



Faculty of Engineering

**IMPLEMENTATION OF FUZZY NEURAL NETWORK IN  
ACTIVATED SLUDGE PROCESS OF THE WASTEWATER  
TREATMENT PLANT**

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Final Year Project Report

Masters

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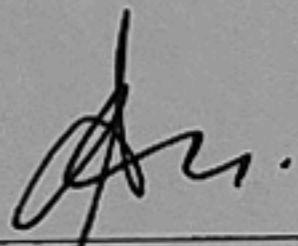
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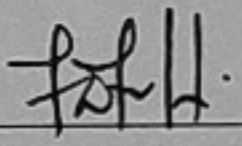
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**IMPLEMENTATION OF FUZZY NEURAL NETWORK IN  
ACTIVATED SLUDGE PROCESS OF THE WASTEWATER  
TREATMENT PLANT**

**Implementation Of Fuzzy Neural Network In Activated  
Sludge Process Of The Wastewater Treatment Plant**

ILAYKA IZIAHWATI BINTI MOHD JAYA @ MOHD YAHYA

A dissertation submitted in partial fulfilment  
of the requirement for the degree of  
Bachelor of Engineering  
Electrical and Electronics Engineering with Honours

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Universiti Malaysia Sarawak

2023

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## **ABSTRACT**

Wastewater treatment plants play an important role in maintaining water quality and preserving the environment. The problem addressed in this study is the inefficiency of controller of the activate sludge process due to high energy consumption of the activated sludge process, lack of adaptability of the default controller, and strict effluent quality compliance set by local and national authorities. The objectives of this research are to develop an effective control strategy for the activated sludge process in tank 5 and to enhance the overall performance of the wastewater treatment plant. The proposed method of research utilizes a fuzzy neural network to model and optimize the control parameter of tank 5 which is the oxygen transfer coefficient. The proposed control strategy combines the benefits of fuzzy logic and neural network techniques to provide robust and adaptive control in complex and uncertain wastewater treatment systems. The modelling of the proposed controller is by employing the data of default controller. The outcomes of this study are expected to include improved process efficiency, enhanced treatment quality, reduced operational costs, and minimized environmental impact. The results will provide valuable insights for the wastewater treatment plant operators and contribute to the advancement of control strategies in wastewater treatment systems.

## **ABSTRAK**

Lembaga rawatan air sisa memainkan peranan penting dalam menjaga kualiti air dan memelihara alam sekitar. Masalah yang ditangani dalam kajian ini adalah ketidakcekapan pengawalan proses lumpur aktif disebabkan penggunaan tenaga yang tinggi, kekurangan adaptabiliti pengawal asal, dan kepatuhan kualiti air sisa yang ketat yang ditetapkan oleh pihak berkuasa tempatan dan negara. Objektif penyelidikan ini adalah untuk membangunkan strategi kawalan yang berkesan untuk proses lumpur aktif terletak di tangki 5 dan meningkatkan prestasi keseluruhan lembaga rawatan air sisa. Kaedah penyelidikan yang dicadangkan menggunakan rangkaian neural kabur untuk memodelkan dan mengoptimumkan parameter kawalan tangki 5 iaitu pekali pemindahan oksigen. Strategi kawalan yang dicadangkan menggabungkan manfaat logik kabur dan teknik rangkaian neural untuk menyediakan kawalan yang berdaya tahan dan adaptif dalam sistem rawatan air sisa yang kompleks dan tidak menentu. Pemodelan pengawal yang dicadangkan dilakukan dengan menggunakan data pengawal asal. Keputusan kajian ini dijangka akan merangkumi peningkatan kecekapan proses, peningkatan kualiti rawatan, pengurangan kos operasi, dan impak alam sekitar yang minimal. Hasil kajian ini akan memberikan wawasan berharga kepada pengendali lembaga rawatan air sisa dan menyumbang kepada pembangunan strategi kawalan dalam sistem rawatan air sisa

