ENGN2225 Systems Engineering and Design

# Individual Design Portfolio

## Secondary treatment improvement for Canberra water treatment system

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## Abstract

The design portfolio focuses on developing a satisfied secondary water treatment system using system engineering approach. Our final design is a system based on rotating biological contactor system fixing with anoxic tanks and auto detectors, which meets the customer requirements best. The system engineering techniques are used to achieve a robust and logical design process, including: Problem scoping, Requirements analysis, idea generation, functional analysis, system architecture, Testing, Verification and Evaluation and design communication.

# Content

# 1.0 Introduction

The water treatment issue still exists in Canberra. Canberra is the only major city which is not located near the sea in Australia. And main Canberra drinking water source is Murrumbidgee river. The water system is administered by a government-owned company—ICON Water Corporation. (The ACT Government, 2016) Nowadays, there still are excessive phosphorus, suspended solids, turbidity and faecal coliforms et cetera caused by rainfall events and low dissolved oxygen caused by hot weather. (The ACT Government, 2014)

Through all the water treatment processes, secondary treatment is the main process relating to these kinds of issues. Solids and organic components can be removed using physical phase separation and biological process separately in secondary treatment.

In this way, the secondary treatment in Canberra needs to be improved to reduce the over-scaled pollution in order to achieve a higher water quality. The design of a good secondary system aims to achieve sufficient water supply with high quality, lower carbon emission and cost.

## Client

The client is ICON Water Corporation in Canberra because of their direct control of the water plant. The water purified by our design must pass government regulations and the government will continue to fund ICON. What's more, there is a closed relation between daily water quality and residents' health. ICON Water Corporation under the government has the responsibility to guarantee a healthy drinking water source. Additionally, other regions suffered from the same problem are also the potential clients of the design.

# 2.0 Solution

The proposed design is an air drive rotating biological contactor system between primary treatment system and tertiary treatment system sketched below:

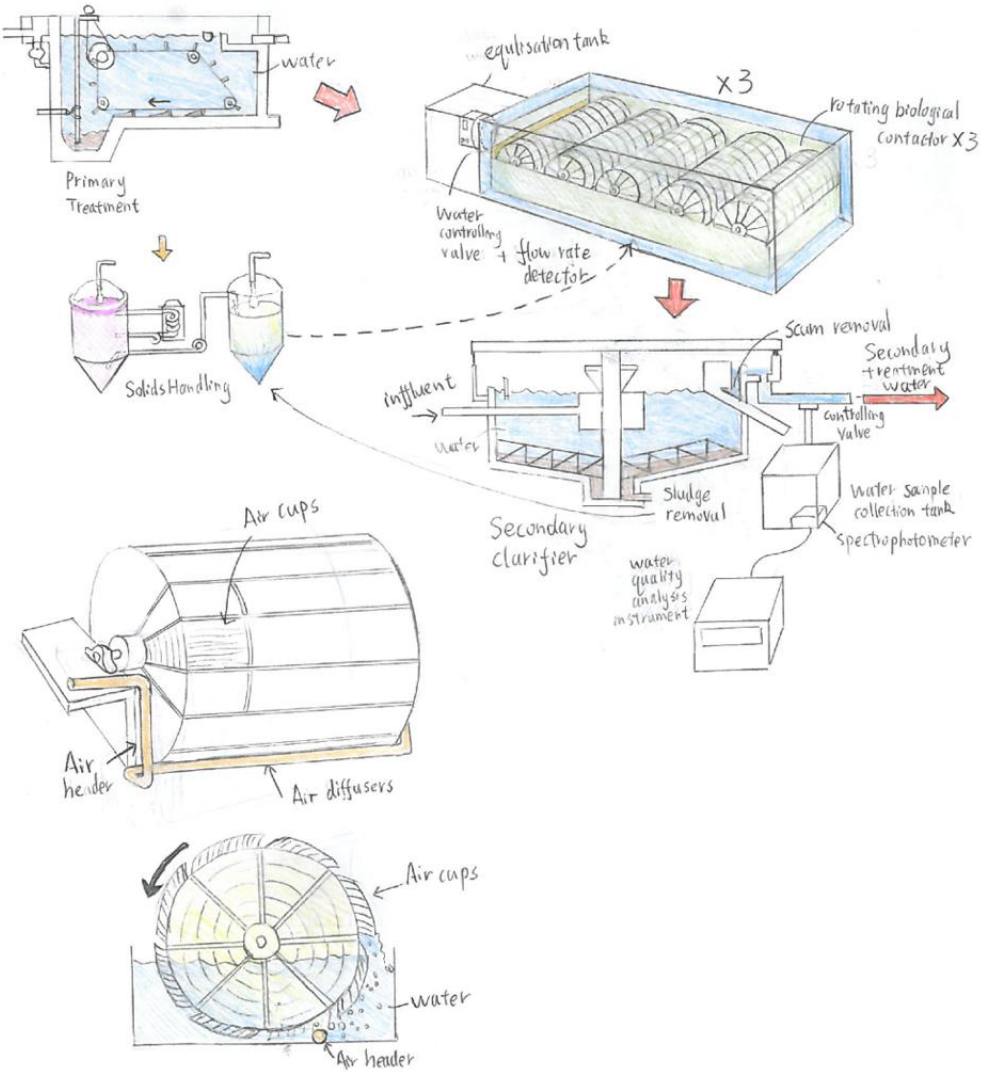



Figure 7. The sketch for the improved system.

The main system consists of a water purification system (three groups of five rotating biological contactors and an anoxic tank), two sedimentation system: primary treatment and secondary clarifier, and two detection systems: water flow controller and water sample collector. The combination of them are able to achieve rigorous and stable physical processes and biological reactions orderly and smoothly. The image in the left bottom corner is the detailed design for the contactor.

The detailed operation flow can be seen in 5.1FFBD.

# 3.0 Problem Scoping

**Main purpose:** Establishing the scope of the problem help focusing the detailed part of our design to guarantee benefit maximization. Transferring from the general question to specific things which can be analysed and solved via systems engineering process.

**Key outcomes: The core stakeholder is operator; ICON is also a key stakeholder.**

## 3.1 Stakeholder analysis

Scope the problem based on the interest of the stakeholder is one of the good ways. Making sure the relation between different stakeholders helps finding the key stakeholder, which can give us a clear direction for the following work.

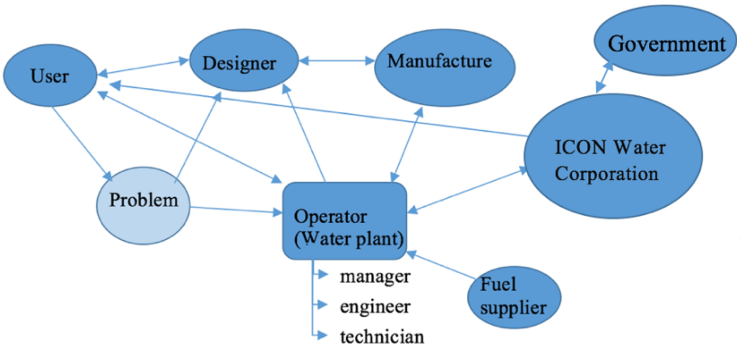



Figure1. Mud-map for water recycling system

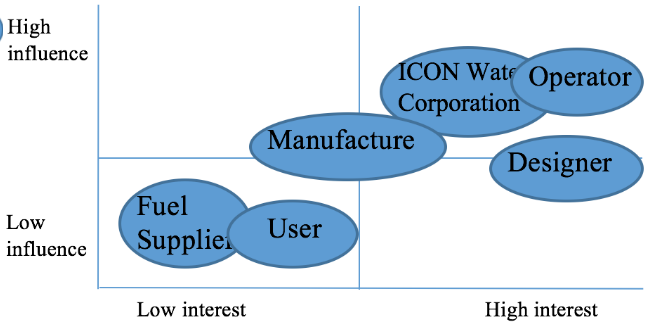



Figure 2. Influence-interest grid.

