Historical information

There is limited access to historical data regarding the systems at “Akvariet i Bergen”. Therefore, parts of the data collection on the tropical shark tank have been done through interviews and conversations with experienced workers from “Akvariet i Bergen”. The following section will be based on a conversation with an employee from “Akvariet i Bergen” called Natalie Stenfeldt. There has been made several changes to the system since it was built in the spring of 2010. At first, the system contained an arrangement of ten circulation pumps, but this led to a high failure rate of the pumps. The solution was to change this setup with two bigger pumps at a more strategic location in the system to decrease the failure rate.

Another problem the system has experienced was regarding the control valve for the water temperature in the tank. At first, a magnetic valve was used to control the amount of seawater into the system. A problem that occurred was that the spring inside the magnetic valve started to corrode, which led to the valve being constantly open. Consequently, large amounts of cold seawater entered the system, which made the temperature too low. This problem was dealt with by replacing the magnetic valve with a manual valve that is set in a constant position, which leads to a continuous flow of cold water into the system. The reason why it is necessary to continuously pump seawater into the system, is because water is drained out of the system from the sump tank, sand filter and the protein skimmer as part of the recirculation process. It is also important to only bring in the required amount of seawater, so the heating cables in the sump tank are not working more than what is strictly necessary to keep the right temperature in the tank.

In order to portray the economic consequences of failures in the shark tank this report will refer to an earlier incident. New fish inside the tank introduced some diseases that made a big population of the fish sick. This cost around 600 000, - NOK. The cause of the incident was not operation and maintenance related, but the cost clearly shows the value of what is inside the tank.

Originally, the RAS of the shark tank had an ozone generator connected to the protein skimmer which was supposed to feed ozone into the protein skimmer to increase its efficiency. However, this ozone generator is no longer in use. “Akvariet i Bergen” have decided to remove it from the process. Accordingly, it will be excluded from the P&ID and RCM analysis in this report. The reason why the ozone generator was removed was that it proved to be a problematic component with a lot of errors. Even though there are benefits of having ozone in the system, the water cleaning process works fine without it. Ozone is toxic for human beings; therefore, it was unnecessary to risk exposure.

5. Results

5.1 Study preparations

In chapter 1 of this Bachelor thesis the project group has defined and clarified the objectives and scope of the analysis, as well as addressing the limitations and assumptions that has been made. The client ("Akvariet i Bergen") has provided some documents and general information on the RAS of the tropical shark tank. This information combined with on-site observations and research on the internet has been used in order to make a P&ID of the system. This is shown in figure **7**. Before starting to analyse the system, it was important that all the group members had a good understanding of the system. The communication between the group and the client has been effective. Any misunderstandings or confusions that have arisen during the work process have been clarified quickly.

5.2 System selection and definition

This analysis is defined at a system level, where the analysed system is the RAS of the tropical shark tank. This report will analyse the whole system; however, boundary conditions have been set to exclude some units from the analysis. These units are two circulation pumps and the seawater pump.

A system hierarchy has been made, showing what subcategories belong to the system as well as which parts of the subcategories are vulnerable maintenance wise. The parts and subcategories are also listed in the FMECA sheet. The system hierarchy is shown below in figure 13.

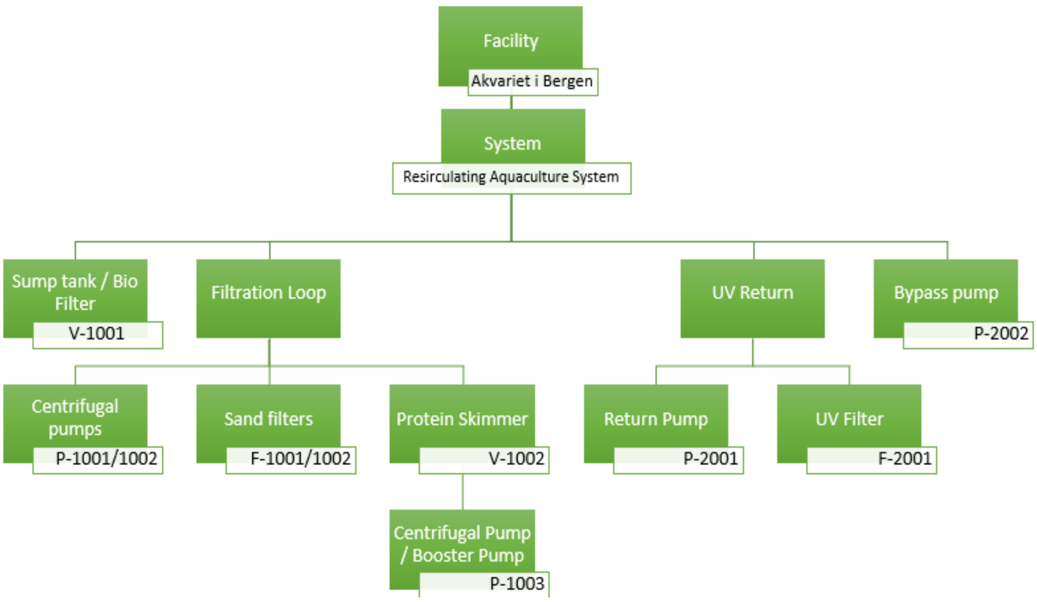

Figure 13: System hierarchy

5.3 Functional Failure Analysis (FFA)

Tag-nr	Unit	Subunit	Main Function	Main Function Failure	Secondary Function	Secondary Function Failure	Consequence for System			
							S	E	A	C
							Safety of personnel	Environmental impact	Production availability	Cost of material loss
F-1001/1002	Sand filters	Inlet pipe	Contain Fluid	Loss of containment	Flow through	No flow	L	L	L	L
		Outlet pipe	Contain Fluid	Loss of containment	Flow through	No flow	L	L	L	L
		Gaskets	Prevent leakage	Loss of containment			L	L	L	L
		Pre-filter	Rough filtration	No filtration	Flow through	No flow	L	L	L	L
		Casing	Contain Fluid	Loss of containment			L	L	M	H
		Filter media	Fine Filtration	No filtration	Flow through	No flow	L	L	M	M
		Diffuser	Evenly distribute fluid	Uneven distribution			L	L	L	L
		Pressure indicator	Messure pressure	Wrong messure			L	L	L	L
P-1001/1002	Centrifugal pumps	Power transmission	Transfer torque	No torque transfer			L	L	L	M
		Pump unit	Pump water	Fail to transfer fluid	Contain Fluid	Fail to contaiin fluid	L	L	L	M
		Lubrication system	Lubricate components	Fail to lubricate			L	L	L	M
V-1001	Biofilter	Outlet pipe	Contain Fluid	Loss of containment	Flow through	No flow	L	L	L	L
		Overflow	Contain Fluid	Loss of containment	Flow through	No flow	L	L	L	L
		Gaskets	Prevent leakage	Loss of containment			L	L	L	L
		Casing	Contain Liquid	Loss of containment			L	L	M	M
		Bio blocks	Biological filtration	No filtration	Flow through	No flow	L	L	M	L
		Pre-filter	Rough filtration	No filtration	Flow through	No flow	L	L	M	L
		Heating element	Heat liquid	Low temperature			L	L	M	L
		Temperature indicator/controller	Messure temperature	Wrong messure	Regulate temperature	Wrong temperature	L	L	L	L
		Temperature indicator on shark tank	Messure temperature	Wrong messure			L	L	L	L
F-2001	UV filter	Chamber	Contain Fluid	Loss of containment			L	L	M	M
		Lamps	Kill bacteria	Fail to kill bacteria			L	L	M	M
		Control unit	Start/stop on demand	Fail to start/stop on demand			L	L	M	M
		Sleeve	Protect lamps	Fail to protect lamps	Let light through	Not letting light through	L	L	M	M
		Inlet pipe	Contain Fluid	Loss of containment	Flow through	No flow	L	L	L	L
		Outlet pipe	Contain Fluid	Loss of containment	Flow through	No flow	L	L	L	L
		Gaskets	Prevent leakage	Loss of containment			L	L	L	L
		Electric power indicator	Messure UV effect	Wrong messure			L	L	M	L
		Pressure indicator	Messure pressure	Wrong messure			L	L	L	L
P-2001	Centrifugal pump	Power transmission	Transfer torque	No torque transfer			L	L	M	M
		Pump unit	Pump water	Fail to transfer fluid	Start/stop on demand	Fail to start/stop on demand	L	L	M	M
		Lubrication system	Lubricate components	Fail to lubricate			L	L	M	M
V-1002	Protein skimmer	Inlet pipe	Contain Fluid	Loss of containment	Flow through	No flow	L	L	L	L
		Outlet pipe	Contain Fluid	Loss of containment	Flow through	No flow	L	L	L	L
		Gaskets	Prevent leakage	Loss of containment			L	L	M	L
		Reaction tank	Contain Fluid	Loss of containment			L	L	H	H
		Foam Beaker	Collecting foam	Loss of containment			L	L	M	M
		Foam Tube	Feed foam into beaker	No flow	Contain Fluid	Loss of containment	L	L	M	M
		Internal/external rinsing nozzles	Clean beaker/tube	Insufficient cleaning			L	L	M	M
		Injector	Injects air	Not injecting air			L	L	M	L
		Level indicator	Show liquid level	Not showing level	Contain Fluid	Loss of containment	L	L	L	L
		Flow indicator	Measure flow rate	Not measure flow rate			L	L	L	L
P-1003	Centrifugal pump	Power transmission	Transfer torque	No torque transfer			L	L	M	M
		Pump unit	Pump water	Fail to transfer fluid	Start/stop on demand	Fail to start/stop on demand	L	L	M	M
		Lubrication system	Lubricate components	Fail to lubricate			L	L	M	M
P-2002	Bypass Centrifugal pump	Power transmission	Transfer torque	No torque transfer			L	L	L	M
		Pump unit	Pump water	Fail to transfer fluid	Start/stop on demand	Fail to start/stop on demand	L	L	L	M
		Lubrication system	Lubricate components	Fail to lubricate			L	L	L	M

Tabell 6: Functional Failure Analysis (FFA)

All items are considered to be “low” in the consequence categories “safety to personnel” and “environmental impact”. This is because the process liquid is seawater at 25 degrees and the pressures in the system are relatively low. Either the process media itself (saltwater) or the temperature and pressure are of harmful nature regarding humans or environment.