## TABLE OF CONTENTS

<b>ACKNOWLEDGEMENT</b>	<b>ii</b>
<b>ABSTRACT</b>	<b>iii</b>
<b>ABSTRAK</b>	<b>iv</b>
<b>TABLE OF CONTENTS</b>	<b>v</b>
<b>LIST OF TABLES</b>	<b>viii</b>
<b>LIST OF FIGURES</b>	<b>ix</b>
<b>LIST OF ABBREVIATIONS</b>	<b>x</b>
<b>Chapter 1 INTRODUCTION</b>	<b>1</b>
1.1 Background	1
1.2 Problem Statement	2
1.3 Objectives	4
1.4 Project Scope	4
1.5 Project Benefits	6
1.6 Project Outline	6
1.7 Research Gaps	7
<b>Chapter 2 LITERATURE REVIEW</b>	<b>8</b>
2.1 Overview	8
2.2 Related Studies	8
2.2.1 Aeration Control	10
2.2.2 FNN Control Strategy	14
2.3 Summary of Previous Literature Works	21
<b>Chapter 3 METHODOLOGY</b>	<b>26</b>
3.1 Overview	26
3.2 FYP 1 Flowchart	26
3.3 FYP 2 Flowchart	28



3.4	BSM 1 Overview	29
3.4.1	BSM1 and ASM1	29
3.4.2	Influent Data	34
3.4.3	BSM1 Simulation flow chart	36
3.5	Performance Assessment	38
3.5.1	Effluent Quality	38
3.5.2	Cost Factors of The Operation	38
3.6	Proposed Control Method	40
3.6.1	Proposed Control Model Design	40
3.6.2	The Topology of The Proposed ANFIS Model	41
3.6.3	Membership Functions	44
3.6.4	Training Algorithms of Proposed controller	45
3.7	MATLAB Implementation of FNN Simulink Model	47
3.7.1	Simulink Model of Conventional DO Controller	48
3.7.2	Simulink Model of proposed FNN DO Control	48
3.8	Summary	49
<b>Chapter 4</b>	<b>RESULT AND DISCUSSION</b>	<b>50</b>
4.1	Overview	50
4.2	Performance of Effluent Average Concentrations	51
4.2.1	Ammonia ( $S_{NH}$ )	51
4.2.2	Total Suspended Solid (TSS)	52
4.2.3	Total Nitrogen ( $N_{TOT}$ )	53
4.2.4	Total Chemical Oxygen Demand (COD)	53
4.2.5	Total Biological Oxygen Demand (BOD)	54
4.3	Performance of Effluent Violations	55
4.3.1	Effluent Violations in $S_{NH}$	55

4.3.2	Effluent Violations in $N_{TOT}$	57
4.4	Performance of Effluent Quality Index and Operational Cost Index	58
4.4.1	Influent Quality Index (IQ)	58
4.4.2	Effluent Quality Index (EQ)	60
4.4.3	Aeration Energy Cost Index (AE)	61
4.4.4	Pumping Energy Cost Index (PE)	62
4.4.5	Mixing Energy Cost Index (ME)	63
4.4.6	Sludge Production Index (SP)	64
4.4.7	Total Operational Cost Index (OCI)	65
4.5	Summary	67
<b>Chapter 5</b>	<b>CONCLUSION</b>	<b>68</b>
5.1	Project Summary	68
5.2	General Conclusions	69
5.3	Recommendations	70
	<b>REFERENCES</b>	<b>71</b>
	<b>Appendix A</b>	<b>76</b>
	<b>Appendix B</b>	<b>77</b>