Operator is found having the largest number of interactions from Figure 1. The detailed interactions between different stakeholders can be seen in appendix. And from figure 2, operator and ICON Water Corporation are the most necessary two stakeholders that should be managed closely. In this way, the operators in the water plant can be the core stakeholder but our client ICON oversees the operators. Hence we should take both of their requirement and benefit into consideration.

# 4.0 Requirements Analysis

**Main purpose:** Requirement analysis helps further specifying the operator and ICON's requirements into detailed design requirements. Their demand is gotten through emailing. We can get the improvement direction hints of design from specific standard and grasp the theoretical approaches about how to satisfy customers.

**Key outcomes: There are trade-offs between economical and worker friendly, high water quality and economical. The key design attributes are durability, impurity removal rate, chemical waste amount and corrosion rate.**

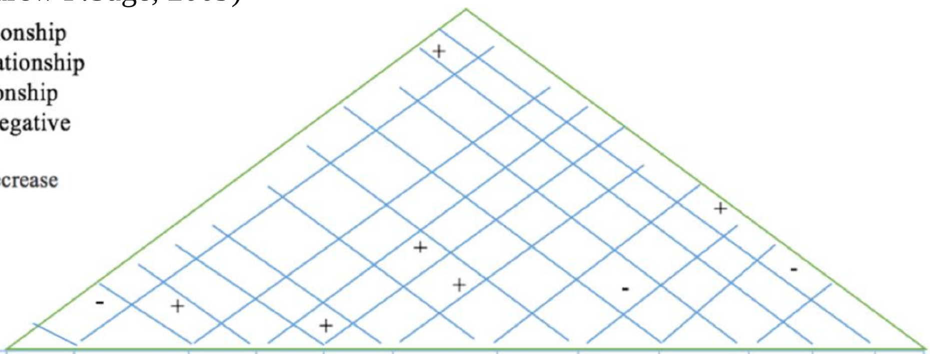
## 4.1 Pairwise analysis

Firstly, a pairwise analysis gives us the most important needs for the key stakeholder. The pairwise analysis can be seen in Table3 in appendix. The importance rank is used in the following HoQ.

## 4.2 Requirements mapping

Now we can use HoQ to provide a good assessment for the design. HoQ transfers general requirements into design criteria and measureable engineering characteristics in each facility and process. Through the use of a house of quality, influential requirements are identified and prioritized. (Andrew P.Sage, 2009)

9: Strong relationship
3: Medium relationship
1: Weak relationship
+/-: Positive/Negative correlation
↑/↓: Increase/Decrease
-: Optimise




| Customer requirement \ Design attributes | Importance | High Durability(not easy to be broken) | Corrosion in purification process | High instrument precision | High impurity removal rate | Less chemical waste | Equipment material recycling | Easy to clean | Less noise | Automatic monitoring equipment | Energy consumption | Long Lifespan | Small area occupation | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Safe | 5 | 9 | 9 | | | 3 | 1 | 1 | | | | | | 115 |
| High water quality | 4 | | 3 | 9 | 9 | 3 | | 1 | | 3 | | | | 112 |
| Environmental-friendly | 3 | 1 | 3 | | 3 | 9 | 9 | | 1 | | 9 | 1 | | 90 |
| Worker-friendly | 2 | 3 | | 3 | | | | 9 | 9 | 9 | | | 1 | 66 |
| Economical | 1 | 3 | | | | | 3 | 1 | | 1 | 9 | 9 | 9 | 35 |
| Direction of improvement | | ↑ | ↓ | ↑ | ↑ | ↑ | ↑ | ↓ | ↓ | -(more than number of processes) | ↓ | ↑ | ↓ | |
| TPMs | | Time | mm/a(Rate of corrosion) | mg/L | mg/L | Ton | %(degree of reuse percentage) | Time | Decibel | Integer | kW.h | Time | $m^2$ | |

Table4. House of quality for secondary water treatment system.

- Safety is the most significant requirement, and it possesses strong relationship with durability and corrosion rate. Reduce the corrosion can also improve the durability and protect instrument. The long lifespan also has positive correlation with high durability. So increase the durability and reduce the corrosion rate are able to effectively improve three aspects at the same time.
- For achieving environmentally-friendly, reduce corrosion and chemical waste relating to safety requirement seems to be useful. And reduce energy consumption can also make the system more economical.
- High water quality can be guaranteed by high instrument precision and high impurity removal rate. And impurity removal rate has positive correlation with the requirements less chemical waste and easy to clean.
- There are trade-offs between high water quality and economical. The improvement on reduce corrosion, high instrument process and impurity removal all need more costs. The balance will be further argued in the following part.
- There are trade-offs between economical and worker-friendly. If the system needs to be easy to clean, less noise and auto-controlled, more cost must be taken on improving functions of the equipment. Workers' demands seem to be a little more important.

## 5.0 Idea Generation

**Main purpose:** Idea generation diverge our thinking to find useful ideas for out secondary water treatment system design. The ideas should be generated and selected within problem scope and based on the key design attributes. Trade-offs should also be considered about.

**Key outcomes: the selected ideas rotating biological has direct ideas, water quality detector and water flow detector have indirect ideas.**

## 5.1Structured Brainstorming

The research question is "How might we improve secondary wastewater treatment". Adding and removing constrains in brainstorming can help to remove inherent thinking. The brainstorming part can be found in table 4 in appendix.

## 5.2 Concept Generation

Ideas generated in brainstorming can be divided into different groups by concept classification tree. Concept generation process not only gives a thorough and logical look for the topic, but also refines the particular problem decomposition. The selection should be based on customer requirement mentioned before.