All inlet/outlet pipes and gaskets have been evaluated as “low” consequence for the system because they are cheap and fast to replace. There is however one exception: the gasket between foam beaker and reaction tank of the protein skimmer. The pumps in the system are evaluated differently. The most critical pumps for the system are located at the protein skimmer and UV filter. These are marked as medium consequence for the production availability, because no liquid will be transported to the other components without the pumps. The pumps connected to the sand filters are marked as low consequence for production availability because they work in parallel and aren't as critical as the others. The same goes for the bypass pump. This pump is only operating when maintenance is performed on the UV filter.

5.4 Critical Item Selection

In the criticality analysis in the FFA (Table 6), all the maintainable items were considered in order to identify the functional significant items (FSI). Information about the costs of maintenance activities, spare parts, lead times etc. are not available. Thus, this report will not classify any maintainable items as "maintenance cost significant items" (MCSI). Therefore, FSI will be considered equivalent to MSI in this report. It can be argued that all maintainable items should be included in the further analysis in FMECA, however some items have been excluded in this report because they have been considered less significant. Arguments for excluding some items can be to save time and money.

In this report the criteria for being a MSI is that the item have been given consequence level "medium" in at least two of the four categories (S, E, A and C) or "high" in one of the categories.

The following items will be excluded from further analysis in FMECA:

- All the inlet pipes, outlet pipes and gaskets.
- Centrifugal pumps for sand filters and bypass
- The pre-filter, diffuser, and pressure indicator in the sand filter.
- Overflow, bio blocks, pre-filter, heating element and temperature indicator/controller for the biofilter.
- Electrical power indicator and pressure indicator on UV filter
- Injector, level indicator and flow indicator on protein skimmer

The gasket between the foam beaker and the reaction tank on the protein skimmer have been included in the FMECA analysis even though it was not evaluated as an MSI in the FFA analysis. This is reasoned by personal on-site observations. Failure mode already existed, and it was a clear problem that needed further investigation. Miscellaneous

5.5 FMECA

					Effect of failure												
					Consequence Class				Risk class								
Unit	Subunit	Functions	Failure mode	Likelihood of Failure	S	E	A	C	S	E	A	C	Failure mechanism	Failure characteristic	Detection method	Maintenance action	Maintenance interval
Sand filters (F-1001 / 1002)	Casing	Contain Fluid	Leakage	N	L	L	M	H	L	L	L	L	Fatigue, stress-cracking, wear.	Gradual failure	Inspection	See chapter 5 for all	See chapter 5 for all
	Filter media	Fine Filtration, Flow through	Blockage	L	L	L	M	M	L	L	L	L	Fatigue, wear.	Gradual failure	Inspection		
Protein skimmer (V-1002)	Reaction tank	Contain Fluid	Leakage	L	L	L	H	H	L	L	M	M	Fatigue, stress-cracking, wear.	Gradual failure	Inspection		
	Gasket between foam beaker and reaction tank	Sealing connection	Leakage	H	L	L	M	L	L	L	H	L	Fatigue, corrosion, microbiological corrosion, wear.	Gradual failure	Inspection		
	Foam Beaker	Collecting foam	Leakage	L	L	L	M	M	L	L	L	L	Fatigue, stress-cracking, wear.	Gradual failure	Inspection		
	Foam Tube	Feed foam into beaker	Leakage	L	L	L	M	M	L	L	L	L	Fatigue, stress-cracking, wear.	Gradual failure	Inspection		
	Internal/external rinsing nozzles	Clean beaker/tube	Blockage	L	L	L	M	M	L	L	L	L	Fatigue, corrosion, wear.	Gradual failure	Test		
Centrifugal pumps (P-1003) [Protein Skimmer]	Power transmission	Transfer torque	Low output, vibration, overheating	L	L	L	M	M	L	L	L	L	Fatigue, corrosion, stress-cracking, wear.	Sudden failure	Test		
	Pump unit	Pump water	Low output, vibration, overheating	L	L	L	M	M	L	L	L	L	Corrosion, erosion, fatigue, stress-cracking, wear.	Gradual failure	Inspection		
	Lubrication system	Lubricate components	Leakage, friction, vibration, overheating	L	L	L	M	M	L	L	L	L	Fatigue, wear.	Gradual failure	Inspection		
Biofilter (V-1001)	Casing	Contain liquid	Leakage	N	L	L	M	M	L	L	L	L	Fatigue, stress-cracking, wear.	Gradual failure	Inspection		
UV filter (F-2001)	Chamber	Contain fluid	Leakage	L	L	L	M	M	L	L	L	L	Fatigue, stress-cracking, wear.	Gradual failure	Inspection		
	Lamps	Kill bacteria	Broken lamps	H	L	L	M	M	L	L	M	M	Stress-cracking, wear	Sudden failure / gradual failure	Inspection		
	Control unit	Start/stop on demand	Fail to start/stop on demand	L	L	L	M	M	L	L	L	L	Software bug, wear	Sudden failure / gradual failure	Test		
	Sleeve	Protect lamps	Broken lamps	L	L	L	M	M	L	L	L	L	Fatigue, stress-cracking, wear.	Gradual failure	Inspection		
Centrifugal pumps (P-2001) [UV filter]	Power transmission	Transfer torque	Low output, vibration, overheating	L	L	L	M	M	L	L	L	L	Wire corrosion, decaying cable	Sudden failure	Test		
	Pump unit	Pump water	Low output, vibration, overheating	L	L	L	M	M	L	L	L	L	Corrosion, erosion, fatigue, stress-cracking, wear.	Gradual failure	Inspection		
	Lubrication system	Lubricate components	Leakage, friction, vibration, overheating	L	L	L	M	M	L	L	L	L	Fatigue, wear.	Gradual failure	Inspection		

Tabell 7: Failure Mode, Effects and Criticality Analysis (FMECA)

See attachment 5 for larger format

5.6 Selection of Maintenance Actions

The suggested maintenance actions in this report are based on the decision tree shown below.