## LIST OF TABLES

<b>Table</b>	<b>Page</b>
<b>Table 2.1</b> Summary of previous literature reviews	21
<b>Table 3.1</b> Effluent quality limits	30
<b>Table 3.2:</b> List of state variables	31
<b>Table 3.3:</b> Layers of the control model	43
<b>Table 4.1:</b> Effluent Average of $S_{NH}$ on all weather conditions	51
<b>Table 4.2:</b> Effluent Average of $T_{SS}$ for all three weather conditions	52
<b>Table 4.3:</b> Effluent Average of $N_{TOT}$ for all three weather conditions	53
<b>Table 4.4:</b> Effluent Average of COD for all three weather conditions	54
<b>Table 4.5:</b> Effluent Average of BOD for all three weather conditions	55
<b>Table 4.6:</b> Effluent Violations in $S_{NH}$	56
<b>Table 4.7:</b> Effluent Violations in $N_{TOT}$	57
<b>Table 4.8:</b> IQ Index for All Three Weather Conditions	58
<b>Table 4.9:</b> Percentage Difference of Contaminants Reduction by Default Controller	59
<b>Table 4.10:</b> Percentage Difference of Contaminants Reduction by Proposed Controller	60
<b>Table 4.11:</b> EQ Index for All Three Weather Conditions	61
<b>Table 4.12:</b> Average Aeration Energy per day of All Three Weather Conditions	61
<b>Table 4.13:</b> Average Pumping Energy per day of All Three Weather Conditions	63
<b>Table 4.14:</b> Average Mixing Energy per day for All Three Weather Conditions	64
<b>Table 4.15:</b> SP Index for All Three Weather Conditions	65
<b>Table 4.16:</b> Total OCI for All Three Weather Conditions	66

## LIST OF FIGURES

<b>Figure</b>	<b>Page</b>
<b>Figure 1.1:</b> Example of municipal wastewater treatment plant [2]	2
<b>Figure 1.2:</b> Typical treatment processes of wastewater	3
<b>Figure 1.3:</b> Block diagram of project scope	5
<b>Figure 2.1:</b> Municipal WWTPs process [10]	9
<b>Figure 2.2:</b> Proposed block diagram of [11]	12
<b>Figure 2.3:</b> Proposed block diagram by [22]	14
<b>Figure 2.4:</b> Proposed DANC block diagram by [26]	16
<b>Figure 2.5:</b> Proposed method by [27]	17
<b>Figure 2.6:</b> Proposed control method by [28]	18
<b>Figure 2.7:</b> Proposed model by [29]	19
<b>Figure 2.8:</b> Proposed model by [30]	20
<b>Figure 3.1:</b> FYP 1 Flowchart	27
<b>Figure 3.2:</b> FYP 2 Flowchart	28
<b>Figure 3.3:</b> General BSM 1	29
<b>Figure 3.4:</b> General ASM 1	31
<b>Figure 3.5:</b> Dry Weather Influent Data	35
<b>Figure 3.6:</b> Rainy Weather Influent Data	35
<b>Figure 3.7:</b> Stormy Weather Influent Data	35
<b>Figure 3.8:</b> BSM1 Simulation Flowchart	37
<b>Figure 3.9:</b> The Block Diagram of Proposed Fuzzy Neural Network	40
<b>Figure 3.10:</b> Topology of Proposed Control Model	42
<b>Figure 3.11:</b> The Flowchart of Proposed Controller Modelling	46
<b>Figure 3.12:</b> DO controller in Simulink Model of BSM1	47
<b>Figure 3.13:</b> Default controller of DO control.	48
<b>Figure 3.14:</b> Proposed controller of DO control.	48

## LIST OF ABBREVIATIONS

- AE – Aeration Energy
- ANFIS – Adaptive Neural Fuzzy Inference System
- ASP – Activated Sludge System
- BOD5 – Biochemical Oxygen Demand
- BSM1 – Benchmark Simulation Model No 1
- COD – Chemical Oxygen Demand
- DO – Dissolved Oxygen
- EQ – Effluent Quality
- FL – Fuzzy Logic
- FNN – Fuzzy neural Network
- ILC – Iterative Learning Control
- NN – Neural Network
- Ntot – Total Nitrogen
- OCI – Operational Cost Index
- SNH – Ammonia
- TSS – Total Suspended Solid
- WWTPs – Wastewater Treatment Plant System

# CHAPTER 1

## INTRODUCTION

### 1.1 Background

In today's life, there is a huge population of people migrating to the cities due to better job opportunities, better educational facilities, and great healthcare facilities. The increasing number of populations is leading to an increase in the generation of wastewater in the cities. The wastewater is generated from daily activities in the residential areas in the city as well as the educational setups and industrial setups. Proper treatment of wastewater is crucial because it could affect human health, the environment, and aquatic lives as it will be discharged into the environment after it is being treated.