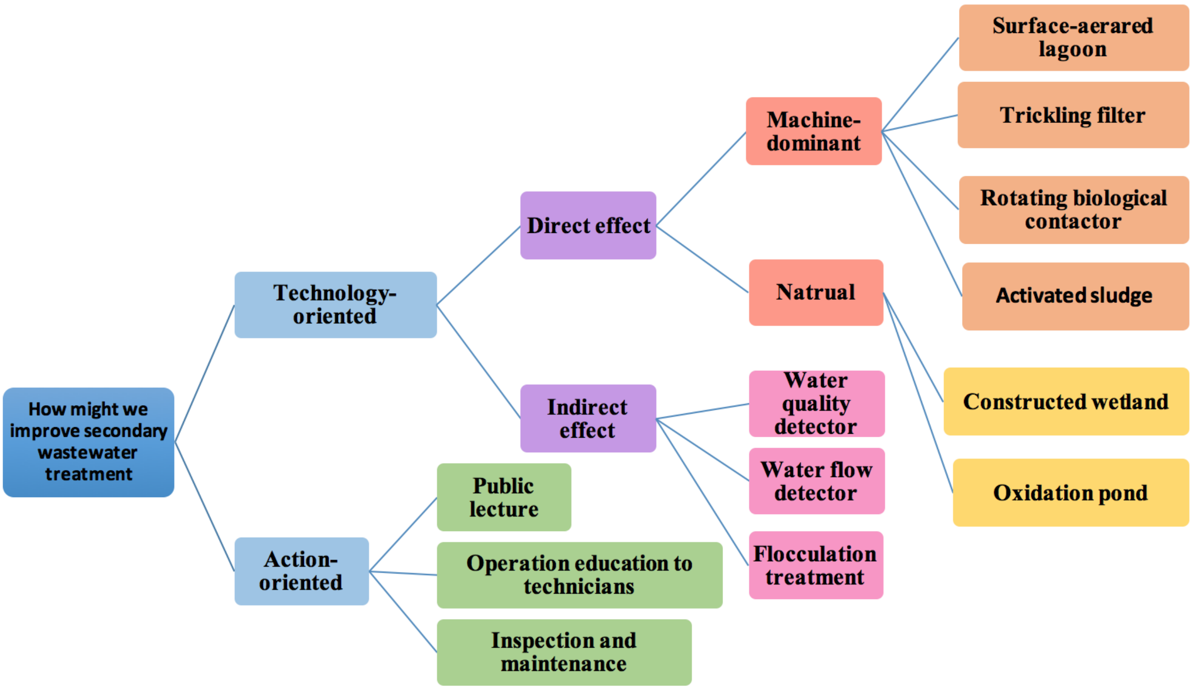



Figure 2. Concept classification tree.

The most useful ideas are easily to be highlighted in this process.

- 'Action-oriented'
  - Holding activities and excessive inspection and maintenance cannot make effective and obvious improvement to the system, so we prune the 'Action-oriented' bunch.
- 'Technology-oriented'
  - 'Direct effect': Both have potential to be explored.
    - Activated sludge has higher removal rate of biochemical oxygen demand(BOD) than biological filter, but it is hard to clean and sensitive to temperature. (Damir Bradjanovic, 2015)
    - Surface-aerated lagoon has high reduction of BOD and pathogens, but requires a large land area and has high energy consumption.
    - Trickling filter has high incidence of clogging and have potential odour problems, which is not such safe. (R.Spellman, 2000)
    - Rotating biological contactor(RBC) is easy to monitor and has relatively low-cost and low-energy consumption.
    - The effectiveness of oxidation ponds and constructed wetlands are economical, but easy to be affected by plant diseases and insect pests. (Vymazal, 2010)
  - 'Indirect effect'

- Water quality detector and water flow detector seems all economical and just need a little electricity. The improvement of inspection equipment can not only reduce the number of monitoring and maintenance staff, but also achieve system operation real-time monitor.
- Flocculation treatment can remove suspended particles less than 1 μm in size. (Bratby, 2016) But the idea may have the same effect with the biological filter and sludge.

As a conclusion, activated sludge, rotating biological constructor and surface-aerated lagoon are all good idea for the purification system, which is also the most important subsystem in the secondary water treatment. Water quality detector and water flow detector also seems useful.

## 5.3 Concept Evaluation

We need to choose a best purification way among activated sludge, rotating biological constructor and surface-aerated lagoon in order to continue our further improvement process.
Concept evaluation matrix compares alternatives systematically. The tool helps us testing out the final idea based on customer requirement again.

Scale: 5 = Exceeds compliance; 3 = Full compliance; 1 = Partial compliance; 0 = Non-compliance
R = Relative compliance; W = Weighted value

| Requirement | Importance | Rotating biological constructor | | Activated sludge | | Surface-aerated lagoon | | Benchmark |
|---|---|---|---|---|---|---|---|---|
| | | R | W | R | W | R | W | |
| Worker-friendly | 2 | 3 | 6 | 1 | 2 | 3 | 6 | 3+ |
| High water quality | 4 | 3 | 12 | 3 | 12 | 5 | 20 | 3+ |
| Environmentally-friendly | 3 | 3 | 9 | 3 | 9 | 3 | 9 | 3+ |
| Economical | 1 | 5 | 5 | 3 | 3 | 1 | 1 | 3+ |
| Safe | 5 | 5 | 25 | 3 | 15 | 3 | 15 | 3+ |
| Sum | | | 57 | | 41 | | 51 | |

Table 6. Evaluation matrix for three types of secondary treatment.

The lagoon can convert the soluble biodegradable organics to a biomass, which guarantees high water quality. Activated sludge is hard to maintain and clean, causing the low achievement of worker-friendly. For economical evaluation, the energy requirements comparison among three solutions can be seen in appendix. (C. P. Leslie Grady, 2011) RBC spend 120000kWh/year and costs least. However, surface-aerated lagoon takes 1000000 kWh/year, which is a big number. The construction cost for an aerated lagoon is also high. (Diederik Rousseau, 2016)
From Table 6 we find the choice with the highest score is RBC, which means it achieves the requirement best in this form. RBC has the advantage about mechanically simple, low energy requirements, which can satisfy the key attributes in requirement analysis part. But it has limited process flexibility and need pre-treatment.
Benchmark is also a reference for us. Both activated sludge and surface-aerated lagoon have a requirement that cannot reach the benchmark.

The final results for evaluation can be a judging condition for the final decision, but the combination between evaluation and testing is also significant. Additionally, feedback from client, situation in market and prospect for development can also be taken into account.

# 6.0 Functional Analysis

**Main purpose:** At this stage, we breakdown the system to subsystems levels. We transfer functional requirements to functional flow-block diagram to explore further practical operability. Detailed description of how the system works is emphasised on in this topic, which helps to systematically explore how subsystems interact with the whole system. In this way, the user's experience and design stability can also be improved.

**Key outcomes: The process of the chemical and biological reactions is improved and the auto control detection flows are designed under this topic. The function of the system is divided to four second levels and is grouped to 4 subsystems sedimentation, purification, water flow control and water sample collection system with detailed components.**

## 6.1 Functional Flow(FFBD)

A FFBD is a multilevel model orderly describing actual operations and define system functionality. The FFBD for the treatment system can be seen in Figure 3 and Figure 4.

Although the diagram is based on water instead of users' point of view, a functional flow is still useful to help gaining a deep thinking about decision-making and resulting steps. By the functional flow, how system requirements interact with its functions and how sub-systems work for each system becomes quite easy to be understood.

**TOP LEVEL FUNCTIONAL FLOW**

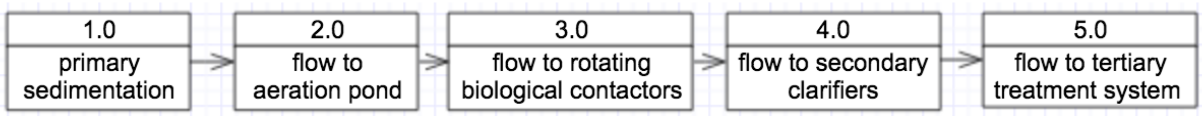



Figure 3. Top level functional flow for the improved secondary treatment system.