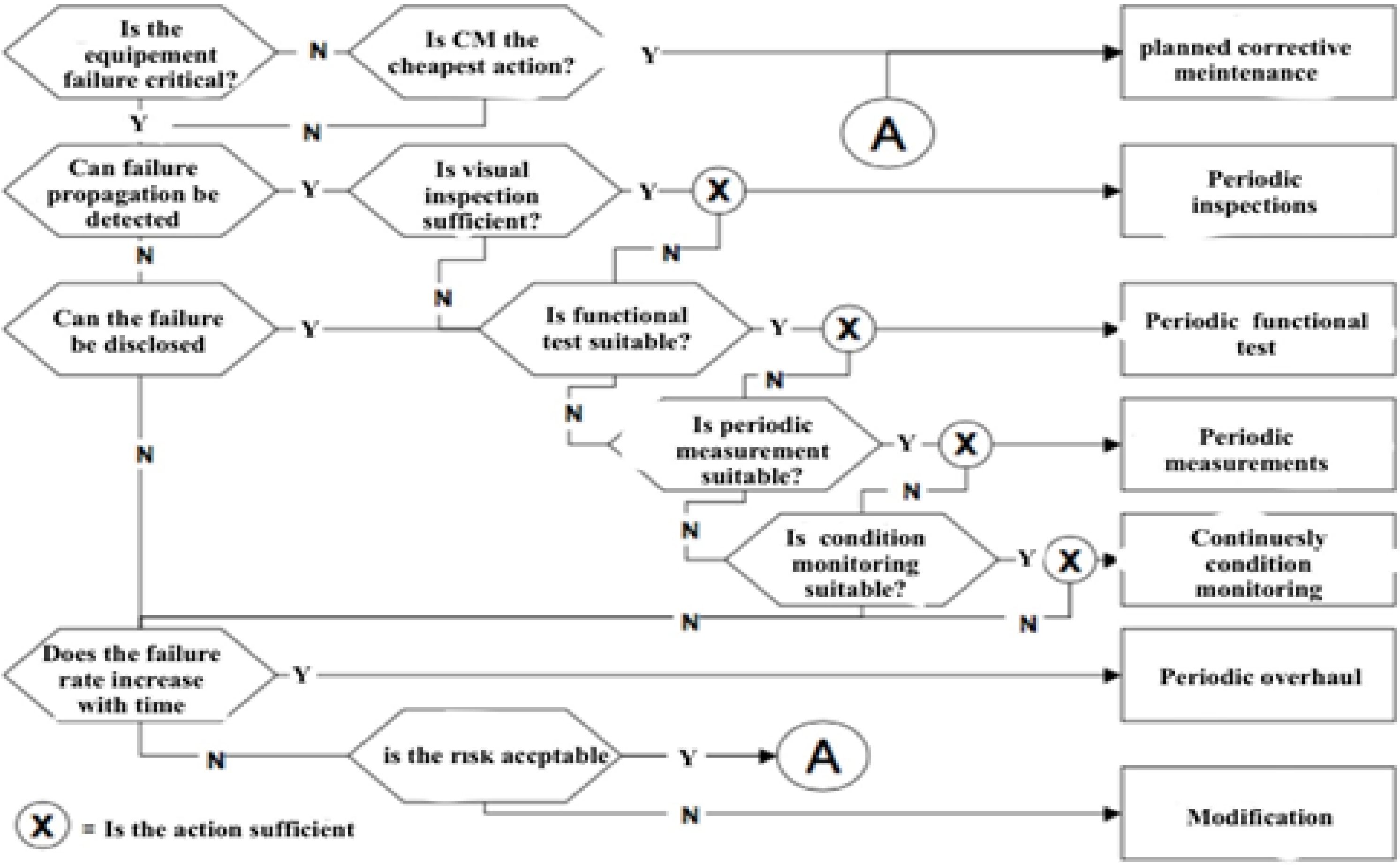

Figure 14: Maintenance actions [47]

Unit	Subunit	Maintenance action	Specific action
Sand filter	Casing	Periodic inspections	Visual inspection of the external surface
	Filter media	Periodic inspections	Visual inspection of the gauge pressure
Centrifugal pumps P-2001/P-1003	Power transmission	Functional test	Functional test
	Pump unit	Periodic overhaul	Visual inspection of deviations

	Lubrication system	Periodic inspection	Visual inspection of oil level
Protein skimmer	Reaction tank	Periodic inspections	Visual inspection of the external surface.
	Gasket between foam beaker and reaction tank	Periodic inspections	Visual inspection of surface
	Foam beaker	Periodic overhaul	Inspect and do necessary manual rinsing
	Foam tube	Periodic overhaul	Inspect and do necessary manual rinsing
	Internal/external rinsing nozzles	Functional test	Functional test
Biofilter	Casing	Periodic inspections	Visual inspection of the external surface
UV filter	Chamber	Periodic overhaul	Visual inspection of surface and cleaning
	Lamps	Periodic overhaul	Change of faulty lamps or cleaning
	Control unit	Periodic overhaul	Start/stop
	Sleeve	Periodic overhaul	Visual inspection and cleaning

Tabell 8:Selection of maintenance actions

5.7 Determination of Maintenance Intervals

The maintenance intervals in the following table are based on the OREDA Database [8]. Each unit consists of subunits, and the subunits are divided into maintainable items. This report will not focus on the lowest level of maintainable items because of limited access to data and information about the system.

The percentages referred to in the column "Maintenance interval" for the centrifugal pump is gathered from the table on page 149-150 in the OREDA Database. This table shows how the different failure modes are connected to the different maintainable items and the probability that one maintainable item has caused a complete failure of the whole centrifugal pump. The OREDA Database contains detailed information about centrifugal pumps. Therefore, it will be possible to make more accurate calculations for centrifugal pumps than for the other units. These calculations are done by adding together statistical data from applicable maintainable items in the OREDA Database. This will improve the reasoning behind the recommended maintenance interval for the different subunits in the table below.

To determine suitable maintenance intervals for the other units, prior work in the field and recommendations from our supervisor has been used as inspiration to make as accurate assumptions as possible.

Unit	Subunit	Maintenance Interval
Sand filter	Casing	Every 10th year, because glass fiber has a long lifetime in seawater. [38]
	Filter media	Every day. Because according to [14], it is recommended to backwash every 24 hours. It is an easy procedure and too high pressure can damage the sand filter.
Centrifugal pumps P-2001/P-1003	Power transmission	Every 15th month. Because according to OREDA [8, p. 149-150] database, 24.77% of all failures of the pump are due to the power transmission.

	Pump unit	Every 12th month. Because according to OREDA [8, p. 149-150] database, 45.8% of all failures of the pump are due to the pump unit.
	Lubrication system	Every week, because its and easy task and failure can lead to friction in pump. According to OREDA [8, p. 149-150] database, 40.5% of all failures of the pump are due to the lubrication system.
Protein skimmer	Reaction tank	Every 10th year because polypropylene have a long lifetime in seawater. [39]
	Gasket between foam beaker and reaction tank	Every 5th year, because of knowledge of the current gasket and its state.
	Foam Beaker	Every 7th year because they mainly contain seawater and is not too vulnerable to defects.
	Foam Tube	Every 7th year because they mainly contain seawater and is not too vulnerable to defects.
	Internal/external rinsing nozzles	Every year because they are important for the protein skimmer to fully function.
Biofilter	Casing	Every 10th year, because concrete material combined with seawater has a long lifetime. [15]
UV filter	Chamber	Every year, because this is included in the yearly overhaul of the UV filter from external company.

	Lamps	Every year, because this is included in the yearly overhaul of the UV filter from external company.
	Control unit	Every year, because this is included in the yearly overhaul of the UV filter from external company.
	Sleeve	Every year, because this is included in the yearly overhaul of the UV filter from external company.

Tabell 9: Determination of maintenance interval

5.8 Preventive Maintenance Comparison Analysis

Unit	Subunit	PM task	Effective?	Result
Sand filter	Casing	Visual inspection of the external surface	**Yes**, does not require a lot of resources	PM task selected
	Filter media	Visual inspection of the gauge pressure	**Yes**, does not require a lot of resources	PM task selected
Centrifugal pumps P-2001/P-1003	Power transmission	Functional test	**Yes**, easy routine, if not executed it can lead to negative impacts regarding economy and performance	PM task selected
	Pump unit	Visual inspection of deviations on	**Yes**, small amount of work for extending the lifetime of the pump,	PM task selected

		the external surface	but it will not prevent a sudden failure of a part	
	Lubrication system	Visual inspection of oil level	**Yes,** easy routine. Can be implemented to weekly routines	PM task selected
Protein skimmer	Reaction tank	Visual inspection of the external surface	**Yes**, does not require a lot of resources	PM task selected
	Gasket between foam beaker and reaction tank	Visual inspection of surface	**No**, because it is difficult to detect the onset of a failure and the PM task is a comprehensive process which requires dismantling protein skimmer	PM task **not** selected
	Foam Beaker	Inspect and do necessary manual rinsing	**Yes,** but since it requires dismantling of skimmer, it is recommended to do in combination with change of gasket	PM task selected
	Foam Tube	Inspect and do necessary manual rinsing	**Yes,** but since it requires dismantling of skimmer, it is recommended to do in combination with change of gasket	PM task selected

	Internal/external rinsing nozzles	Functional test	**Yes**, easy routine, if not executed it can lead to negative impacts regarding the economy and performance of the protein skimmer	PM task selected
Biofilter	Casing	Visual inspection of the external surface	**Yes**, inspection is a easy routine	PM task selected
UV filter	Chamber	Visual of inspection of surface and cleaning	**Yes**, current procedures are effective	PM task selected
	Lamps	Change of faulty lamps or cleaning	**Yes**, current procedures are effective	PM task selected
	Control unit	Start/stop	**Yes**, current procedures are effective	PM task selected
	Sleeve	Visual of inspection and cleaning	**Yes**, current procedures are effective	PM task selected

Tabell 10: Preventive Maintenance Comparison Analysis

5.9 Treatment of non-critical items

In the FFA it was decided if a maintainable item was critical or not. In this part of the report a recommendation on how to maintain the non-critical items will be presented.

Miscellaneous

- Inlet/outlet pipes: Corrective maintenance
- Gaskets: Corrective maintenance

Centrifugal pumps

- Sand filter pumps: Corrective maintenance
- Bypass pump: Corrective maintenance

Sand filter

- Pre-filter: Corrective maintenance
- Diffuser: Backwashing
- Pressure indicator: Corrective maintenance

Biofilter

- Overflow: Periodic inspection
- Bio blocks: Periodic inspection
- Pre-filter: Corrective maintenance
- Heating element: Corrective maintenance
- Temperature indicator/controller: Corrective maintenance
- Temperature indicator on shark tank: Corrective maintenance

UV filter

- Electrical power indicator: Corrective maintenance
- Pressure indicator: Corrective maintenance

Protein skimmer

- Injector: Corrective maintenance
- Level indicator: Corrective maintenance
- Flow indicator: Corrective maintenance

5.10 Implementation

"Akvariet i Bergen" have provided information about the expected lifetime of the aquarium. The aquarium has a expected lifetime equal to about 10 years. The Shark tunnel opened the spring of 2010, which means a total expected lifetime of around 20 years. Based on on-site inspection and observations of the system there are a few maintenance actions "Akvariet i Bergen" should do in order to keep the system going for ten more years. One of these actions is to replace the gasket between the foam beaker and the reaction tank on the protein skimmer as soon as possible. The current gasket is close to total failure, which can lead to a critical leakage in the protein skimmer at any time. In order to access the gasket, it is necessary to take apart the flange, which means taking off the upper part of the protein skimmer. This can be a comprehensive process and is not frequently done to big protein skimmers like in this system. "Akvariet i Bergen" can use this as an opportunity to perform other maintenance activities that require taking apart the protein skimmer. This applies for a manual wash of the foam beaker and the foam tube. This process is not demanding and can be crucial for the protein skimmer to be able to last for 10 more years.