Wastewater requires multiple cleaning processes to be able to be discharged back into the environment as the wastewater discharged from residential areas, sewage system and industrial areas all have different substances contained in the wastewater that could affect the environment. The constituents of wastewater are organic substances, pathogens, pesticides, nitrogen, phosphorus, and heavy metals, including cadmium and chromium [1]. These contaminants present in the wastewater would lead to water pollution if it were not meticulously treated. If the wastewater is not treated, it may have a negative effect on the environment and people's health.

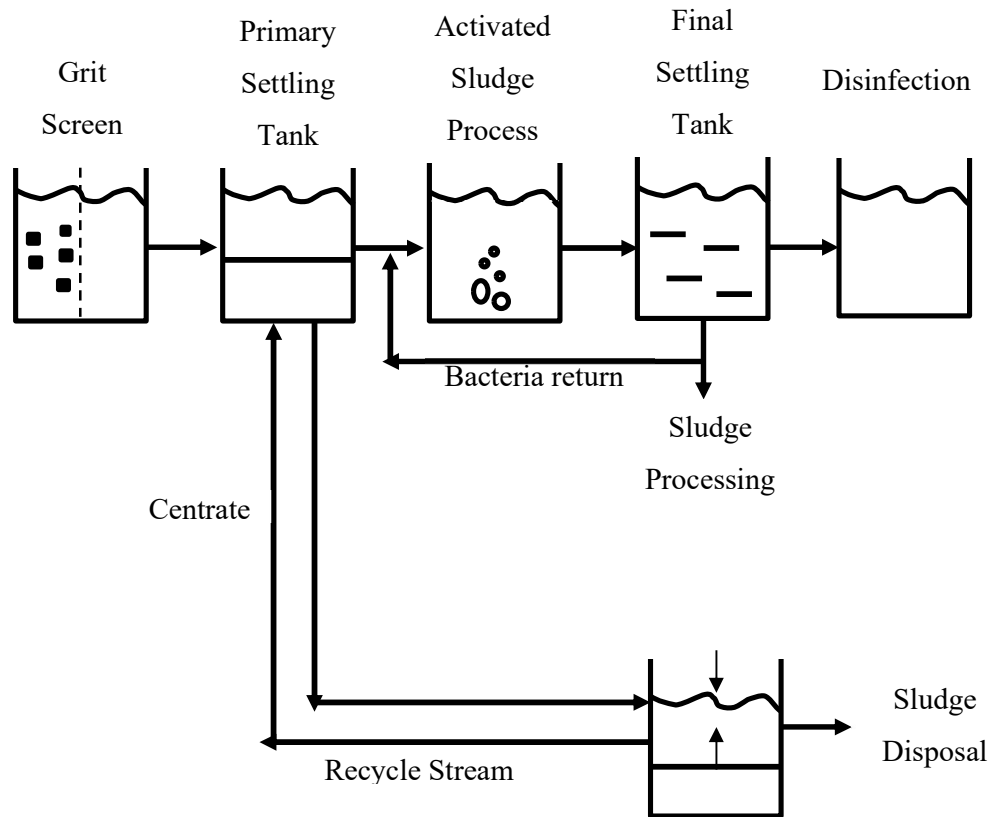
These implications include the potential harm to aquatic ecosystems, wildlife populations, oxygen depletion, closures of beaches, and the likelihood of drinking water contamination. Hence, it is crucial to do a treatment to the municipal wastewater generated to meet the standard effluent level of the wastewater after treatment set by the government before it is discharged to the environment. **Figure 1.1** shows the example of the implementation of WWTPs in real life to treat wastewater.



**Figure 1.1:** Example of municipal wastewater treatment plant [2]

## 1.2 Problem Statement

The treatment of municipal wastewater is a complex process which involve a physical, biological, and chemical elements throughout the treatment of the wastewater. For the typical municipal wastewater treatment plant, the cost for energy consumption accounts for 25% to 40% of the total operating cost of the wastewater plant in which the activated sludge process accounts for 50% to 60% from the overall energy consumption cost of the plant [3]. The conventional treatment of municipal wastewater is indeed an energy intensive procedure as it involves the activated sludge process (ASP) which requires a huge supply of oxygen gas into the process [4]. **Figure 1.2** shows the typical processes of the municipal wastewater treatment. In the ASP process, the microbial population is aerated inside the aeration tank to sped up the decomposition of the organic matter which is also referred as the chemical oxygen demand (COD) [5]. The ASP consumes a huge amount of energy as it requires a huge amount of air to be pumped into the aeration tank.