**SECOND LEVEL FUNCTIONAL FLOW**

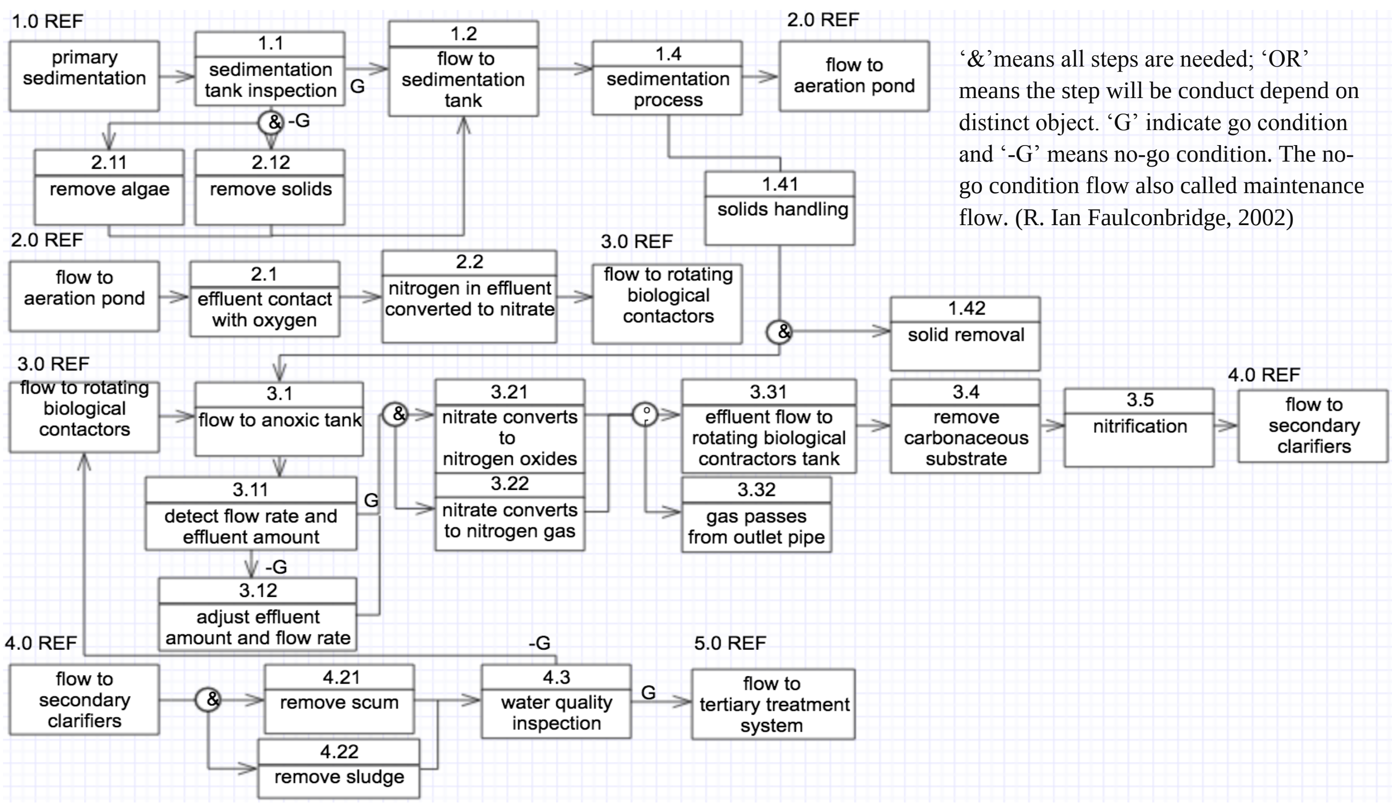



Figure 4. Second level functional flow for the improved secondary treatment system.

From the FFBD in Figure 3 and Figure 4 (Mogens Henze, 2008), three main improvements are highlighted: 2.2: nitrogen convert to nitrate, 3.21, 3.22: nitrate converts to nitrogen oxides and nitrogen gas and 3.4, 3.5: remove carbonaceous substrate and nitrification. They are all important chemical or biological processes to ensure the hazardous chemicals and organic components are removed effectively. The subsystems about purification and sedimentation are related to the achievement of these functions. What's more, two improved functions are added in 3.0 and 4.0, they are 3.11 detect flow rate and effluent amount and 4.3 water quality inspection. These two inspection functions have auto-controlled feedback. If the standards are not met, the flow rate can be adjusted or the effluent will flow back to RBC to have twice purification automatically.

## 6.2 Functional Allocation

After knowing the main functions that we need to pay attention to, it is significant to make sure the function can be presented through subsystems. In this way, a functional allocation becomes quite indispensable. In functional allocation, we logically divide the system into different groups based on distinct functions.

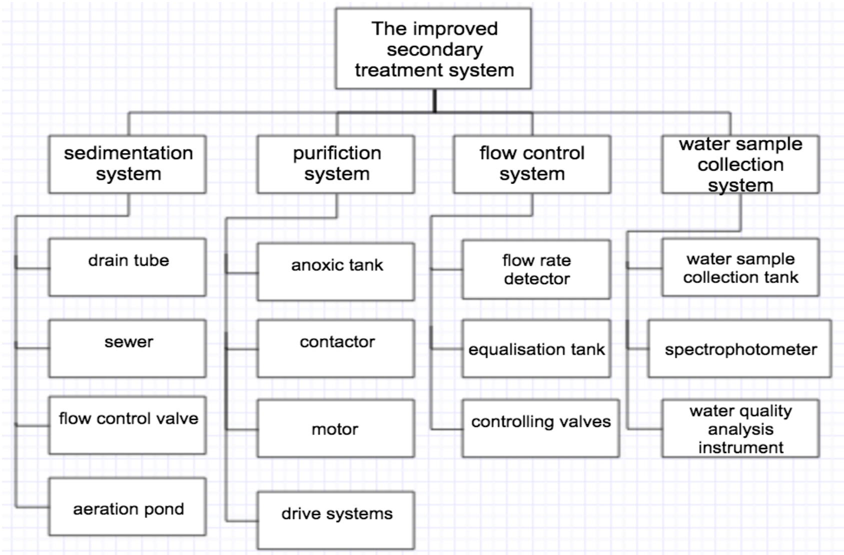



Figure 5. The improvement secondary treatment system functional allocation.

There are four main function groups in Figure 5 each has several functional components.

Sedimentation tank and secondary clarifier are grouped under one system because their functions are quite similar. Aeration pond is combined with sedimentation tank to reduce cost and interactions. Other highlighted function blocks are under purification system and they are able to combine together to achieve the high water quality requirement more effectively. Flow control system and water sample collection system have two auto-detection functions separately. Functional allocation will provide a reference to system architecture step.

# 7.0 System Architecture

**Main purpose:** The system is further break downed from subsystem to component level. And through analyse interactions between different components and external factors, the system is further adjusted to satisfy the requirements and reduce the attached risks caused by the interactions.

**Outcomes: There are two more subsystems added in system interface based on system boundary chart. A motor is also added on the RBC to provide sufficient power. The interactions between the subsystems are analysed in detail.**

## 7.1 System Boundary Chart

System boundary chart evaluates which component or stakeholder has direct influence and can be controlled and which part can be ignored. The parts directly affecting the whole system will be included in system interface.

| Internal | | External | Exogenous |
|---|---|---|---|
| Bio contactor | Electrical power | Water plant staff | Influent conditions |
| Drive | User interface | User | Weather |
| Flow rate | Motor | Cost | Demand of quantity |
| Treatment water quality | Sedimentation tank | Air | |
| | Control | Solar | |

Table 7. System boundary chart for the secondary treatment.

Analyse the components in internal part in Table 7, most of them are included in the system in function allocation parts. Nevertheless, 'control' and 'electrical power' components cannot be put in any systems above. This means that we still need two additional subsystems to achieve centre control function and power function. In this way, the system can be divided into six subsystems. The purification system and sedimentation system are responsible for sewage purification. A flow rate detector and a water sample collection system aim to inspect the water quantity and water quality. Electrical power system provides required power to other subsystems. The operations of other subsystems are under the control of centre control system, which is like an executive centre.