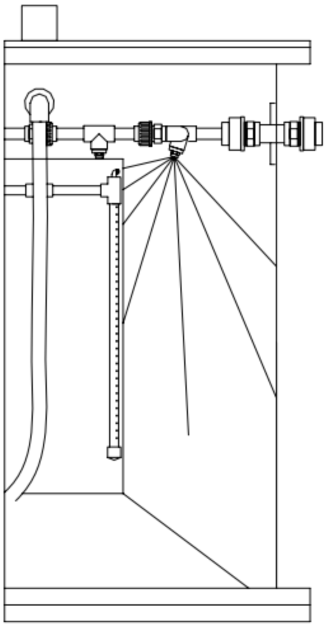

Figure 15: External rinsing system [17]

5.11 In-service data collection and updating

The current system "Akvariet i Bergen" uses to collect data is basic. Logging papers printed out and manually written on is the standard. A new digital system is being implemented in order to log data using tablets and a digital database. This new system is currently under development.

6. Discussion

6.1 Maintenance program

Unit	Subunit	Why	How	Where	Who	When
Sand filter	Casing	Fatigue, stress-cracking, wear.	Periodic inspections	On site	Maintenance worker	Every 10th year
	Filter media	Fatigue, wear	Periodic inspections	On site	Maintenance worker	Every day
Centrifugal pumps P-2001/ P-1003	Power transmission	Fatigue, corrosion, stress-cracking, wear.	Functional test	On site	Maintenance worker	Every 15th month
	Pump unit	Corrosion, erosion, fatigue, stress-cracking, wear.	Periodic overhaul	On site	Maintenance worker	Every 12th month
	Lubrication system	Fatigue, wear.	Periodic inspections	On site	Maintenance worker	Every week
Protein skimmer	Reaction tank	Fatigue, stress-cracking, wear.	Periodic inspections	On site	Maintenance worker	Every 10th year
	Gasket between foam beaker and reaction tank	Fatigue, corrosion, microbiological corrosion, wear.	Periodic inspections	On site	Maintenance worker	Every 5th year
	Foam Beaker	Fatigue, stress-cracking, wear.	Periodic overhaul	On site	Maintenance worker	Every 7th year.
	Foam Tube	Fatigue, stress-cracking, wear.	Periodic overhaul	On site	Maintenance worker	Every 7th year

	Internal/external rinsing nozzles	Fatigue, corrosion, wear.	Functional test	On site	Maintenance worker	Every year
Biofilter	Casing	Fatigue, stress-cracking, wear.	Periodic inspections	On site	Maintenance worker	Every 10th year
UV filter	Chamber	Fatigue, stress-cracking, wear.	Periodic overhaul	On site	External company	Every year
	Lamps	Stress-cracking, wear.	Periodic overhaul	On site	External company	Every year
	Control unit	Software bug, wear.	Periodic overhaul	On site	External company	Every year
	Sleeve	Fatigue, stress-cracking, wear.	Periodic overhaul	On site	External company	Every year

Tabell 11: Maintenance program

6.2 Implementation of Industry 4.0

This subchapter will analyse how to potentially implement predictive maintenance to the new aquarium using principles from Industry 4.0 and what level of predictive maintenance is most appropriate to implement for "Akvariet i Bergen".

Predictive maintenance is often mentioned in relation to the production industry, where the goal is to optimise production in terms of products. "Akvariet i Bergen" is not producing products directly, but it is possible to apply some of the same principles to the aquarium industry. This can be justified by looking at "Akvariet i Bergen" as a company who is producing clean water for the species living in the shark tank. In that case, it is desirable to optimise the production of the clean water, and this can be done with the use of predictive maintenance. However, "Akvariet i Bergen" need to make a thorough analysis and evaluation of whether it is profitable or beneficial to implement predictive maintenance to their new aquarium or not.

It can be a time-consuming and difficult process to properly implement predictive maintenance. According to "Predictive Maintenance for Industry 4.0 | Complete Guide" [33] this should be done in the following way: "To implement a predictive maintenance system effectively, manufacturers need to map the parameters of failure for machines and create a blueprint for their connected system – the manufacturing assets and sensors, business systems, communication protocols, gateways, cloud, predictive analytics, and visualisation”. Engineers can capture the production processes in a company using an IoT modeler. This modeler includes data flows, dashboards, the logic of the system and a set of rules that monitor and alert maintenance issues. The modeler provides a system blueprint, which is extremely important for accurate predictive analytics. [33]

Machine learning use predictive analytics and the system blueprint to predict potential upcoming failures. A dashboard for predictive analytics then unites operational data, which makes it possible for engineers to use this insight to take the right corrective action. [33]

Chapter 2.2.4 Using Industry 4.0 for Predictive Maintenance addressed that there are different approaches of implementing predictive maintenance, which affect the cost of the implementation. This is an important factor to include in the analysis and evaluation regarding whether or not it is profitable and beneficial for “Akvariet i Bergen” to implement predictive maintenance. There is a huge difference between investing in a rule-based and a machine learning-based predictive maintenance system. The machine learning-based approach demands way more advanced machines and software to fully function. Accordingly, this investment would be considerably larger. "Predictive Maintenance for Industry 4.0 | Complete Guide" [33] describes the rule-based approach as follows: “Rule-based predictive maintenance is achievable, affordable, and delivers measurable business benefits. The easiest way to get started is with an industrial IoT platform centred on a rule-based model, which enables teams to quickly define, simulate and deploy a predictive maintenance solution for their products”. Another benefit with the rule-based approach is that manufacturers do not need large sets of historical data, which “Akvariet i Bergen” is lacking. One possible option for “Akvariet i Bergen” is to start with a rule-based model and later upgrade to a machine learning model when it is appropriate. [33]

An IoT predictive maintenance system is dependent on skilled workers. According to Trout [35], a lot of companies lack internal skilled personnel. If “Akvariet i Bergen” can combine the rule-based model with skilled personnel, it would be easier to further develop the system at a later stage.

This report will provide a qualitative analysis and evaluation due to the lack of data. However, this will hopefully illuminate important aspects which “Akvariet i Bergen” can turn into a more detailed quantitative analysis with the access to important data.

6.2.1 Advantages/Disadvantages

Implementing predictive maintenance using Industry 4.0 to the new aquarium can initially be a comprehensive process requiring a lot of resources. New sensors, complex IT systems and digitally educated employees are some of the requirements for implementing the new system.

Listed below are some advantages and disadvantages for implementing the new system. This table is based on “Near-zero downtime: Overview and trends" [28] and "Six benefits of Industrie 4.0 for businesses" [23].

Advantage	Disadvantage
Less downtime Value: medium	Invest in IT systems Value: high
More efficient operations Value: high	Vulnerable to cyberattacks Value: medium
Better working conditions Value: medium	Invest in new sensors Value: low
Increased equipment reliability (lower risk for fish) Value: medium	Educate employees Value: medium
Easy to adapt for new systems Value: high	

Tabell 12: Advantages and disadvantages

As shown in table 12, the initial cost of the system installation will be high. A new IT system that will be able to communicate with sensors and make predictions of failure will have to be installed. Employees would also have to be trained and educated in using the new system. What makes up for these disadvantages is that it leads to more cost-effective and efficient maintenance, better working conditions and decreased risk to the fish in the aquarium. [30]

Predictive maintenance can reduce unexpected downtime and operating costs, by increasing equipment reliability and improve information for planning. However, the initial investment of establishing predictive maintenance is often higher than preventive maintenance because of factors like additional monitoring hardware and software investing. [28], [30]

In addition, cyberattacks and hacking needs to be attended properly to ensure the safety of the system, environment and the people around it. One example is the cyberattack on Hydro which occurred in March 2019. This attack affected the entire global organisation and caused large organisational challenges and financial losses estimated to be in the range 550-650 million NOK. It is therefore important to focus on cyber security and invest in cyber insurance with recognised insurers. [41]

“Akvariet i Bergen” have provided information about the expected lifetime of the facility. The aquarium opened in 1960 and it is expected to last about ten more years. This equals to a total lifetime of 70 years. It is therefore reasonable to assume that the new aquarium is going to last for around 100 years, because of access to better technology. According to the former director of “Akvariet i Bergen” Geir Olav Melingen [27], the new Aquarium is expected to cost around 1 billion NOK. Even though this is a high initial investment cost, it is possible to implement smart solutions regarding operation and maintenance systems which can save costs and increase efficiency over a lifetime of 100 years.

The implementation of predictive maintenance with inspiration from Industry 4.0 will also be a significant investment, but it will be small compared to the cost of building the whole aquarium. One argument for implementing predictive maintenance to the new aquarium is that when you start building a whole new facility, you might as well use this as an opportunity to implement this futuristic maintenance solution. Another argument for implementing predictive maintenance is that considering the long lifetime of the facility, a smart maintenance solution like this could reduce the maintenance costs markedly, making it a profitable investment over time.