**Figure 1.2:** Typical treatment processes of wastewater

The ASP is a complicated process for conventional wastewater treatment controllers to manage because it is complex and nonlinear, with time constants that vary widely and never reach steady state [6]. In some cases, with the irregular rising and falling of influent flow, concentration and content, the wastewater treatment process is unstable and causes the other parameters and the quality of effluent to change continuously [7]. In the conventional controller, Proportional Integral controller is used as the controller. Proportional Integral (PI) controller is a linear controller while the biological treatment process of wastewater is a nonlinear system. If proper tuning is not performed, high control performance using a traditional controller such as a PI controller is hardly ever achieved [8]. Therefore, it is important to have a better control on the wastewater treatment processes to ensure the operation of the wastewater treatment, and the quality of the effluent after treatment are in satisfaction. With the increasing cost for the electricity consumption from the treatment process, it is wise to explore a way to enhance the control system of wastewater treatment process to help in lowering the cost of the



wastewater treatment as well as to maintain or improve the wastewater quality after the treatment by analysing its effluent level of the treated water. An enhancement in the effluent quality of wastewater treatment plant can be achieved by modifying the Benchmark Simulation Model No.1 (BSM1) by implementing a fuzzy neural network controller to replace the conventional PI controller to control the aeration of dissolved oxygen (DO) in the ASP.

### **1.3 Objectives**

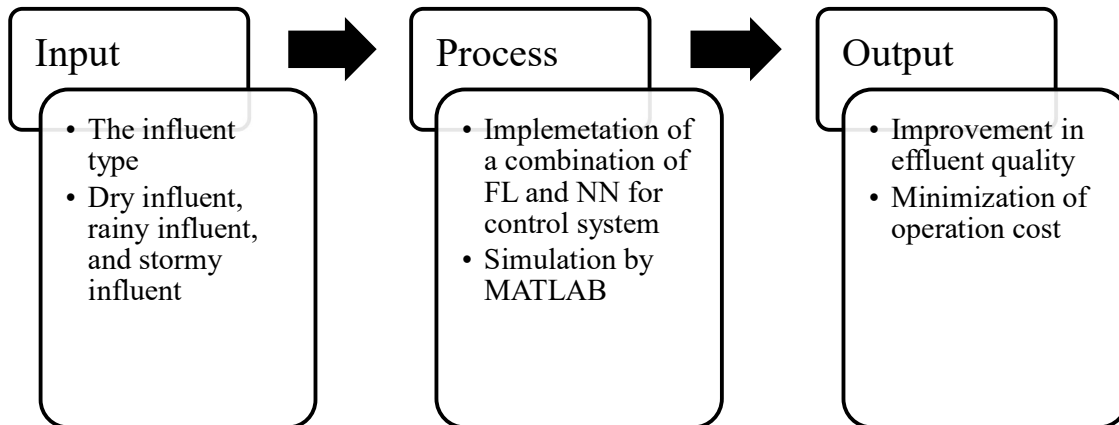
The primary goal of this study is to observe the efficiency of the wastewater treatment plant in controlling the DO by implementing the fuzzy neural network (FNN) controller design into the BSM 1. To achieve the goal, the sub-goals are outlined as follows:

1. To model a fuzzy neural network (FNN) controller to replace the conventional controller exist in the BSM 1 to further improve the efficiency of the wastewater treatment plant by perfecting the ASP.
2. To analyse and compare the energy consumption of the wastewater treatment plant when using a conventional controller and the energy consumption when using the FNN controller.
3. To analyse the effluent quality whether it achieve the standard effluent level by analysing few parameters such as the DO, Biological Oxygen Demand (BOD), COD, Total Suspended Solid (TSS), nitrogen and phosphorus.