## 7.2 System interface

Here is a system interface mapping helps showing interactions between the subsystems, the components and external factors clearly. (Office of Wastewater Management, 2014) Every subsystem runs independently with distinct functions and may have input or output relation with other subsystems.

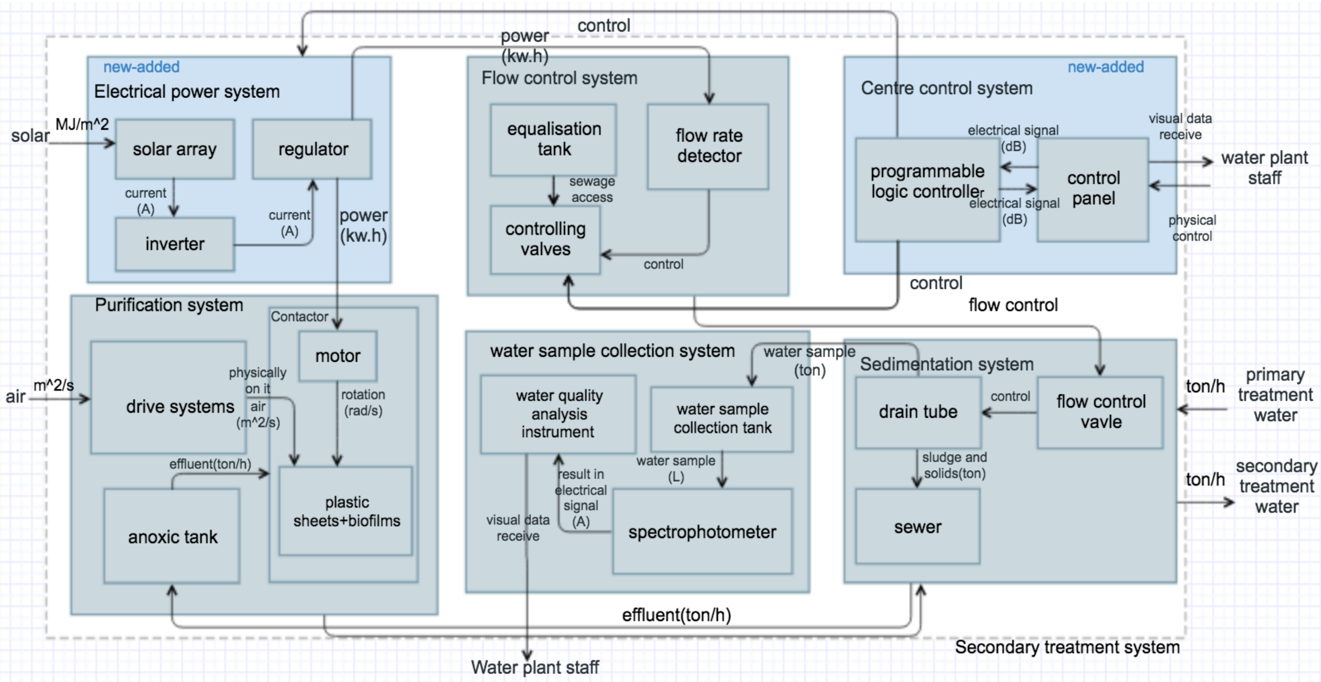



Figure 6. Subsystem interface map for secondary treatment.

There are several improvements made in the system interface map in Figure 6. The main problem for air drive RBC is that it is more susceptible to loping, which is rotation in an uneven speed because of the biofilm growth on the RBC sheets cannot be uniform. so a motor on contactor subsystem and a flow control system are added to achieve a more even rotation speed. (C. P. Leslie Grady, 2011) Additionally, the new design of rotating biological conductor possesses more effective water detection systems to guarantee suitable water flow rate and high water purification quality.

We use central control system to control motor and controlling valves instead of just cut-off the power is aimed to adjust and cut off the water flow rate at any time, which increases the flexibility and robustness. The system cannot cut off the system effectively when emergency occurs because the indirect interaction.

Additionally, the maintenance and regular inspection is important in the system, because the interactions between different subsystems cannot be cut down to a low level.

# 8.0 Testing and Evaluation

**Main purpose:** Testing and evaluation are important to ensure the safety of the water is maintained and the high quality of the equipment to prove to ICON that the process works. **Key outcomes: Five tests are designed to decide if the design meets all the requirements. Then the improved system is evaluated theoretically and is confirmed to be better than the other potential systems.**

## 8.1 Subsystem mapping

Every DR's corresponding subsystem is determined by subsystem mapping in appendix.

The most important subsystem is the purification system, the sedimentation system and the control system which should be tested strictly. Their responsible stakeholders are manufacture and designer.

## 8.2 Testing

Testing are direct methods to verify if the design matches the design requirements. Our main purpose is to demonstrate to our client that our design is reliable and valuable through robust repeatable, objective and scientifically-reasonable testing procedures. There are five testing types: Analytical testing, Proof-of-concept testing, Model/Prototype testing, Operational testing and support testing. The first three are more relevant to our project.

The test type used depends on different design requirements and design attributes. The customer requirements, design requirements obtained from technical performance measures are detailed in Appendix. DR2.1: 'number of process' is removed because it does not have a specific design attribute.

| DR | Design attributes | Test type | Subsystem |
|---|---|---|---|
| **DR.1.1** | Strength of the material and the structure | Analytical testing | Sedimentation system & Sample collection system & Flow control system |
| **DR.1.2** | Strength of the material | Analytical testing | |
| **DR.2.2** | Instrument precision | Model/Prototype testing | Centre control system |
| **DR.2.3** | Sedimentation effect | Model/Prototype testing | Sedimentation system |
| **DR.3.1** | Effective energy consumption | Model/Prototype testing | Electrical power system |
| **DR.3.2** | Firm level of the outlet pipe | Proof-concept-energy | Sedimentation system |

| | | | |
|---|---|---|---|
| | | testing | |
| **DR.3.3** | Material of the equipment | Analytical testing | Sedimentation system & Sample collection system & Flow control system |
| **DR.4.1** | Structure of the equipment | Analytical testing | |
| **DR.4.2** | Type of the motor | Model/prototype testing | Purification system |
| **DR.4.3** | Control precision | Model/Prototype testing | Centre control system |
| **DR.5.1** | Energy consumption | Analytical testing | Electrical power system |
| **DR.5.2** | Strength of the material and construction | Analytical testing | All system |
| **DR.5.3** | Size of the equipment | Analytical testing | All system |

Table 9. Test type and subsystem for each design requirement.

The most important subsystem is the purification system, the sedimentation system and the control system which can be found in the subsystem mapping in appendix. Their responsible stakeholders are manufacture and designer.