Peycheva [30] describes how predictive maintenance (PdM) can save costs in the following way. "Although setting up all resources for a PdM program might be expensive, this is a cost-efficient strategy in a long-term perspective, reducing total time and cost spent on equipment maintenance". When talking about the new aquarium, it is logical to think in a long-term perspective. According to Peycheva [30], PdM is a cost-efficient strategy in a long-term perspective. This is promising for the new aquarium, which is expected to have a long lifetime.

Figure 16 shows how the predictive maintenance market has grown over the last couple of years, and that it is expected to grow further in the years to come. This shows that more companies are investing in predictive maintenance, and that this will most likely be the future within maintenance.

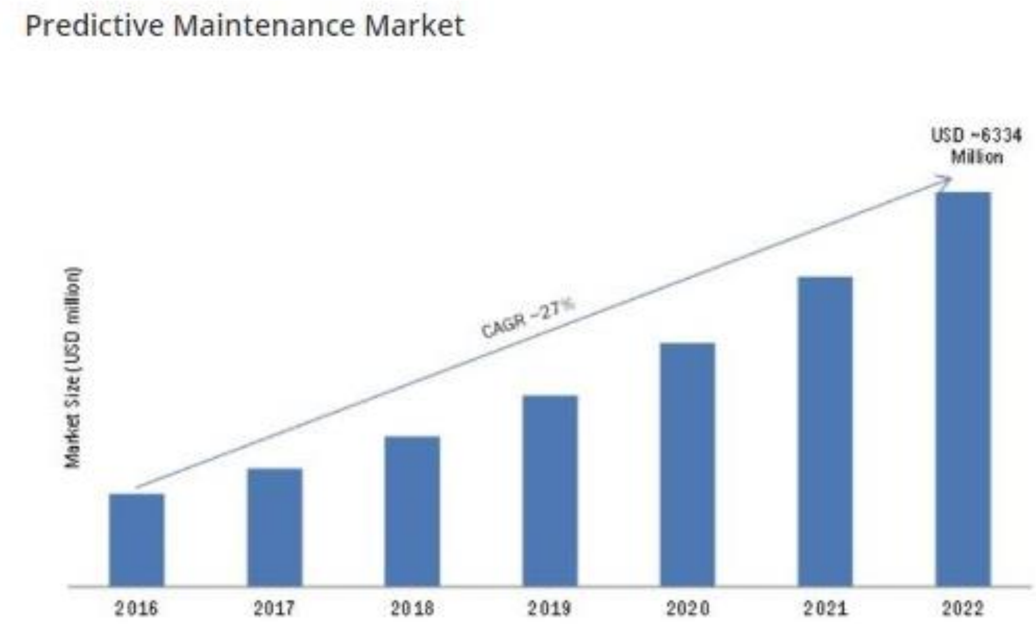

Figure 16: Predictive maintenance diagram [32]

6.2.2 Recommendation

The different sections in this report regarding Industry 4.0 have illuminated how predictive maintenance with the use of Industry 4.0 can be implemented, different approaches and levels to it, and finally advantages and disadvantages related to it. Based on these sections, this report will provide a recommendation on whether or not "Akvariet i Bergen" should implement predictive maintenance to the new aquarium or not.

Based on the previously written benefits regarding the rule-based predictive maintenance approach, this report recommends “Akvariet i Bergen” to implement this solution to the new aquarium. This is justified by the fact that it does not require as advanced software and machines as the machine learning-based approach, which makes it a much more affordable option. Even though it is a smaller investment than the machine learning-based approach, one can expect great results. [33]

"Predictive Maintenance for Industry 4.0 | Complete Guide" [33] describes how companies implementing predictive maintenance for the first time should to it in the following way: “But for companies implementing a connected system for the first time, with the ultimate goal of implementing machine learning and AI for predictive maintenance, a pragmatic way to get started with Industry 4.0 predictive maintenance is rule-based predictive maintenance”. This is exactly what this report recommends “Akvariet i Bergen” to do. Once you have implemented the rule-based model together with skilled personnel, is easier to take this to the next level at a later stage and introduce artificial intelligence and machine learning. Another advantage of the rule-based approach is that it is not dependent on large amounts of historical data, which “Akvariet i Bergen” is lacking. [33]

This chapter will hopefully give “Akvariet i Bergen” relevant insights to predictive maintenance and Industry 4.0 and be helpful when deciding on what kind of maintenance they should implement to the new aquarium.

6.3 Digital maintenance system

A possible idea “Akvariet i Bergen” should investigate further is creating a digital maintenance logging program in Excel with the use of simple programming in Python. “Akvariet i Bergen” provided the group with information regarding a current implementation of a new digital logging program delivered from an outsourced IT company. It was desirable to see the content of this program and how comprehensive it is, in order to deliver an appropriate recommendation that is useful for “Akvariet i Bergen”. The draft of this digital program was never presented, which led to a more general recommendation. However, it is reasonable to believe that this program would only be a generic digital data logging system using programming.

With this in mind, one could clearly see the potential for transferring the maintenance program in section 6.1 into a digital system in Excel with the use of programming in Python. This would make the program tailored to “Akvariet i Bergen”, which automatically would tell how often to do maintenance and what kind of maintenance is needed. The key here is to combine the unique knowledge of the system with expertise within maintenance and RCM into a more advanced preventive maintenance program with the use of Excel and programming in Python.

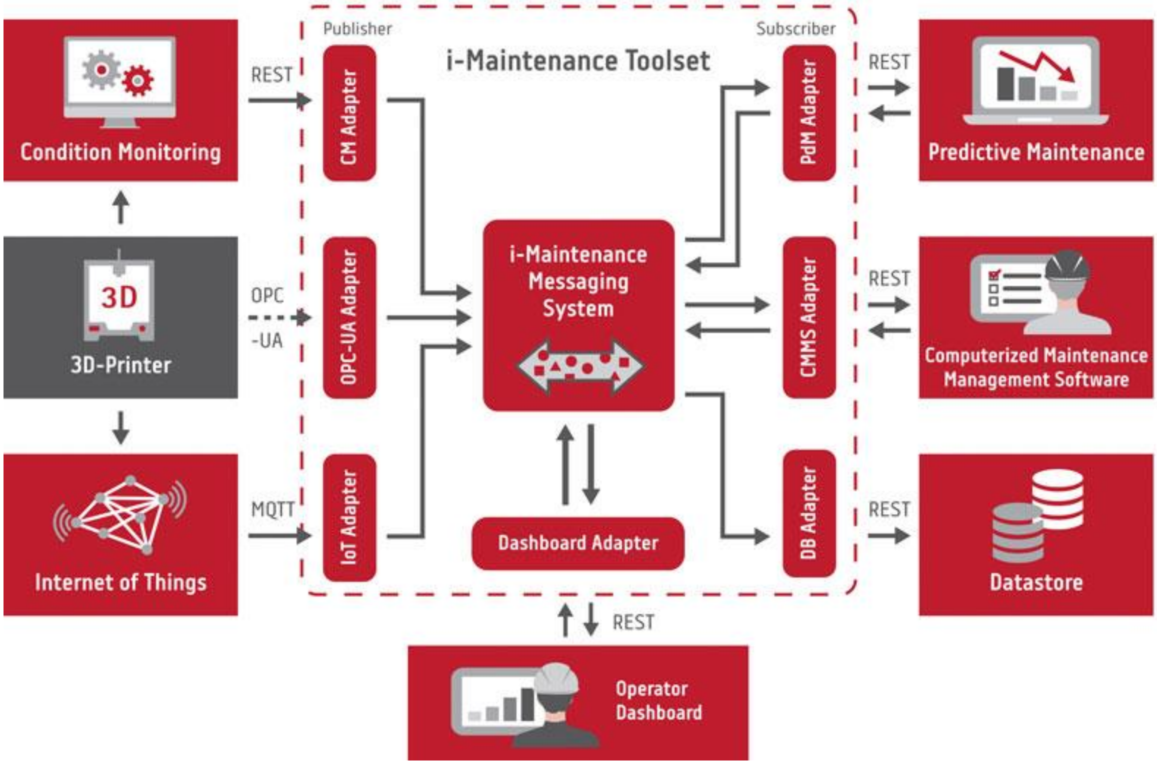

Figure 17: Integrated maintenance system [46]

It is therefore recommended that “Akvariet i Bergen” gathers a workgroup as soon as possible to make this happen. This workgroup should consist of an employee of “Akvariet i Bergen” who possesses thorough information about the system, a consultant with expertise within operation and maintenance and RCM and a consultant with expertise within programming. It is reasonable to believe that this solution will optimise the operation and maintenance of the RAS of the tropical shark tank and greatly benefit “Akvariet i Bergen” for the remaining lifetime of the system. If this turns out to be right, this can easily be implemented to the other systems of the aquarium as well.

If implemented, this solution will be a small investment compared to another solution that this report discussed in the section “6.3 Industry 4.0” regarding the new aquarium. This is because the recommended maintenance solution will not rely on expensive factors like advanced software and internet of things (IoT). It has been assessed not economically justifiable for “Akvariet i

Bergen" to invest in advanced software for condition monitoring in the current system, because of the short-expected lifetime the facility has left. However, the recommended maintenance solution listed in the previous paragraph will be a big step towards Industry 4.0 and predictive maintenance with the use of minimal resources.