### **1.4 Project Scope**

The proposed project aims to control the concentration of DO in the ASP in the BSM 1. By controlling DO concentration in aeration process efficiently, great implications such as the improvement of the overall treatment efficiency, minimization of energy consumption from the treatment processes, maximization of effluent quality and minimization of operational cost of the plant can be achieved. The simulation work for the proposed project can be done through simulation by using MATLAB software. One of the project's goals is to design a fuzzy neural network with minimum input to minimize computational time. The project general timeline is divided into three parts as seen in

**Figure 1.3.** There are three main parts of the project which are the input, the process and the output as shown in **Figure 1.3.**



**Figure 1.3:** Block diagram of project scope

For the input of the FNNs model, the influent data obtained from the BSM 1 is used for training, validation, and testing input for the fuzzy neural network model. The influent data are categorized as the dry, rain, and storm influent, which is real data obtained from a real WWTPs. The influent data is real data collected from real WWTPs for two weeks. The project process occurred when the input, the influent data, was selected and processed before undergoing training. The training process will keep on going and will only stop once it achieves a satisfying result. Once the training process is completed, a fuzzy neural network function is generated to be used in the MATLAB Simulink. Finally, to make sure that the FNN controller model is functioning as desired, the graphs of DO concentration, effluent quality parameters, and energy consumption from the implementation of the fuzzy neural network will be generated and compared to the graphs of DO concentration, effluent quality parameters, and energy consumption from the system using the conventional PI controller.

## **1.5 Project Benefits**

The benefits of the project are:

- There is a possibility that the aeration energy cost to reduce with the employment of FNN controller to replace the conventional PI controller in the BSM 1.
- The controlling of DO control of the ASP in WWTPs is useful for the efficiency of aeration process.
- Overall efficiency improvement of the WWTPs can be expected.

## **1.6 Project Outline**

Project outline shows the overview of the contents inside every chapter in this project which emphasizes the main scope of the chapters.

Chapter one is divided into six subparts which are the project background, problem statements, project aims, project scope, project benefit and project outline. Overall, chapter one is the introduction on the basic concept of the overall project ideas which is the modelling of suitable controller to replace the conventional PI controller in the BSM 1 to enhance the efficiency of the WWTPs.

Chapter two is the more detailed explanation of the project based on the research related with it by focusing on the earlier research made by researchers. It is about the WWTPs and the applications of conventional control methods, intelligent control methods or even the hybrid control method which combine both conventional control and intelligent control. Other than that, it also shows the importance of the treatment of wastewater by ASP and the issues that are involved with the process.

Chapter three is more on the explanation on the methodological methods. This is considered as the most important chapter since it includes a brief explanation on BSM 1 and the influent type. This chapter also describes the data processing methods and how the implementation of the fuzzy neural network is done through MATLAB software.

## 1.7 Research Gaps

The use of FNNs for the control of DO in wastewater treatment plants has been an active area of research in recent years. However, despite the promising results that have been reported, there are still several research gaps that need to be addressed in order to fully realize the potential of FNNs for DO control.

One major research gap is the lack of robustness and generalizability of FNN-based DO controllers. Many existing FNN-based controllers are designed and trained for specific wastewater treatment plants or processes and may not perform well when applied to different systems or under varying operating conditions. Developing FNN-based controllers that are more robust and generalizable across different wastewater treatment plants and processes is a key area of ongoing research.

Another research gap is the lack of understanding of the underlying mechanisms of FNN-based DO controllers. While FNNs have been shown to be effective at controlling DO, the exact mechanisms by which they achieve this are not well understood. More research is needed to understand how FNNs work and how to optimize their design and training for DO control.

A third research gap is the lack of integration of FNNs with other control strategies and technologies. FNNs have often been used as standalone controllers, but there is a need to integrate them with other control strategies and technologies, such as model predictive control and advanced sensors, to achieve more efficient and effective control of DO [9].

In summary, research gaps in the use of FNNs for DO control in WWTPs include lack of robustness and generalizability, lack of understanding of underlying mechanisms, and lack of integration with other control strategies and technologies.