We merge some design attributes that can have the same way to test.

| **Design attributes** | **Testing procedure** |
|---|---|
| Strength of the material and the structure | **Pass/ Fail criteria:** The specimen must satisfy a 1.6 factor of safety.<br>**For material:** Using the specimen of each equipment, testing their stresses ($\sigma = F/A$) and strains ($\epsilon = (l - l_0)/l_0$). (F.S.=$F_{fail}$ / $F_{allow}$)<br>**Procedure:**1. Placing two punch marks along the specimen and measure the gauge-length.<br>2. Measure specimen's cross-sectional area.<br>3. Using stretching machine to stretch the specimen slowly.<br>4. Record load, gauge-length and cross-sectional area when fail. (The testing should be done for both tension and compression)<br>5. Using the data to calculate if the specimen satisfies the required F.S.<br>**For structure: Procedure:** Using a prototype, testing the maximum load it can support. Calculate if the specimen satisfies the required F.S. |
| Instrument precision | **Pass/Fail criteria:** The error for and instrument should <±5%, the response speed should be less than 0.5s.<br>**Procedure:** 1. Using a prototype for the instrument to test treatment water.<br>2. Using several high-accurate instruments available in the market to test the same water at the same time<br>3. Using the data for prototype comparing with the average data for other instruments |
| Sedimentation efficiency | **Pass/Fail criteria:** The solids content should achieve secondary water quality standard as noted in appendix.<br>**Procedure:** 1. Using a prototype to remove solids in primary treatment water<br>2. Using water quality detector to test if the solids content is less than water quality standard limitation. |
| Energy consumption | **Pass/Fail criteria:** Meets the 'economical' benchmark in 4.3 and the energy consumption should less than +105% of the energy requirements in appendix.<br>**Procedure**: Analytical: Using data for biological contactor's motor, flow rate detector and water quality detector to calculate energy consumption.<br>**Operational:** 1. Constantly use the system for three days:72hours<br>2. Record the electricity consumption<br>3. Calculate the energy consumption and compare it with the criteria. |

Table 10. Testing procedure for each design attributes.

## 8.3 Evaluation

**Evaluation Matrix (weighted)**

After testing, we evaluate our improved design comparing with other three potential solutions combined with the existing solutions. Evaluation matrix is a tool to inform our decision about the final design. The evaluation is related to the customer requirements and informed by testing.

Solution 1: The group air drive RBC system we designed.
Solution 2: The group air drive RBC system with regular manual water quality and flow testing.
Solution 3: The group air drive RBC system without anoxic tank.
Solution 4: The group mechanical drive RBC system with regular manual water quality and flow testing and anoxic tank.
Scale: 5 = Exceeds compliance; 3 = Full compliance; 1 = Partial compliance; 0 = Non-compliance
R = Relative compliance; W = Weighted value

| Requirement | Importance | Solution 1 | | Solution 2 | | Solution 3 | | Solution 4 | |
|---|---|---|---|---|---|---|---|---|---|
| | | R | W | R | W | R | W | R | W |
| Worker-friendly | 2 | 3 | 6 | 1 | 2 | 5 | 10 | 3 | 6 |
| High water quality | 4 | 5 | 20 | 3 | 12 | 1 | 4 | 3 | 12 |
| Environmentally-friendly | 3 | 3 | 9 | 3 | 9 | 5 | 15 | 1 | 3 |
| Economical | 1 | 3 | 1 | 5 | 5 | 5 | 5 | 3 | 3 |
| Safe | 5 | 5 | 25 | 3 | 15 | 5 | 25 | 3 | 15 |
| **Sum** | | | 61 | | 43 | | 59 | | 49 |

Table 11. Evaluation matrix for three types of secondary treatment.

The disk of all the three rotating biological contactor is made by polyethylene or PVC (Koelsch, 1985) . Plastic is not environmentally-friendly enough, but it is quite economic and occupies relatively small area.

- For solution 1, it consists of three rotating biological contactor groups combined with auto water flow and quality detector.
- For solution 2, technicians must equip with more knowledge to operate the test instrument and their workload will increase. The cost for training also increases. Water quality stability and system control efficiency will reduce.
- For solution 3, remove anaerobic tank can save cost for anaerobic environment build and frequent maintenance. But there will be denitrification process in anaerobic tank, nitrate nitrogen will become nitrogen and escape (Lesley A. Robertson, 1984). In this way, shorter reaction time will be taken on bio film to achieve same purification quality. If we remove the tank, the purification efficiency will obviously reduce.
- For solution 4, the mechanical drive RBC spend less energy comparing to air drive RBC. and it has the rotational speeds of 1.2 to 1.6 rpm comparing to air drive RBC of 1.0 to 1.4rpm, which guarantee its efficiency. But the air drive RBC can raise the oxygen transfer capacity effectively and reduce number of electrical motors to improve water quality and make the system be more environmentally-friendly. The detailed data for both RBCs are attached in appendix.

From evaluation matrix, group rotating biological contactors is the best choice. Solution 1 and solution 3 results are close to each other. The final results for evaluation can be a judging condition for the final decision, but it is not thorough enough. Different evaluation method can be used. Additionally, feedback from client, situation in market and prospect for development can also be taken into consideration. We can also know from system architecture that the economy problem can be settled from material changing and robustness of the whole system will not decrease.

## 9.0 Design communication

**Main purpose:** We need to communicate our design to audience to get feedback. After that, it is possible to go through the whole engineering system design approach again to see if there are any possible improvements.

**Key outcomes: Suggestions about good design delivery and future direction for the next team.**

## 9.1 Delivery

Delivery topic aims to deep our understanding about the design from client's perspective. For our design, practicality communication seems impossible. But a brochure and several prototypes can be provided to ICON Water Corporation and other water company to show how the design works and what benefits will bring. Clients' suggestions are quiet important for further exploration about the project. If the design is accepted, it should be constructed in a relatively small scale to test the performance.

## 9.2 Roadmap

Roadmap helps us thinking about the future direction for the project and gives inspiration to the next team. Here are some advises:

Firstly, the anoxic tank concept is good. The automatic control concept also should be continued with further exploration on system stability and accuracy.

For air drive RBC, further exploration should focus on how to increases the rotation speed of the sheets and the refresh rate of the biofilm to improve the total reaction efficiency. What's more, the next team could also find out a more environmentally-friendly material for rotating sheets. Last but not least, mechanical drive RBC system can also be tried. The exploration can focus on the improvement of its specific disadvantages like how to reduce the energy consumption and how to improve the oxidation reaction rate.

Additionally, the market can be global, not just Canberra and Australia. The design can be further modified and applied in other places. For example, in the middle of Australia, the input water quality is much worse than Canberra. So three contactor tanks can be changed to five contactor tanks with a flocculation tank after them.

# 10.0 Lifecycle

**Main purpose:** The lifecycle is about products' production, technical use time and retirement. Resources in the group RBC system are decided to be better utilized and reused by looking at the different phases of the product's lifecycle.

**Key outcomes: Suggestions about how to improve lifetime and sustainability of the system and the analysis of risk and alternatives.**

## 10.1 Manufacture & Installation & Operation

### 10.11 Manufacture & Installation

All the components in the system should be manufactured separately and installed at the water plant.

The RBC system should be tested in a small range at first with just one group rotating with relating detection and centre control system. If the system works well, instruments are accurate and the water standard is achieved, then the complete system can be installed and has its first rollout. In this way, the problem can be found in the primary process and the money can be saved. The product can be spread through the advertisement in professional magazines and websites.

### 10.12 Operation

From system architecture part we find that the majority of parts in the system are automatic, workers only need to pay attention to water quality detector to make sure the water treatment system works well as normal. If there is something wrong, a worker can cut off the power supply through the control panel in the centre control system. Meanwhile, regular maintenance is quite important due to auto control may increase the instability.

## 10.2 Recycling

The sludge produced in the water treatment process is decided to be dewatered and reused and the nitrogen gas is passed directly to the environment because it is pollution free.

The group RBC system is inferred to have a lifespan around 50 years.

The material for RBC sheets is considered to be made of high-density polyethylene that is more chemically inert and nontoxic comparing to PVC to make sure the water quality will not be influenced and is more flexible to be made in complex structure. It is also the easiest plastic polymers to recycle.

## 10.3 Risk analysis

We know from the system architecture and function flow that the flow control system and the sample collection system are automatic controlled. So if there is something wrong with two detectors or the signal transport, there will be risk about low water quality and equipment damage caused by inaccurate water quality reveal and over flow. In these way, the maintenance for these two systems is significant.