7. Conclusion

A comprehensive analysis of the operation and maintenance procedures has been completed with the use of RCM, applying a combination of qualitative and quantitative decision making. Critical items have been selected and analysed. This resulted in a maintenance program including maintenance intervals and whether or not preventive maintenance was applicable for certain components.

This report recommends “Akvariet i Bergen” to gather a workgroup as soon as possible to create a tailored digital maintenance logging system. Extensive research of Industry 4.0 and the applicability of this technology for the new aquarium has also been conducted.

A piping and instrumentation diagram (P&ID) has been made of the recirculating aquaculture system (RAS). This improves the system understanding and is one of the main deliverables of this report besides the operation and maintenance analysis.

Some actions and implementations should be considered to execute or continue to analyse further upon. The following proposals should be taken into consideration:

- Implement the maintenance program from results
- Physically add the assigned tag numbers to components in the system
- Further improve the analysis with more quantitative data from the system if possible
- Change gasket between reaction tank and foam beaker in protein skimmer and clean the inside of the skimmer
- Conduct further research of Industry 4.0 and predictive maintenance (for the new aquarium)
- A rule-based approach of predictive maintenance should be implemented to the new aquarium

“Akvariet i Bergen” should continue the research done on Industry 4.0 to look at the possibilities for implementing predictive maintenance to the new aquarium. However, at this point in time “Akvariet i Bergen” is recommended to implement a rule-based approach of predictive maintenance to the new aquarium in order to obtain a cost-effective maintenance solution for the next century.

References

[1] Instruction and Operational Manual https://www.astralpool.com/en/products/swimming-pool/filters/sand-filters-5/bobbin-wound-filters-4/vic-filter-2/ [Online]. Available: https://gestor-doc-s3.s3.eu-west-1.amazonaws.com/documents/category/MAN10_filtro_industrial_polt_AP_00545E200-00-.pdf [Accessed: 29- Jan- 2020].

[2] A. Bergen, "Om Akvariet i Bergen", Akvariet.no, 2020. [Online]. Available: https://www.akvariet.no/informasjon/om-akvariet/om-akvariet/ [Accessed: 06- Feb-2020].

[3] Bergen.kommune.no, 2020. [Online]. Available: https://www.bergen.kommune.no/politikere-utvalg/api/fil/1980062/Innstilling-vedtak-Dokken-Jekteviken-oppstart-av-transformasjon-til-ny-bydel- [Accessed: 06- Feb-2020].

[4] E. Johansen, "Akvariet vil bli et verdenshav i Bergen", Nordnesrepublikken.no, 2020. [Online]. Available: https://nordnesrepublikken.no/2019/05/29/akvariet-vil-pa-dokken-sammen-med-hi/ [Accessed: 06- Feb- 2020]

[5] R. Ravnå og P. Schjølberg, Industry 4.0 and Maintenance, Norsk forening for Vedlikehold, 2016. Available: https://www.nfv.no/images/Temahefter/Industry_4_0_and_Maintenance-revised_-_27.10.16.pdf [Accessed: 25- Mar- 2020].

[6] "What Does a UV Water Filter Do and How Do They Work?", Filterbutler.com, 2020. [Online]. Available: http://filterbutler.com/blog/what-does-a-uv-water-filter-do-and-how-do-they-work/ [Accessed: 02- Mar- 2020].

[7] "More details", OREDA, 2020. [Online]. Available: https://www.oreda.com/more-details/ [Accessed: 11- Mar- 2020].

[8] OREDA (2009).: Offshore Reliability Data.5.ed. Volume 1-Topside equipment, SINTEF.

[9] M. Rausand, *Reliability centered maintenance*. Northern Ireland: Elsevier, 1998, pp. 121-132.

[10] M. Rausand and A. Høyland, *System Reliability Theory*. Hoboken: Wiley-Blackwell, 2004.

[11] Durgananda Singh Chaudhary, Saravanamuthu Vigneswaran, Huu-Hao Ngo, Wang Geun Shim, and Hee Moon. (2007). Biofilter in Water and Wastewater Treatment. Available from: https://link.springer.com/content/pdf/10.1007/BF02706936.pdf [Accessed: 11- Feb- 2020].

[12] Louis A. Helfrich and George Libey. (1991). Fish farming in recirculating aquaculture systems (RAS). Available from:

https://pdfs.semanticscholar.org/80d4/2a4cc5dfd309b2aadac4e38b0f13fa6e13d0.pdf [Accessed: 11- Feb- 2020].

[13] O. Moniz and P. Girdhar, Practical Centrifugal Pumps: Design, Operation and Maintenance (Practical professional books from Elsevier). Burlington: Elsevier, 2005.

[14] Rain bird,"Sand Media Filter Installation Manual", 2020. [Online]. Available: https://ww3.rainbird.com/documents/turf/man_SandMediaFilter.pdf [Accessed: 02- Mar- 2020].

[15] Sosa, M., Pérez-López, T., Reyes, J., Corvo, F., Camacho-Chab, R., Quintana, P., & Aguilar, D., "Influence of the Marine Environment on Reinforced Concrete Degradation Depending on Exposure Conditions", International Journal of ELECTROCHEMICAL SCIENCE, vol. 6, 2011. Available: http://www.electrochemsci.org/papers/vol6/6126300.pdf [Accessed: 02- Mar- 2020].

[16] "Sander Aquarium Systems", Aqua-sander.de, 2020. [Online]. Available: https://www.aqua-sander.de/fileadmin/downloads/kataloge/en/Sander-Catalogue-Protein-Skimmers-EN-20121006-Web.pdf [Accessed: 02- Mar- 2020].

[17] Erwin Sander Elektroapparatebau GmbH, "Manual - Water Treatment System," Unit No: 2218, May 2009

[18] "AFM - aktivert filtermedie (overlegne filteregenskaper)", Enwa, 2020. [Online]. Available: https://www.enwa.no/enwa-badeanlegg/produkter/alle-produkter/renseteknikk-og-renseanlegg/filter/afm-aktivert-filtermedie [Accessed: 02- Mar- 2020].

[19] "Pool Supplies | Family Leisure", Familyleisure.com, 2020. [Online]. Available: https://www.familyleisure.com/Discount-Pool-Supplies [Accessed: 02- Mar- 2020].

[20] C. Roser, "A critical look on Industry 4.0 | AllAboutLean.com", AllAboutLean.com, 2015. [Online]. Available: https://www.allaboutlean.com/industry-4-0/ [Accessed: 03- Mar- 2020].

[21] M. Burgess, "What is the Internet of Things? WIRED explains", Wired.co.uk, 2020. [Online]. Available: https://www.wired.co.uk/article/internet-of-things-what-is-explained-iot [Accessed: 03- Mar- 2020].

[22] "Hva er egentlig Industri 4.0?", Innovasjonsbloggen, 2020. [Online]. Available: https://innovasjonsbloggen.com/2015/10/22/hva-er-egentlig-industri-4-0/ [Accessed: 03- Mar- 2020].

[23] "Six benefits of Industrie 4.0 for businesses", Control Engineering, 2020. [Online]. Available: https://www.controleng.com/articles/six-benefits-of-industrie-4-0-for-businesses/ [Accessed: 03- Mar- 2020].

[24] "How Predictive Maintenance Fits into Industry 4.0", Engineering.com, 2020. [Online]. Available: https://www.engineering.com/AdvancedManufacturing/ArticleID/15798/How-Predictive-Maintenance-Fits-into-Industry-40.aspx [Accessed: 03- Mar- 2020].

[25] Maintenance terminology. [London]: [British Standards Institution], 2010.

[26] O. Dalland, Metode og oppgaveskriving. Oslo: Gyldendal akademisk, 2017.

[27] A. Edvardsen, "Vil bruke én milliard på nytt «isfjell»-signalbygg", Aftenposten, 2018. [Online]. Available: https://www.aftenposten.no/norge/i/J1BQab/akvariet-i-bergen-vil-flytte-og-bygge-isfjell-pris-en-milliard-kroner [Accessed: 04- Mar- 2020].

[28] “Near-zero downtime: Overview and trends", Reliableplant.com, 2020. [Online]. Available: https://www.reliableplant.com/Read/6971/downtime-trends [Accessed: 06-Mar- 2020].

[29] K. Wang, Y. Wang, J. Strandhagen and T. Yu, *Advanced manufacturing and automation V*.

[30] R. Peycheva, "Predictive Maintenance: Expensive, but Worth It", *Mobility Work*, 2016. [Online]. Available: https://www.mobility-work.com/blog/predictive-maintenance-expensive-but-worth-it [Accessed: 11- Mar- 2020].

[31] B. Christiansen, "A Complete Guide To Predictive Maintenance", *The Ins and Outs of Maintenance*, 2019. [Online]. Available: https://limblecmms.com/blog/predictive-maintenance/ [Accessed: 11- Mar- 2020].

[32] "Predictive Maintenance Market by Component, Type, Growth and Forecast – 2024 | MRFR", *Marketresearchfuture.com*, 2020. [Online]. Available: https://www.marketresearchfuture.com/reports/predictive-maintenance-market-2377. [Accessed: 11- Mar- 2020].

[33] "Predictive Maintenance for Industry 4.0 | Complete Guide", *Seebo*, 2020. [Online]. Available: https://www.seebo.com/predictive-maintenance/ [Accessed: 19- Mar- 2020].