# Chapter 2

## LITERATURE REVIEW

### 2.1 Overview

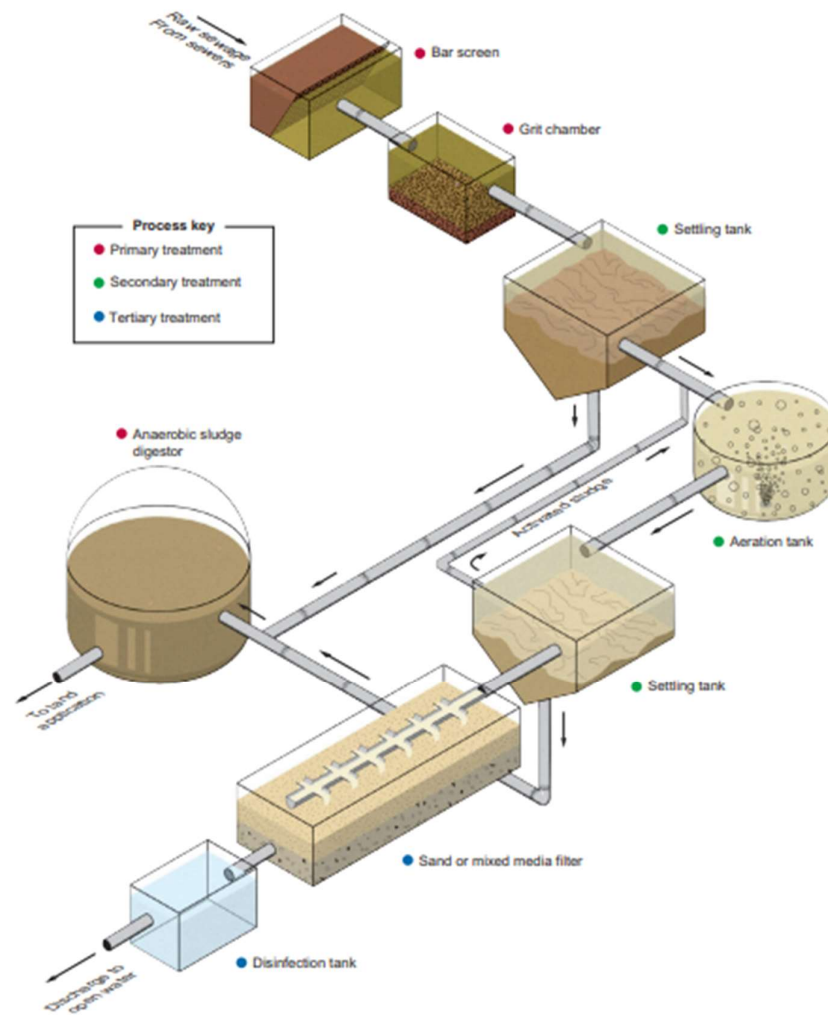
The problem of power usage in the water industry, especially in wastewater treatment, has gained significant attention in recent decades because of rising energy supply costs and the simultaneous introduction to the strict environmental requirements set by the governments. As a result, to follow strict emission restrictions, WWTPs need to minimise energy consumption, operational expenses, and maximize its effluent quality standards. Consequently, strict regulations for WWTPs are currently a major force behind the development of new treatment technologies as well as the optimization of the ones that already exist. The secondary wastewater treatment, which is the biological process where the ASP of wastewater treatment occurs, is considered as the most energy-consuming process within all the processes in wastewater treatment as it involves the process where the aeration of oxygen into the tank occurs.

### 2.2 Related Studies

The main aim of wastewater treatment is to remove and degrade the organic matter and contents from the wastewater under controlled conditions. A complete typical wastewater treatment process includes three major steps which are the primary treatment, secondary treatment, and the tertiary treatment as seen in **Figure 2.1**.

The primary treatment is the first step in municipal wastewater treatment, and it involves physical separation of large solids waste from the wastewater stream. When the raw wastewater enters the treatment plant, it passes through a metal grating that removes large debris, and then continues to the next screening to filter a smaller waste item. After that, the wastewater stream will enter the grit chamber to let the sand and gravel settle down. The wastewater stream is then pumped into the primary settling tank, also known as the

sedimentation tank. In this tank, the solids such as sludge sink to the bottom of the tank and are pumped into an anaerobic sludge digester. Since the sedimentation tank is large, it allows the heavy solids sludge to sink into the bottom of the tank while the cleaner influent flows at the top. The influent at the top of the bottom will be pumped into the aeration tank which is the second treatment process. The sludge in the anaerobic sludge digester will be dried and hauled away.