If these two system cannot be passed in trial operation stage mentioned below in Lifecycle part. The flow rate control system can be replaced by a half-automatic control system human controlled valve instead of auto controlled valve. If the overflow happens, the replaced system just will give warning to the valve controller. The water sample collection system just can be removed and workers need to collect and test water by themselves regularly.

# 11.0 Conclusion

Our project aims to achieve client's requirements. **The main improvement in the system is the air drive RBC system combined with an anoxic tank and motors, water flow controller and water sample collector.** Using system engineering techniques, the design become more and more concrete from just have a scope to specific components and subsystems. The group RBC system also be tested, evaluated and communicated according to the customer requirements.

Through the process, we gain an ability to organize our thinking in a system engineering way. Techniques are trying to be chosen in a logical and meaningful way to help us achieve a good solution step by step.

# 12.0 Reflection

From the seminar, tutorial and resources relating to the portfolio, I gain a better understanding about how to use systems engineering approach to get a more comprehensive and effective solution for a system. Every system can be analysed using the design spiral to extend our mind and make it easier to approach and make a complete result. The course set up clear learning processes from basic concept to in-depth thinking.

Except for how to use each technique properly, there are several key points I learned through TC writing: 1. Deliver meaningful analysis and decisive insights instead of explain; 2. High words efficiency; 3. Smaller the scope and bigger the solution to create effective and excited solutions. My original project topic is “Improve the water recycling system in Australia”. However, this topic is too general and big to be controlled. And I changed my topic to “Improve the secondary water treatment system in Canberra” through the system architecture part. This is a more specific problem with ICON Corporation as my real client. In this way, the system is easier to analyse and more useful solutions can be generated based on the customer requirements.

What’s more, my TCs are relatively segmented, so an outline for the portfolio draft is created with extended techniques in the most suitable order and form. Through writing the draft, the integration between each topics also becomes quite important. Some references from TC are also used but enhanced with other references to make them more valuable and reliable. Through draft to final portfolio, modification is mainly discussed in the peer review feedback part.

## Peer review feedback

One peer review has low-quality and just describe my process, but another one is helpful and constructive. I gain the skill to evaluate my portfolio thoroughly from different perspective.

| Peer review suggestions | Comment or improvement |
|---|---|
| It would have been better to see topics integrated to support the arguments | I enhance the link between each technique and create a clearer relationship between each mini-outcomes |
| Explaining why the process is relevant to your design at the beginning of each section instead of describing | I add a specific main purpose to explain the and benefits of the topic at the beginning of each section |
| Summaries things learned in each section and how it is relevant to system | Outcomes of each section is revised to be easier to find and interpret and the reference becomes more complete |
| logical arguments and conclusions were at times unclear, this could be improved. There are many spelling and grammar mistakes in my portfolio | The portfolio was proofread and re-wording by team members and given advises by Chris |
| Some parts are crammed together. Maybe removing some parts to increase spacing so it is easier to read | Some not useful parts are deletes and several useful but not such significant tools are attached in appendix |
| There were no sources cited for the customer requirements. | The customer requirement is based on the contacts with client, so there is no additional reference needed |

## Further improvement

1. Language should be more succinct to get the point across quickly and make the word more valuable and efficient.
2. Try to combine and modify techniques and try spiral design procedure in different ways to make them more unique and suitable for my own project. For example, the subsystem mapping can be contained in the house of quality to define the function and subsystem for each requirements and rank them directly. Then the analysis effectiveness can be improved.
3. There could be more creative and unique ideas in the system to build the final solution.
4. The improved system can be further modified and applied to different places to meet the requirements of a huge potential market.

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# Appendix.

## Detailed relations between stakeholders.

| | User | Designer | Manufacture | Operator | ICON Water Corporation |
|---|---|---|---|---|---|
| User | - | User releases feedback about water recycling facilities | - | User provides feedback about water quality | - |
| Designer | Designer does surveys | - | Provides equipment design concepts | - | - |
| Manufacture | - | Lists requirement about equipment design | - | Sales equipment and facilities to operator | - |
| Operator | Provides clean water and collect waste water | Provides requirements helping designer to design more suitable equipment | Raises requirements about the equipment | - | Provides water data and make sure enough water supply |
| ICON Water Corporation | Improves water recycling awareness of the public | - | - | Supervises operator and make further development plans | - |

## Pairwise analysis for customer requirements.

| | Worker-friendly | High water quality | Environmental-friendly | Economical | Safe | sum | Ranking of the customer requirements |
|---|---|---|---|---|---|---|---|
| Worker- | | 0 | 0 | 1 | 0 | 1 | 4 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| friendly | | | | | | | |
| High water quality | 1 | | 1 | 1 | 0 | 3 | 2 |
| Environmental-friendly | 1 | 0 | | 1 | 0 | 2 | 3 |
| Economical | 0 | 0 | 0 | | 0 | 0 | 5 |
| Safe | 1 | 1 | 1 | 1 | | 4 | 1 |

## Constraints brainstorming.

| | |
|---|---|
| Unlimited technology | No technology |
| Micro electrolysis technology, biological aerated filter | Surface-aerated lagoons or ponds, lecture about water purification system to public |
| Unlimited money | No money |
| Import the latest equipment, Relatively frequent inspection and maintenance | Constructed wetlands, rotating biological contactor, Trickling filter |
| Unlimited resource | No resource |
| Oxidation ponds, Flocculation treatment | Activated sludge, Operation education to technicians, Water quality detector, Water flow rate detector |

## Numbers for customer requirements and design requirements:

| | |
|---|---|
| CR.1.0 Safe | DR.1.1 High durability(not easy to be broken) |
| | DR.1.2 Low corrosion in purification process |
| CR.2.0 High water quality | DR.2.1 Number of processes |
| | DR.2.2 High instrument precision |
| | DR.2.3 High impurity removal rate |
| CR.3.0 Environmental-friendly | DR.3.1 Low embodied energy |
| | DR.3.2 Less chemical waste |
| | DR.3.3 Equipment material recycling |
| CR.4.0 Worker-friendly | DR.4.1 Easy to clean |
| | DR.4.2 Less noise |
| | DR.4.3 Automatic monitoring equipment |
| CR.5.0 Economical | DR.5.1 Energy consumption |
| | DR.5.2 Long Lifespan |
| | DR.5.3 Small area occupation |

## Subsystem mapping

| Design Requirement | Importance | Function | Subsystem | Responsible Stakeholder |
|---|---|---|---|---|
| Instrument precision | 4 | Information transport & Control | Centre control system | Manufacture |
| High Impurity removal rate | 4 | Solids sedimentation | Purification system & Sedimentation system | Designer |
| Less chemical waste production | 3 | Biological purification | Purification system | Designer |
| Easy to maintain | 2 | Sedimentation & | Purification system & | Designer & |

| | | | | |
|---|---|---|---|---|
| | | Purification & Control | Sedimentation system & Sample collection system & Flow control system | Manufacture |
| Automatic monitoring equipment | 2 | Control | Sample collection system & Flow control system | Designer |
| Low Energy consumption | 1 | Power | Electrical power system | Water plant |