[34] B. Marr, "What Is The Difference Between Artificial Intelligence And Machine Learning?", *Forbes*, 2016. [Online]. Available: https://www.forbes.com/sites/bernardmarr/2016/12/06/what-is-the-difference-between-artificial-intelligence-and-machine-learning/#53b4c2de2742 [Accessed: 19- Mar- 2020].

[35] J. Trout, "While Predictive/Preventive Maintenance Is Still King, Maintenance Personnel Are Reluctant to Use Internet-based Maintenance", *Reliableplant.com*, 2019. [Online]. Available: https://www.reliableplant.com/Read/31707/predictive-maintenance-survey-2019 [Accessed: 19- Mar- 2020].

[36] Probability And Uncertainty. DNV-GL, 2018, p. 3. Available: https://www.dnvgl.com/Images/Cyber-security-whitepaper-Probability-and-uncertainty_tcm8-137894.pdf

[37] J. Warde, "HOME CLINIC; Plastic May Have Some Advantages Over Metal Plumbing Pipe", Nytimes.com, 1992. [Online]. Available: https://www.nytimes.com/1992/09/13/nyregion/home-clinic-plastic-may-have-some-advantages-over-metal-plumbing-pipe.html [Accessed: 25- Mar- 2020].

[38] R. Dejhalla and D. Legović, Disposal of Worn Out Fiberglass Recreational Boats. Rijeka: University of Rijeka, 2020. Available: https://hrcak.srce.hr/file/293175 [Accessed: 25- Mar- 2020].

[39] R. Leblanc, "Polypropylene Recycling - An Introduction", The Balance Small Business, 2019. [Online]. Available: https://www.thebalancesmb.com/an-overview-of-polypropylene-recycling-2877863 [Accessed: 27- Mar- 2020].

[40] "Libelium Smart World", Libelium.com. [Online]. Available: http://www.libelium.com/wp-content/themes/libelium/images/content/applications/libelium_smart_world_infographic_big.png. [Accessed: 14- May- 2020].

[41] "Cyber-attack on Hydro", Hydro.com, 2019. [Online]. Available: https://www.hydro.com/en/media/on-the-agenda/cyber-attack/. [Accessed: 14- May- 2020].

[42] "AFM - Aktivt filtermedia Klart Vann", *Klart Vann*, 2020. [Online]. Available: https://www.klart-vann.no/afm-1. [Accessed: 14- May- 2020].

[43] "Preventative Maintenance", Precision IT Consulting.net, 2020. [Online]. Available: https://www.precisionitconsulting.net/managed-it-services/preventative-maintenance/. [Accessed: 14- May- 2020].

[44] "Akvariet i Bergen", Flickr, 2020. [Online]. Available: https://www.flickr.com/photos/tlindfors/28940350202. [Accessed: 14- May- 2020]

[45] "Akvariet i Bergen vil bygge spektakulært «isfjell» | ABC Nyheter", *Abcnyheter.no*, 2020. [Online]. Available: https://www.abcnyheter.no/reise/reisenyheter/2018/02/22/195374334/akvariet-i-bergen-vil-bygge-spektakulaert-isfjell. [Accessed: 15- May- 2020].

[46] F. Strohmeier, C. Schranz and G. Güntner, "i-Maintenance: A Digital Twin for Smart Maintenance", Ercim-news.ercim.eu, 2018. [Online]. Available: https://ercim-news.ercim.eu/en115/special/2095-i-maintenance-a-digital-twin-for-smart-maintenance. [Accessed: 15- May- 2020].

[47] Eikeland, E. Hjørnevik, K. Døssland, k. Olsen, H. (2017). Semesteroppgave «utvikle optimalisert forebyggende vedlikeholdsprogram for offshore CCTV kameraer», Høgskulen på vestlandet, Bergen, p. 20 (Note: Translated by the writers of this report)

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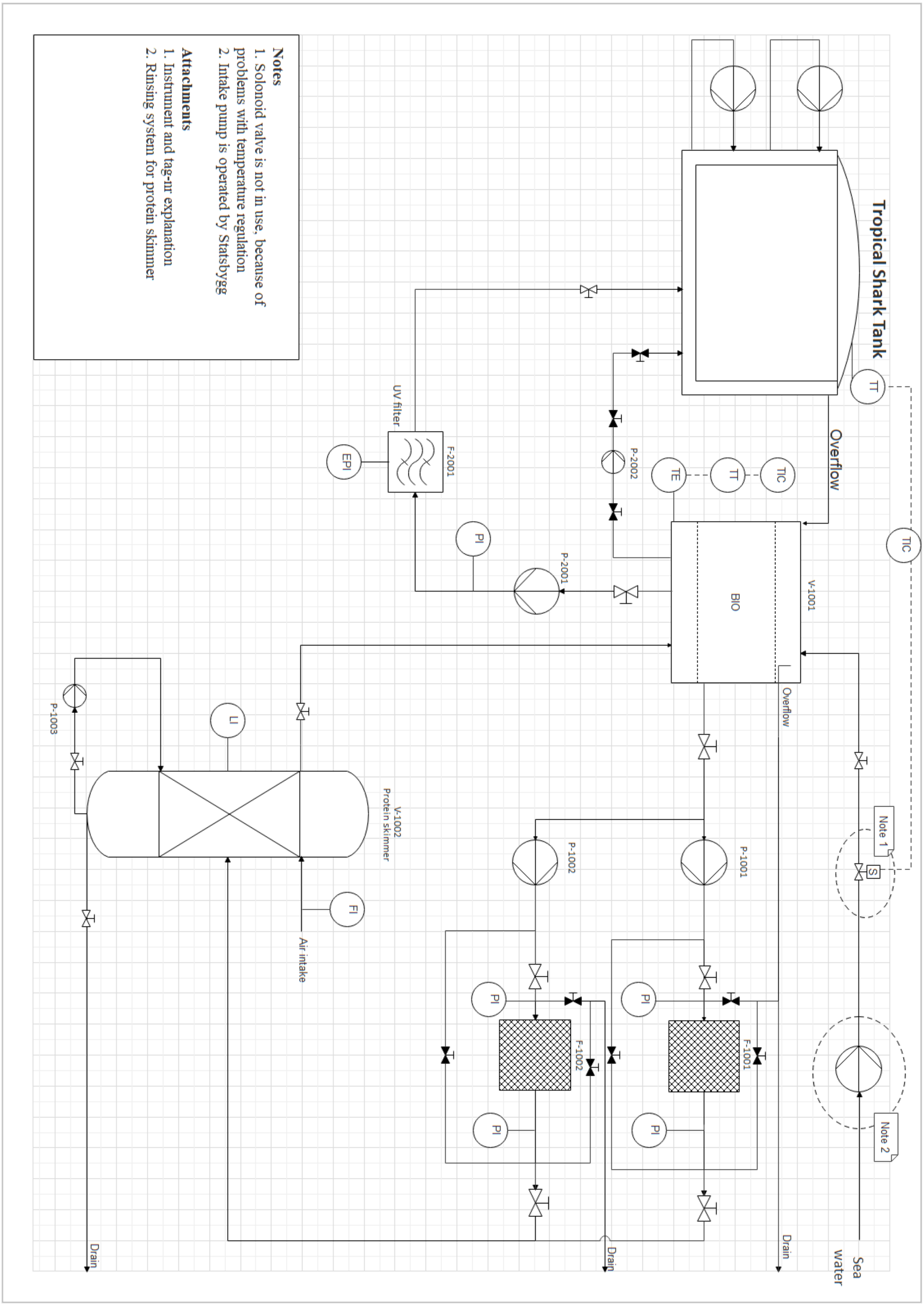
List of tables

Attachment 1 - P&ID



Attachment 2 - Instrument and Tag Number Explanation

F-1001 Sand filter	-	Filter 1
F-1002 Sand filter	-	Filter 2
F-2001 UV filter		
P-1001 Centrifugal pump	-	Sand filter pump 1
P-1002 Centrifugal pump	-	Sand filter pump 2
P-1003 Centrifugal pump	-	Booster pump for protein skimmer
P-2001 Centrifugal pump	-	Return pump via UV filter
P-2002 Centrifugal pump	-	Bypass pump of UV filter
V-1001 Biofilter		
V-1002 Protein Skimmer		