**Figure 2.1:** Municipal WWTPs process [10]

In secondary treatment, the effluents that are pumped into the aeration tank from the first settling tank will be mixed with activated sludge which contains a lot of bacteria. In this stage, air will be pumped into the aeration tank to encourage the growth of bacteria and the breakdown of organic material. This process is crucial and needs to be effectively managed to ensure the process works efficiently [10]. The concentration of oxygen in the

tank must be monitored thoroughly to ensure the plant's efficiency. It is then pumped into a second settling tank or also known as the clarifier tank or sedimentation tank, where the water is drained off the top of the tank into the sand or mixed media filter tank for tertiary treatment, and some of the sludge that sink into the bottom of the tank is removed and pumped into the anaerobic sludge digester while some other of the sludge will be inoculate to the primary effluent and reused in the activated sludge process.

Finally, is the tertiary treatment which is the last stage of the wastewater treatment. Tertiary treatment processes are involving a physical and chemical processes that can be effective to further reduce the pathogens and enhance the effectiveness of disinfection processes by the removal of soluble and particulate organic matter which is done by filtration process [10]. The effluent from the secondary clarifier is pumped into the filter tank to filter out the unnecessary contents, and pathogens. The filtered effluent then will then flow into the disinfection tank to ensure that the concentration of bacteria that will be released into the environment is not too high and following the strict wastewater effluent emission restrictions.

After completing all three stages of wastewater treatment, the effluent quality should be checked before it could be discharged to the river. The effluent quality should meet the strict emissions restrictions to avoid being subject to fines from the responsible authorities involved.

### **2.2.1 Aeration Control**

Generally, the main aim of the WWTPs is to maximize the standard quality of effluent but at the same time to minimize the operating cost and the energy consumption to as low as possible. A lot of research has been done thoroughly of the optimization of ASP which is related to the controlling of aeration process which are mostly focusing on DO concentration. All that research were conducted mostly focusing on DO concentration to minimize the operational cost of aeration. Researchers are targeting to implement the operation of wastewater plant with minimal energy consumption by manipulating the DO according to the oxygen demand of the microbial. Even so, it is incredibly challenging to predict how much the actual oxygen needed by the microbial. A variety of control strategies need to be investigated and implemented to the WWTPs to achieve the aim to get the efficient results for both effluent quality and operational costs. As cited in [3], more than half of the operation energy consumption in municipal WWTPs is contributed

by the aeration process which takes about 50% to 60% from the overall energy consumption cost. Thus, aeration control has become the focus for researchers to implemented strategies to improve the aeration process. Aeration is important because it supplies DO in which will be consumed by the aerobic organisms to carry out the BOD removal and nitrification. There are several types of aeration control by controlling DO by using the conventional control strategy such as PI controller, PID controller, and Model Predictive Control (MPC), or by using the intelligent control strategy such as FL and NN control or even by implementing hybrid control strategy which are the idea of combining both the conventional control method and intelligent control method by controlling the DO at a pre-set setpoint. Other than that, there are also two aeration control strategies which can be considered for the improvement of the WWTPs which are by changing the aeration intensity and by changing the aerated volume.

#### **2.2.1.1 Aeration Control by Implementations of Controllers**

There is numerous research that emphasizes the implementation of several types of controllers for the sake of controlling the aeration process by altering the DO concentration at a pre-set setpoint. The conventional PID controller is one of the most popular and widely used in control application due to its simple and convenient operation. By tuning the PI controller properly, the controller worked efficiently in achieving the aims of the control strategies. The proposed controller varies from a simple PI controller to a Proportional-Integral-Differential (PID) controller. As proposed by [11] the PI controller is combined with the Finite-Time Extended State Observer (FTESO) to create an MPI controller. **Figure 2.2** shows the block diagram of the proposed control strategy.