## EPA secondary drinking water regulations:

(Institude of food technologists, 2008)

| Contaminant/characteristic | Recommended level |
|---|---|
| Aluminum | 0.05 to 0.2 mg/L |
| Chloride | 250 mg/L |
| Color | 15 color units |
| Copper | 1 mg/L |
| Corrosivity | Non-corrosive |
| Fluoride | 2 mg/L |
| Foaming agents | 0.5 mg/L |
| Iron | 0.3 mg/L |
| Manganese | 0.05 mg/L |
| Odor | 3 threshold odor number |
| pH | 6.5 to 8.5 |
| Silver | 0.10 mg/L |
| Sulfate | 250 mg/L |
| Total dissolved solids | 500 mg/L |
| Zinc | 5 mg/L |

## RBC design and operational parameters:

| Parameters | Treatment level | | |
|---|---|---|---|
| | Secondary | Combined nitrification | Separate nitrification |
| Hydraulic loading, $m^3/m^2 \cdot day$ | 0.08~0.16 | 0.03~0.08 | 0.04~0.1 |
| Organic loading | | | |
| $gSBOD_5/m^2 \cdot day$ | 3.7~9.8 | 2.4~7.3 | 0.5~1.5 |
| $gTBOD_5/m^2 \cdot day$ | 9.8~17.2 | 7.3~14.6 | 1.0~2.9 |
| Maximum loading on first stage | | | |
| $gSBOD_5/m^2 \cdot day$ | 19~29 | 19~29 | |
| $gTBOD_5/m^2 \cdot day$ | 39~59 | 39~59 | |
| $NH_3$ loading, $gN/m^2 \cdot day$ | | 0.7~1.5 | 1.0~2.0 |
| Hydraulic retention time, hr | 0.7~1.5 | 1.5~4 | 1.2~2.9 |
| Effluent $BOD_5$, mg/L | 15~30 | 7~15 | 7~15 |
| Effluent $NH_3$, mg-N/L | | < 2 | < 2 |

## Facilities and Energy usage for RBC calculation:

(W. G. Gilbert, 1986)

### Facilities:

**Table 2—Facilities with air drive RBC units.**

| Plant location | Total no. of shafts | Media surface area, m²/shaft[a] | Blowers measured | Blowers used at one time | Motor size, kW | Rotational speed, rpm | Biofilm growth[b] |
|---|---|---|---|---|---|---|---|
| Albion, Pa. | 2<br>4 | 9 290<br>13 935 | 2 | 1 | 18.6 | 0.8 to 1.7 | A |
| Allendale, Mich. | 2<br>2 | 9 290<br>13 935 | 1 | 1 | 18.6 | 1.2 to 1.3 | — |
| Plainwell, Mich. | 4<br>2 | 9 095<br>13 006 | 2 | 1 | 29.8 | 0.8 to 1.0 | B |
| Jonesville, Mich. | 2<br>2 | 8 918<br>13 192 | 2 | 2 | 14.9 | 1.5 | A |
| Clinton, Mich. | 4 | 8 918 | 2 | 1 | 11.2 | 1.2 to 1.3 | B |
| Dexter, Mich. | 4<br>2 | 5 388<br>10 219 | 2 | 1 | 29.8 | 1.2 to 1.9 | A |
| Jackson, Wis. | 4<br>4 | 9 290<br>13 935 | 2 | 2 | 22.4 | 1.1 to 1.6 | A |

**Table 1—Facilities with mechanical drive RBC units.**

| Plant location | Number of shafts | Number of trains | Number of stages | Number of shafts measured | Media surface area, m²/shaft[a] | Motor size, kW | Biofilm growth[b] |
|---|---|---|---|---|---|---|---|
| Cheyney, Pa. | 2 | 1 | 4 | 2 | 11 914<br>15 398 | 3.7 | A, B |
| Washington, N. J. | 6 | 6 | 4 | 4 | Std. | 3.7 | B |
| Pennsville, N. Y. | 6 | 2 | 3 | 6 | 11 148<br>13 935<br>16 722 | 3.7 &<br>5.6 | B, C |
| King of Prussia, Pa. | 10 | 2 | 5 | 5 | 9 290<br>13 935 | 3.7 | A |
| Philadelphia, Pa. | 280 | [c] | [c] | 7 | 9 290 | 3.7 | B |
| Canonsburg, Pa. | 40 | 8 | 5 | 10 | 9 920<br>13 935 | 5.6 | A, B |
| St. Clairsville, Ohio | 10 | 2 | 5 | 7 | 9 290<br>13 935 | 3.7 | A, B |
| Fairmont, W. Va. | 24 | 4 | 6 | 8 | 9 290 | 3.7 | A, B |
| Mayville, N. Y. | 3 | 3 | 3 | 2 | 8 175 | 3.7 | B |
| Mount Pleasant, Mich. | 24 | 4 | 5 | 6 | 11 148<br>15 793 | 3.7 | A, B, C |
| Holt, Mich. | 8 | 2 | 2 | 4 | 9 290 | 5.6 | C |
| Birdsboro, Pa. | 8 | [d] | 4 | 5 | 12 820 | 5.6 | A |
| Random Lake, Wis. | 8 | 2 | 4 | 4 | 5 574 | 3.7 | A, B |
| Johnson Creek, Wis. | 2 | 2 | 4 | 2 | 4 645 | 5.6 | B |
| Lake Mills, Wis. | 10 | 2 | 5 | 6 | 9 290<br>13 935 | 3.7 | A, B |
| Marshall, Wis. | 3 | 1 | 3 | 3 | 9 290 | 3.7 | A, B |
| Lodi, Wis. | 2 | 2 | 4 | 2 | 10 665 | 5.6 | C |
| Maquoketa, Iowa | 4 | 1 | 4 | 4 | 11 613 | 5.6 | C |
| New Martinsville, W. Va. (South Plant) | 3 | 1 | 4 | 2 | 8 500 | 5.6 | B |
| New Martinsville, W. Va. (North Plant) | 2 | 1 | 3 | 2 | Std. | 3.7 | A, B |
| East Washington, Pa. | 42 | 7 | 5 | 10 | 9 290<br>13 935 | 5.6 | A, B |
| Milesburg, Pa. | 5 | 1 | 5 | 5 | 7 711<br>11 148 | 3.7 | A, B |

[a] More than one entry indicates facilities with both standard and high density media.
[b] Biofilm growth: A—less than 0.76 mm; B—0.76 to 1.52 mm; C—1.52 to 3.18 mm.
[c] 40 RBCs are installed in each of 7 activated sludge tanks.
[d] 2 trains in first stage; 6 trains for stages 2 through 4.

## Energy requirements:

**Table 6—Energy requirements for air drive RBC units.**

| Plant location | Total no. of shafts | Average total power demand, kW | Average power demand, kW/shaft | Average power factor |
|---|---|---|---|---|
| Albion, Pa. | 6 | 22.626 | 3.77 | 0.84 |
| Allendale, Mich. | 4 | 19.606 | 4.90 | 0.82 |
| Plainwell, Mich. | 6 | 26.150 | 4.36 | 0.86 |
| Jonesville, Mich. | 4 | 33.34 | 8.34 | 0.80 |
| Clinton, Mich. | 4[a] | 9.23[b] | 4.61 | 0.86 |
| Dexter, Mich. | 6[c] | 17.02[d] | 5.67 | 0.74 |
| Jackson, Wis. | 8 | 37.758 | 4.72 | 0.74 |

**Table 4—Summary of energy usage measurements for mechanical drive RBC units.**

| Motor size, kW | Average kW/shaft | Range, kW/shaft |
|---|---|---|
| 3.7 | 2.02 | 1.05–3.76 |
| 5.6 | 2.05 | 1.32–2.99 |
| All facilities | 2.03 | 1.05–3.76 |