EPI: Electrical Power Indicator

FI: Flow Indicator

LI: Level Indicator

PC: Pressure Controller

PDC: Pressure Differential Controller

PI: Pressure Indicator

P&ID: Piping & Instrumentation Diagram

TC: Temperature Control

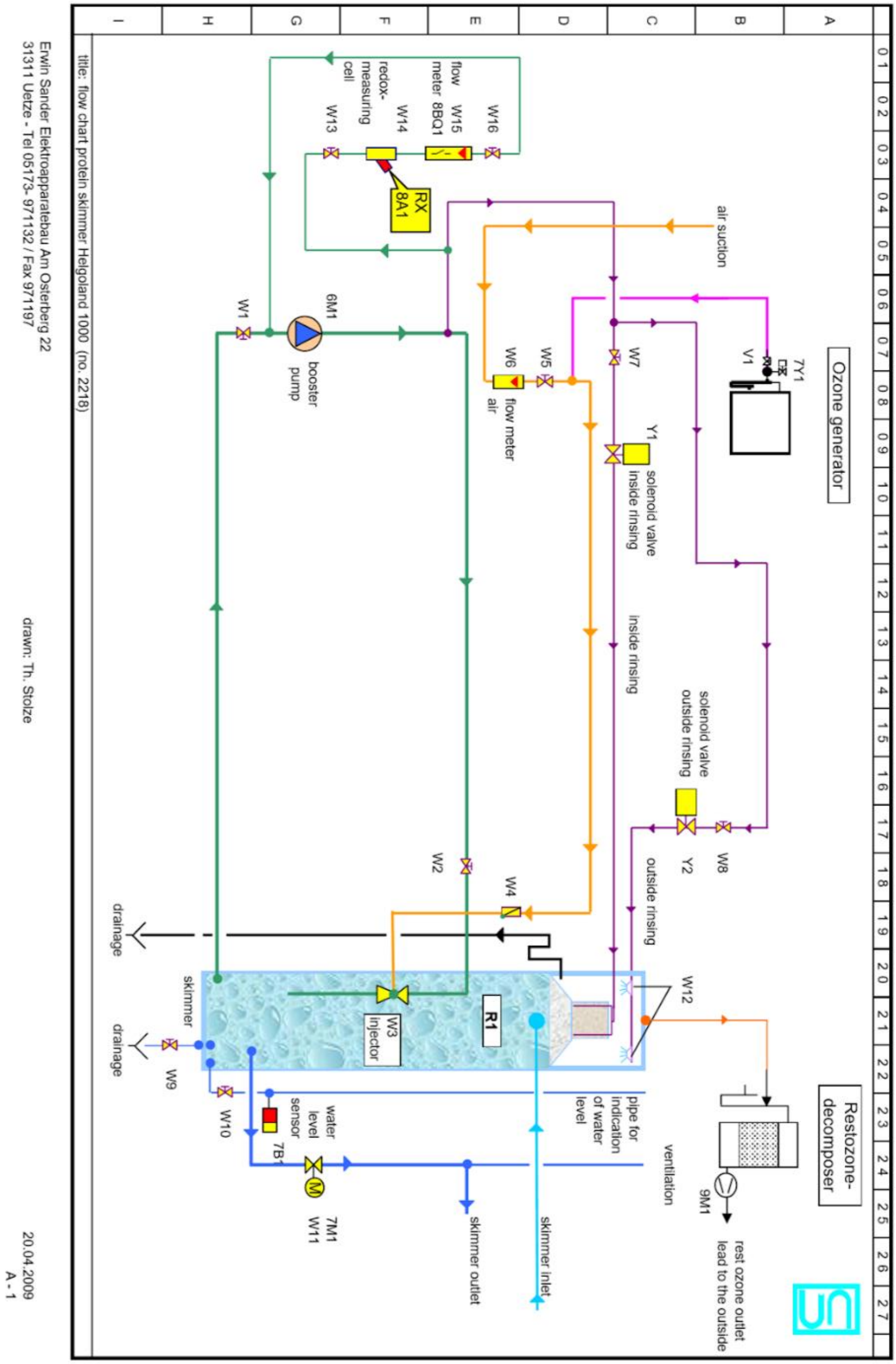
TE: Temperature Element

TI: Temperature Indicator

TIC: Temperature Indicator Controller

TT: Temperature Transmitter

Attachment 3 - Rinsing System of Protein Skimmer



Attachment 4 - Yearly UV filter maintenance report

Aqua&Care

Aqua & Care AS
Lydernhornsveien 293, N-5171 Loddefjord, Norway
T: +47 555 06 760 E: post@aquacare.no W: aquacare.no

SERVICERAPPORT — Årlig service

Kunde: Akvariet i Bergen
Vannverk: Haitank

Deres ref: Espen Hansen
Tekniker: Jan Emil Borge
Dato utført: 26.03.19

Utførte servicepunkt

☑ Rengjort UV-kammer	Skiftet UV-lamper:	3	stk
☑ Rengjort kvartsrør	Skiftet kvartsrør:	0	stk
☑ Testet sensor	Skiftet sensor:	1	stk
☑ Rengjort / skjekket sensorholder	Skiftet sensorholder:	0	stk
☑ Testet alarmgrense	Skiftet o-ringer:	0	stk
☑ Kontrollert e-skap	Skiftet ballast:	0	stk
☐ Kontrollert el.kammer	☐ Kalibrert UV-intensitetsinstrument		
☑ Testet indikatorlamper	☑ Testet/avlest timeteller		

Kalibrering

UV-modell / nr:	Wedeco B60	
Serienummer / produksjonsår:	VA96617.1 - 2009	
Verdi / grense:	25	J/m²
UV-transmisjon:	95%	% v/T = 50mm
Maksimum godkjent vannmengde:	63,6	m³/t
Maksimum tillatt ved drift:		m³/t
Avlest UV-dose ved nye lamper:	142	W/m²
Timeteller:	0	Timer
Antall start / stopp:	0	
Sensortype:	dvgw 160	
Faktisk UV-intensitet målt med referanseinstrument / -sensor:	142	W/m²
Avvik UV-intensitet:	-	%

Kommentarer / forslag til utbedringer:

Utført service i henhold til avkrysning.
Skiftet sensor pga stort avvik.
Etter service er UV-anlegget i forskriftsmessig stand i.h.t. gjeldende typegodkjenning fra Veterinærinstituttet.

Sted og dato: Bergen, 26.03.2019 For Aqua & Care AS: Ketil Troye Signatur: Ketil Troye Digitalt signert av Ketil Troye Dato: 2019.03.26 15:46:30 +01'00'

Vi takker for oppdraget!

Attachment 5 - FMECA

					Effect of failure											
					Consequence Class				Risk class							
Unit	Subunit	Functions	Failure mode	Likelihood of Failure	S	E	A	C	S	E	A	C	Failure mechanism	Failure characteristic	Detection method	Maintenance action	Maintenance interval
Sand filters (F-1001 / 1002)	Casing	Contain Fluid	Leakage	N	L	L	M	H	L	L	L	L	Fatigue, stress-cracking, wear.	Gradual failure	Inspection	See chapter 5 for all	See chapter 5 for all
	Filter media	Fine Filtration, Flow through	Blockage	L	L	L	M	M	L	L	L	L	Fatigue, wear.	Gradual failure	Inspection		
Protein skimmer (V-1002)	Reaction tank	Contain Fluid	Leakage	L	L	L	H	H	L	L	M	M	Fatigue, stress-cracking, wear.	Gradual failure	Inspection		
	Gasket between foam beaker and reaction tank	Sealing connection	Leakage	H	L	L	M	L	L	L	H	L	Fatigue, corrosion, microbiological corrosion, wear.	Gradual failure	Inspection		
	Foam Beaker	Collecting foam	Leakage	L	L	L	M	M	L	L	L	L	Fatigue, stress-cracking, wear.	Gradual failure	Inspection		
	Foam Tube	Feed foam into beaker	Leakage	L	L	L	M	M	L	L	L	L	Fatigue, stress-cracking, wear.	Gradual failure	Inspection		
	Internal/external rinsing nozzles	Clean beaker/tube	Blockage	L	L	L	M	M	L	L	L	L	Fatigue, corrosion, wear.	Gradual failure	Test		
Centrifugal pumps (P-1003) [Protein Skimmer]	Power transmission	Transfer torque	Low output, vibration, overheating	L	L	L	M	M	L	L	L	L	Fatigue, corrosion, stress-cracking, wear.	Sudden failure	Test		
	Pump unit	Pump water	Low output, vibration, overheating	L	L	L	M	M	L	L	L	L	Corrosion, erosion, fatigue, stress-cracking, wear.	Gradual failure	Inspection		
	Lubrication system	Lubricate components	Leakage, friction, vibration, overheating	L	L	L	M	M	L	L	L	L	Fatigue, wear.	Gradual failure	Inspection		
Biofilter (V-1001)	Casing	Contain liquid	Leakage	N	L	L	M	M	L	L	L	L	Fatigue, stress-cracking, wear.	Gradual failure	Inspection		
UV filter (F-2001)	Chamber	Contain fluid	Leakage	L	L	L	M	M	L	L	L	L	Fatigue, stress-cracking, wear.	Gradual failure	Inspection		
	Lamps	Kill bacteria	Broken lamps	H	L	L	M	M	L	L	M	M	Stress-cracking, wear	Sudden failure / gradual failure	Inspection		
	Control unit	Start/stop on demand	Fail to start/stop on demand	L	L	L	M	M	L	L	L	L	Software bug, wear	Sudden failure / gradual failure	Test		
	Sleeve	Protect lamps	Broken lamps	L	L	L	M	M	L	L	L	L	Fatigue, stress-cracking, wear.	Gradual failure	Inspection		
Centrifugal pumps (P-2001) [UV filter]	Power transmission	Transfer torque	Low output, vibration, overheating	L	L	L	M	M	L	L	L	L	Wire corrosion, decaying cable	Sudden failure	Test		
	Pump unit	Pump water	Low output, vibration, overheating	L	L	L	M	M	L	L	L	L	Corrosion, erosion, fatigue, stress-cracking, wear.	Gradual failure	Inspection		
	Lubrication system	Lubricate components	Leakage, friction, vibration, overheating	L	L	L	M	M	L	L	L	L	Fatigue, wear.	Gradual failure	Inspection